# Permanent Forum on Small Modular Reactors (F-SMR)

Plenary session

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August 04, 2023

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Ministério de Minas e Energia

# Agenda

1º Short summary of the previous meeting

2º Isolated Systems in Brazil

3º Questions to the next technical meeting
‘Specificities of remote and off-grid applications’

# Section I

## Conclusions drawn from the previous technical meeting

## TOPIC IV: Specificities of Heat Applications for Industrial Processes and Hydrogen Production

May 12, 2023

1

## Technology and design impacts over specific applications.

Despite the flexibility to produce different services, some technologies may be more appropriate to produce specific services or products.

Hydrogen production is an example where there are several technological routes to production, but some using very high temperatures appear to be more efficient and less carbon footprint.

Considering light water technologies, the PWR has advantage over BWR due to its additional heat exchange cycle that produces steam without contact with radioactive material, it makes it more flexible to be adopted in different applications despite its lower energy transforming efficiency

2

## Technological routes and enhancement

Heat storage systems (as kind of backup) can significantly improve the operating flexibility of power plants including cogeneration.

Green boiler – Large thermal reservoir that can be associated to nuclear facilities

3

## Licence challenges related to non-electrical uses of SMR.

Licensing may have different challenges depending on the technology and its different ways of producing heat, steam or temperature to be achieved.

The way in which the nuclear plant is integrated with the additional plant may bring regulatory challenges, as the heat exchange mechanisms between the two plants must be analyzed and whether this may impact the operation and safety of the nuclear power plant.

Safety issues such as distance from the industrial plant. Transportation and storage (hydrogen) near a nuclear power plant

4

# Competitiveness of non-electrical applications

The competitiveness of the different applications is highly dependent on the country, the market, the need, the type of consumers, the existing infrastructure.

Raw materials availability required for the production (water for process heat generation as steam, natural gas for pyrolysis or steam reforming)

Competitiveness depends on national energy policy and environmental and regulatory requirements

5

# Siting and its influence on technical and economic aspects

Infrastructure is a key point related to the economic competitiveness

Proximity to dense areas can bring advantages. Ex: increasing thermal efficiency for industrial or district heat supply.

Proximity to dense areas can bring disadvantages. Ex: Public acceptance, higher CAPEX due to land prices.

In the case of hydrogen, storage and transportation can significantly impact the cost and feasibility.

6

# Hydrogen production

Different technological routes were pointed. Ex: methane pyrolysis, steam reform, electrolysis or the combination of different processes.

Some theoretical advantages related to hydrogen production may not be suitable for the industrial environment because they may require expensive structures and processes.

Pyrolysis of methane produces solid carbon which can be a byproduct for specific industries.

# Section III

## Introduction to the topic to be discussed in the next technical meeting

### TOPIC V - Specificities of remote and off-grid applications

September 13, 2023

# Topic of the next technical meeting

## Brief overview

TOPIC V | Specificities of remote and off-grid applications

The high cost of electricity generation in remote locations of Brazil, particularly in the Amazon Basin, presents an appealing market opportunity for small-scale power supply systems that offer both flexibility and dispatchability, such as typical SMR technology. While detailed information about these markets is currently available, a better understanding of specific SMR technologies is still required to address the unique concerns of these locations, especially regarding the need to ensure a reliable electricity supply in challenging conditions.

Apart from flexibility and factors impacting the power plant's capacity factor, there are other topics of interest to explore, including but not limited to:

- The technical feasibility of unattended operation.
- The extent to which the power plant would rely on specialized maintenance.
- The possibility of utilizing backup heat sources for the power cycle.

# Topic of the next technical meeting

## Objective

TOPIC V

Specificities of remote and off-grid applications

The main objective of this event is to gather information concerning the economics, operation, safety, security, logistics, and infrastructure of microreactors. Another key goal is to gain a clear understanding of the advantages and challenges related to the remote operation of microreactors. Lastly, the event aims to determine the most suitable business model for microreactors in Brazil

