Adversities and Opportunities in the Transition to Sustainable Energy: Exploring Nuclear Technologies

International Nuclear Atlantic Conference – INAC 2024

Nuclear Energy: Assuring Energy, Health and Food

Giovani Machado
Advisor to the President of EPE

May 9th, 2024

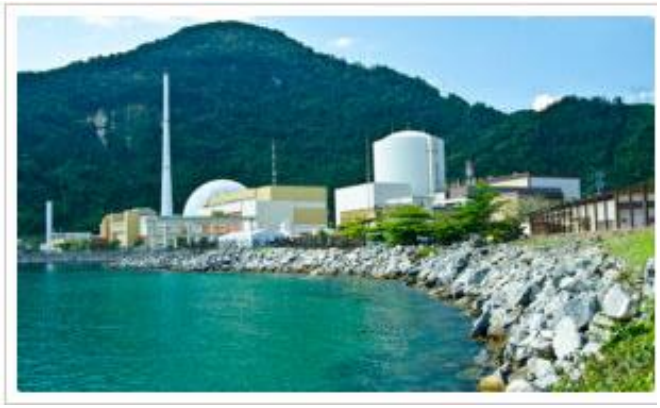
Status of nuclear energy infrastructure in Brazil

Nuclear installed capacity in operation (2022)

1.99 GW	1% of total installed capacity

Nuclear Power Plants

Plant	Installed capacity	Status	Construction period
Angra I	640 MW	Operating	1972/1985
Angra II	1350 MW	Operating	1981/2001
Angra III	1350 MW	Construction halted	1984/...
Plant IV	1000 MW	Planned	.../...



...2029 (projected)

...2031 + ? (expected)

Uranium Production

Mine	Resources	Status	Production Capacity	Potential Capacity (2027)
Caetité – BA	99 k ton uranium	Operation	400 ton/year	800 ton/year
Santa Quitéria – CE	80 k ton uranium	Project	1,600 ton/year	2,300 ton/year

Sources: (i) ANEEL; (ii) INB; (iii) Aben; (iv) PDE 2031

Challenges of cost escalation, cost & time overruns

How to overcome such facts?

Energy Policy 102 (2017) 644–649

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Correspondence

Cost overruns and financial risk in the construction of nuclear power reactors: A critical appraisal

ARTICLE INFO

Keywords:
Construction cost overrun
Nuclear power
Nuclear energy
Atomic energy

ABSTRACT

Lovering and colleagues attempt to advance understanding of construction cost escalation risks inherent in building nuclear reactors and power plants, a laudable goal. Although we appreciate their focus on capital cost increases and overruns, we maintain in this critical appraisal that their study conceptualizes cost issues in a limiting way. Methodological choices in treating different cost categories by the authors mean that their conclusions are more narrowly applicable than they describe. We also argue that their study is factually incorrect in its criticism of the previous peer-reviewed literature. Earlier work, for instance, has compared historical construction costs for nuclear reactors with other energy sources, in many countries, and extending over several decades. Lastly, in failing to be transparent about the limitations of their own work, Lovering et al. have recourse to a selective choice of data, unbalanced analysis, and biased interpretation.

© 2016 Elsevier Ltd. All rights reserved.

It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suite theories, instead of theories to suite facts.

Sherlock Holmes, in Arthur Conan Doyle's *A Scandal in Bohemia*, 1891, p. 78.

1. Introduction

Despite sounding a bit dry, there can be little doubt that the topic of construction cost overruns is of central importance to energy and electricity planning, investment, policy, and regulation. As Bacon and Besant-Jones (1998, p. 317) wrote in the present journal almost two decades ago:

> The economic impact of a construction cost overrun is the possible loss of the economic justification for the project. A cost overrun can also be critical to policies for pricing electricity on the basis of economic costs, because such overruns would lead to underpricing. The financial impact of a cost overrun is the strain on the power utility and on national financing capacity in terms of foreign borrowings and domestic credit.

In other words, evaluations of construction cost escalation and overruns have much to tell regarding inefficiencies in the allocation of resources, and can assist with estimating likelihoods of future infrastructure risks.

It is in this regard that we appreciate and understand the interest in this topic shown by Lovering et al. (2016a), in their effort at analyzing new global data on overnight nuclear construction costs. However, we disagree with their conclusion that there is "no inherent cost escalation trend associated nuclear technology."

In this response, we critique Lovering et al. on three grounds. First, we argue that a series of methodological choices undermine their conclusions and limit the applicability of their results in respect of both historical and future nuclear construction costs. Second, we question the reliability of the data underlying Lovering et al. by discussing three recent studies that are global in scope and focus on trends including the past few decades of nuclear construction. Third, we express concerns that recent public declarations made by the authors when discussing their article are not based on their actual data or on reliable results. The first criticism refutes the piece's methodology; the second questions its comparative novelty; the third challenges the objectivity of the overall framing and interpretation.