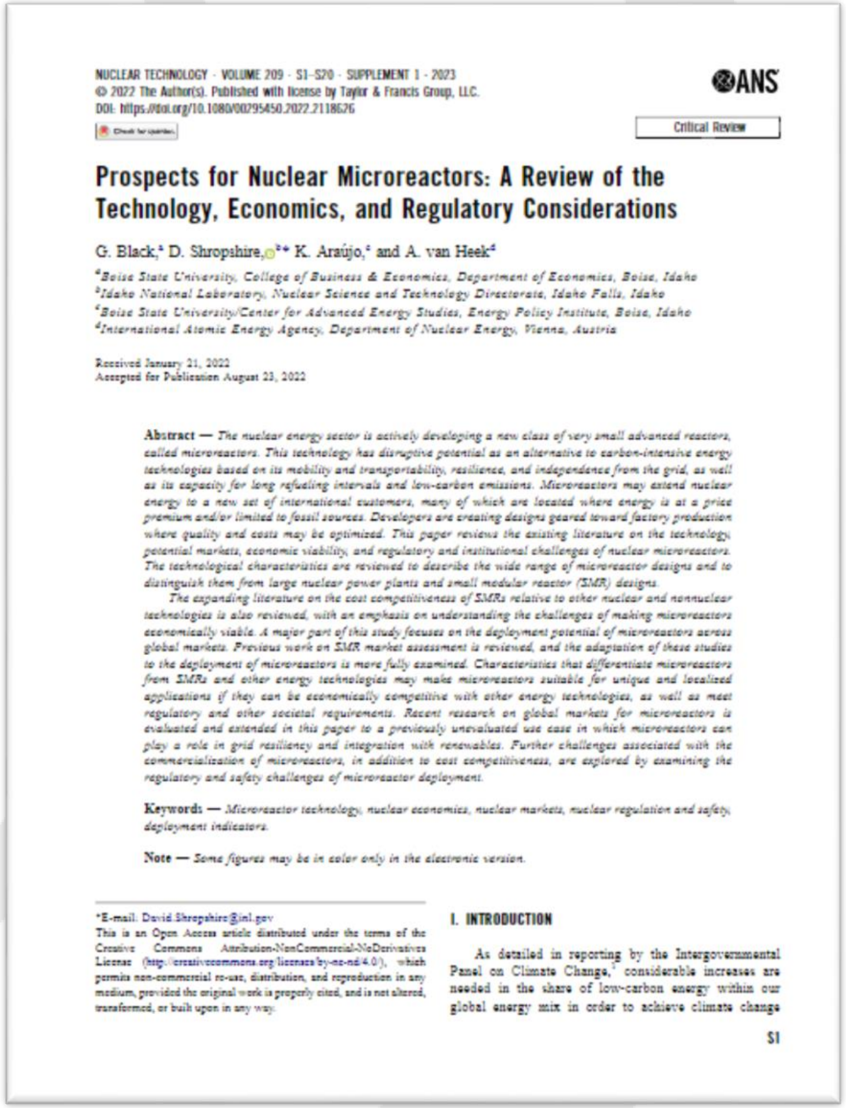
# Topic of the next technical meeting

## Reference #1

G. Black, D. Shropshire, K. Araújo, and A. van Heek

Prospects for Nuclear Microreactors: A Review of the Technology, Economics, and Regulatory Considerations

2022



NUCLEAR TECHNOLOGY · VOLUME 209 · S1–S20 · SUPPLEMENT 1 · 2023

DOI: https://doi.org/10.1080/00295450.2022.2118626

Critical Review

### Prospects for Nuclear Microreactors: A Review of the Technology, Economics, and Regulatory Considerations

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Received January 21, 2022
Accepted for Publication August 23, 2022

**Abstract** — *The nuclear energy sector is actively developing a new class of very small advanced reactors, called microreactors. This technology has disruptive potential as an alternative to carbon-intensive energy technologies based on its mobility and transportability, resilience, and independence from the grid, as well as its capacity for long refueling intervals and low-carbon emissions. Microreactors may extend nuclear energy to a new set of international customers, many of which are located where energy is at a price premium and/or limited to fossil sources. Developers are creating designs geared toward factory production where quality and costs may be optimized. This paper reviews the existing literature on the technology, potential markets, economic viability, and regulatory and institutional challenges of nuclear microreactors. The technological characteristics are reviewed to describe the wide range of microreactor designs and to distinguish them from large nuclear power plants and small modular reactor (SMR) designs.*

*The expanding literature on the cost competitiveness of SMRs relative to other nuclear and nonnuclear technologies is also reviewed, with an emphasis on understanding the challenges of making microreactors economically viable. A major part of this study focuses on the deployment potential of microreactors across global markets. Previous work on SMR market assessment is reviewed, and the adaptation of these studies to the deployment of microreactors is more fully examined. Characteristics that differentiate microreactors from SMRs and other energy technologies may make microreactors suitable for unique and localized applications if they can be economically competitive with other energy technologies, as well as meet regulatory and other societal requirements. Recent research on global markets for microreactors is evaluated and extended in this paper to a previously unevaluated use case in which microreactors can play a role in grid resiliency and integration with renewables. Further challenges associated with the commercialization of microreactors, in addition to cost competitiveness, are explored by examining the regulatory and safety challenges of microreactor deployment.*

**Keywords** — *Microreactor technology, nuclear economics, nuclear markets, nuclear regulation and safety, deployment indicators.*

**Note** — *Some figures may be in color only in the electronic version.*

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#### I. INTRODUCTION

As detailed in reporting by the Intergovernmental Panel on Climate Change,[1] considerable increases are needed in the share of low-carbon energy within our global energy mix in order to achieve climate change

# Topic of the next technical meeting

## Reference #2

GILBERT, Alexander Q.; BAZILIAN, Morgan D.

Can distributed nuclear power address energy resilience and energy poverty?

2020

Joule · CellPress

Commentary

### Can Distributed Nuclear Power Address Energy Resilience and Energy Poverty?

Alexander Q. Gilbert[1,2,3,*] and Morgan D. Bazilian[2,4]

Alex Gilbert is a Project Manager at the Nuclear Innovation Alliance, where he oversees technical and regulatory work on commercializing advanced reactors. He is also a non-resident Fellow at the Payne Institute, where he conducts research on energy markets, climate policy, and outer space resources governance, and Adjunct Faculty at Johns Hopkins University. Alex has a Master of Energy Regulation and Law and Certificate in Climate Law from Vermont Law School and a BA in Environmental Studies and International Relations from Lake Forest College.

Dr. Morgan Bazilian is the Director of the Payne Institute and a Professor of public policy at the Colorado School of Mines. Previously, he was lead energy specialist at the World Bank. He has over two decades of experience in the energy sector and is regarded as a leading expert in international affairs, policy, and investment. He is a Member of the Council on Foreign Relations. Dr. Bazilian has testified before the U.S. Senate and the Irish Oireachtas on issues of energy security.

Three major energy challenges are driving national and international energy decision making. First, the need to mitigate and adapt to climate change. Second, despite recent progress, many communities in both developed and developing countries remain in energy poverty or lack reliable, low-cost energy services. Finally, due to climate-amplified natural disasters and other threats, the reliability and resilience of energy systems is an increasing public concern. Existing distributed energy resources (DERs), especially solar photovoltaics and battery storage, are attempting to address each of these issues. However, more and faster progress is needed. Recent innovations in advanced nuclear designs could make nuclear power a distributed energy solution for the first time. As a dispatchable and resilient energy source, distributed nuclear could complement and accelerate the ongoing distributed energy revolution.

Although decarbonization imperatives are recognized, the role of distributed energy in addressing energy poverty and energy resilience is worth considering. Despite recent progress on electrification, much of the global population lacks access to affordable or reliable electricity. Fuel poverty is a complex problem that goes beyond just access, implicating socioeconomic issues that arise from insufficient energy services. More than half of the world's poor are in rural areas, where they are vulnerable to the energy-poverty-climate nexus.[1] Rural areas are hard to serve from an electric perspective as they require significant transmission infrastructure development to provide service, which is often too costly.

Meanwhile, emerging issues (such as the ongoing COVID-19 pandemic) have led to energy sector resilience being a policy concern. As keystone critical infrastructure, electricity supply is central to the operation of modern economies and social services. Energy disruptions are costly and dangerous. The 2003 blackout in North America impacted 50 million people and cost billions in economic damages. More recently, Puerto Rico's power service has been severely disrupted by natural disasters, first by the 2017 Hurricane Maria and then by a January 2020 earthquake. In a review of electric outages between 2000 and 2016, natural hazards accounted for over 50%, intentional attack for 27%, system operations issues for 8%, and fuel supply emergency for 3%.[2] Most disruptions were due to issues in transmission and distribution. Looking forward, climate change is expected to exacerbate natural hazards and drive additional system stress through air conditioning demand, while physical security, cyber security, and fuel supply threats grow.[3]

In the last 20 years, rapid technological progress in solar photovoltaics, battery storage, and other renewable technologies led to the emergence of DERs.