2. Worrying methodological assumptions

Our first criticism is that the narrow definition of construction costs used by Lovering et al. (2016a), overnight capital costs (OCC), is not an appropriate metric to judge nuclear construction costs. This cost is notionally what it would take to build a reactor "overnight", with financing and other time-related costs omitted. We raise three issues with this methodology:

- OCC are an inappropriate measure of power plant construction costs
- OCC and the author's definition of cost escalation do not include the full impacts of cost overruns

DOI of original article: http://dx.doi.org/10.1016/j.enpol.2016.03.052

http://dx.doi.org/10.1016/j.enpol.2016.04.01
0301-4215/© 2016 Elsevier Ltd. All rights reserved.

https://www.sciencedirect.com/science/article/pii/S0301421516301690/pdfft?md5=215e9af8a66c1ea415522340598cbae1&pid=1-s2.0-S0301421516301690-main.pdf

Table 1
Summary construction cost overrun data for electricity supply projects.

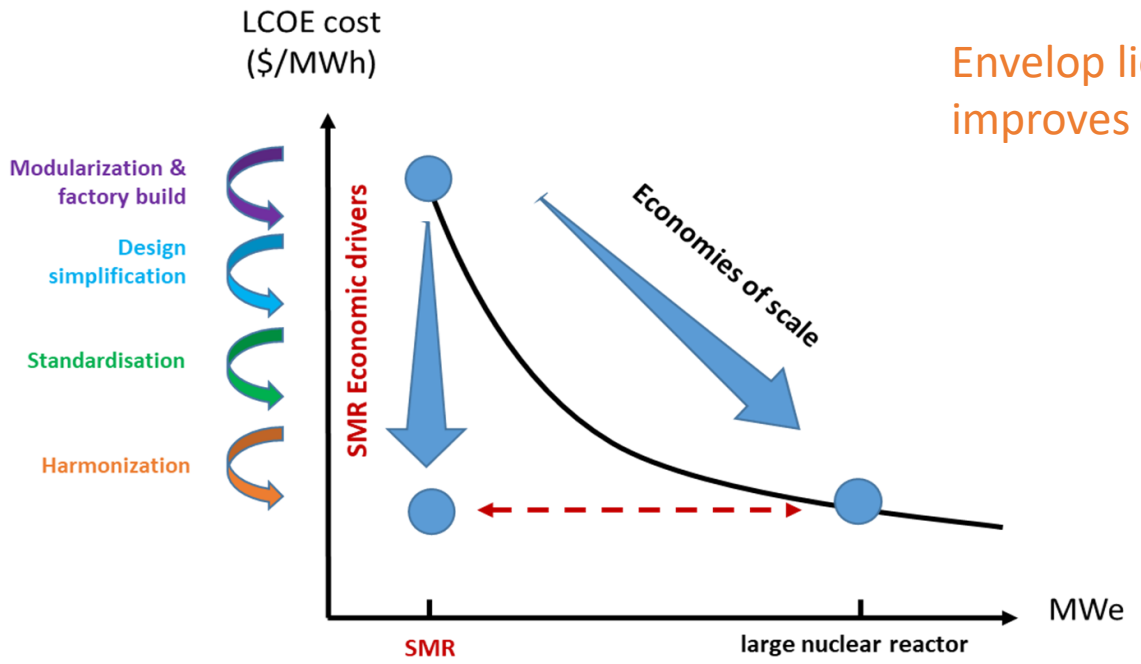
Description		Hydroelectric dams	Nuclear reactors	Thermal plants	Wind farms	Solar facilities
Number of projects (N)		61	180	36	35	39
N with cost overrun		47	175	24	20	16
N with cost overrun (%)		77	92.2	66.7	57.1	41
Cost escalation (%)	Mean	70.6	117.3	12.6	7.7	1.3
	Min	−50.6	−7.9	−50	−9.1	−40.8
	Max	512.7	1279.7	120	44.4	50
	Median	30.1	64.8	9.6	1.7	0
	Mode	–	189.4	75	0	0
	Standard deviation	111.7	152.1	33.5	13.1	17.8
Cost overrun (millions US$)	Mean	2437	1282	168.5	32.8	−4.2
	Min	−671.4	−298.8	−1272.7	−158.5	−266.6
	Max	47,630	16,589	2000	526.4	102.3
	Median	99.5	503.1	51.5	0.96	0
	Mode	–	41.9	–	0	0
	Standard deviation	7054.7	1965.8	579.6	112.9	62.1
Time overrun (%)*	Mean	63.7	64	10.4	9.5	−0.2
	Min	−28.6	−15	−10.7	−19	−11.2
	Max	401.7	261.9	66.7	60	25
	Median	32.7	40	0	0	0
	Mode	30.9	35.4	0	0	0
	Standard deviation	89.8	53.1	19.0	22.6	8.0
Time overrun (months)*	Mean	43.2	35.7	4.8	0.22	−0.2
	Min	−24	−9	24	−4	−5
	Max	241	149	−9	6	5
	Median	19.5	24	0	0	0
	Mode	12	17	0	0	0
	Standard deviation	58.4	30.6	8.9	2.4	2.1
Cost per installed kW (US$)	Mean	3093.2	2427	1943.9	2808	8311.6
	Min	146.8	190.7	279	405.6	1773.5
	Max	10,359.5	13,260.1	5606.8	5793.7	27,180
	Median	2278.4	1776	1787.9	2459	7199.4
	Mode	–	960.2	–	2645.5	–
	Standard deviation	2516.1	1888.5	1163.9	1147.4	5099.7