Joule 4, 1839–1851, September 16, 2020 © 2020 Elsevier Inc. 1839

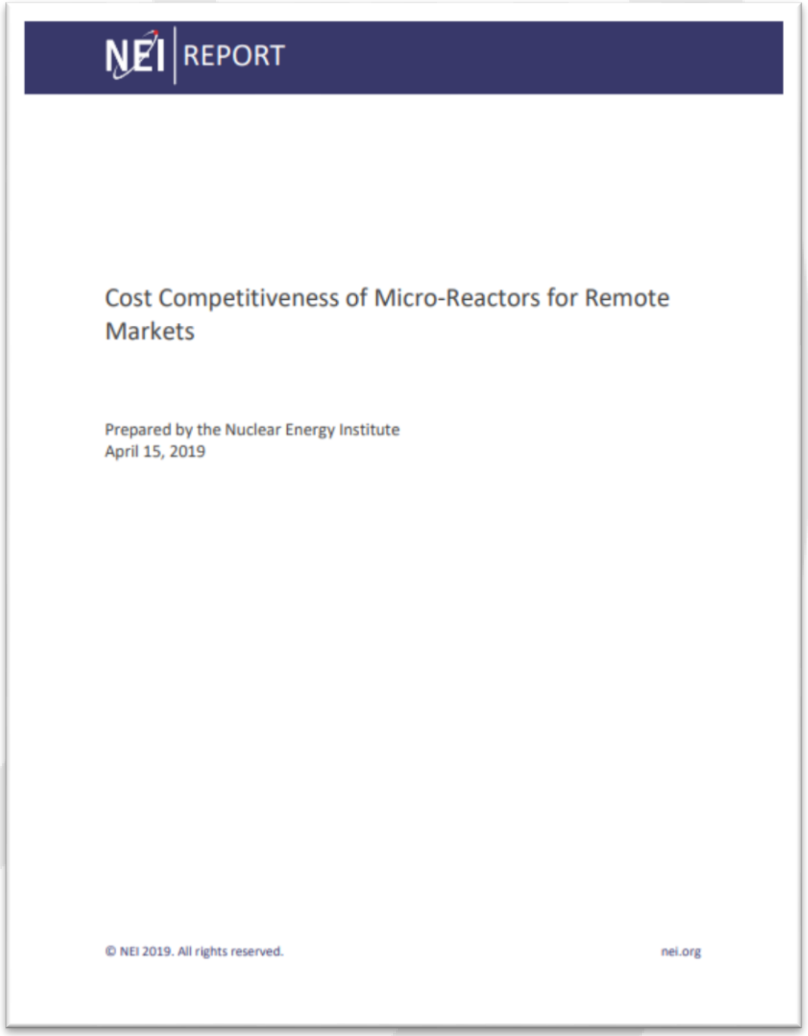
# Topic of the next technical meeting

## Reference #3

NEI report

Cost Competitiveness of Micro-Reactors for Remote Markets

2019



NEI | REPORT

Cost Competitiveness of Micro-Reactors for Remote Markets

Prepared by the Nuclear Energy Institute
April 15, 2019

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nei.org

# Topic of the next technical meeting

## Guiding questions

FOUR global questions

Subtopics

1. Economic perspective
2. Operational perspective
3. Safety and Security
4. Logistics and infrastructure

# Topic of the next technical meeting

## Question Q1

From SMRs vendors perspective, what would be the most promising markets for microreactors?

MORE SPECIFICALLY

When it comes to microreactors, what do vendors consider the best business model? The sale of equipment or power supply service?

Are microreactors being designed for applications beyond power generation? Are they suitable for heat supply, hydrogen production, replacing diesel generators, off-grid applications, or even for use in mining? Under what conditions would they offer more advantages compared to other low-carbon technologies?

Is there any industry effort to adopt standards for fuels or equipment to be used in microreactors?

How does the industry see capex values (US$/MW) of Microreactors vs. SMRs vs. NPPS?

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## Question Q2

How would these plants operate throughout their life cycle? Would microreactors be able to modulate generation to meet the load in isolated or small systems? What would the possible restrictions in operational terms to guarantee continuity of supply be?

MORE SPECIFICALLY

What are the main attributes of microreactors in terms of operating flexibility? Load monitoring capacity, minimum operating capacity, ramp up and ramp down, start and stop restrictions, minimum stay time on (Ton) and off (Toff), provision of ancillary services

What would be a minimum grid size and voltage level? What would be the possible auxiliary systems for these microreactors? (Batteries, thermal storage, auxiliary motor generators)

What is the frequency of stops for maintenance and fuel replacement? What is the duration required for these stops?

What the minimum team needed to operate a microreactor in an isolated or remote area is? Is fully remote operation possible? What is the minimum infrastructure required?

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## Question Q3

Can these microreactors be operated remotely or semi-remotely? Considering the possibility of critical events, whether internal or external, how can we ensure the nuclear safety of the installations and prevent proliferation?

MORE SPECIFICALLY

What critical points, innovations, or technological resources are required to ensure the operational safety of these facilities (such as communication systems, monitoring, and on-site security)? What are the key considerations to guarantee the safety and security of microreactors located in remote areas?

From a safety perspective, is it possible to identify a more suitable technological approach to enable microreactor operations in remote areas (in terms of reactor technology, passive and active safety systems)? If so, which one would be better and why?

The cooling system is the primary concern during NPP shutdowns. What are the cooling mechanisms to be implemented in microreactors?

# Topic of the next technical meeting

## Question Q4

How compact would the microreactors be and what logistical infrastructure would be needed for their transport and for the fuel transport?

MORE SPECIFICALLY

Will they be completely manufactured in the factory and transported to the final site? Will the models be compact enough to be able to be operated from mobile platforms such as ships or even trucks?

What the main regulatory challenges for this type of operation are? What the main regulatory challenges to this kind of operation are? How to fit it in a NPPs regulatory framework?

In the case of on-board microreactors, what would the safety mechanisms in case the vessel sinks be? How would the equipment rescue procedures be carried out?

What are the logistical and regulatory challenges for transporting new fuel and especially spent fuel?

# Thank you

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