* Applies only to a smaller subsample N=33 for hydro, 175 for nuclear, 24 for thermal, 18 for wind, 23 for solar. Source: Modified from Sovacool et al. (2014b).

Complexity and diversity of projects and regression in the learning curve affected construction schedules and costs. FOAK (First of a Kind) vs NOAK (N-of a Kind)

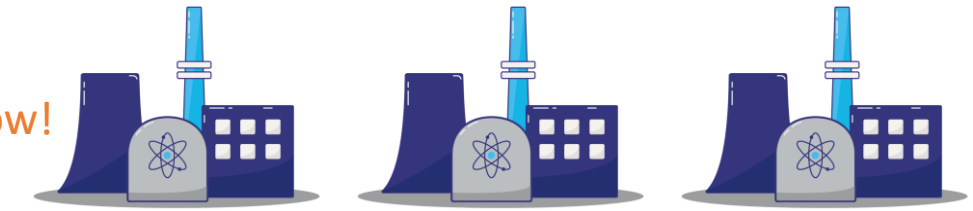
Overcoming challenges for nuclear in energy transition & net zero

Scheduling, innovation & supply-chain: NOAK, standards & sectorial coupling

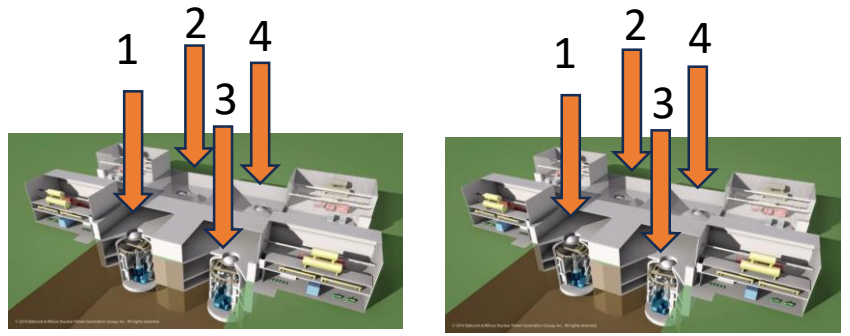


NOAK – "n" of a kind

Envelop licensing improves cash flow!



Large nuclear reactors scheduling



SMRs scheduling by envelop

NOAK: learning economies, scaling-up (standardization in manufacturing, building methods and synergies in sitting & utilities), scope (electricity, capacity, industrial heat, carbon credits & low emission H2) and supply-chain

Overcoming challenges for nuclear in energy transition & net zero

Do not underestimate supply-chain role for economics and stakeholders' engagement!

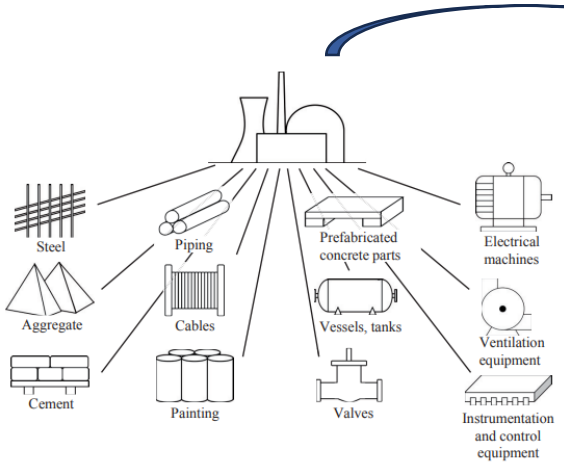
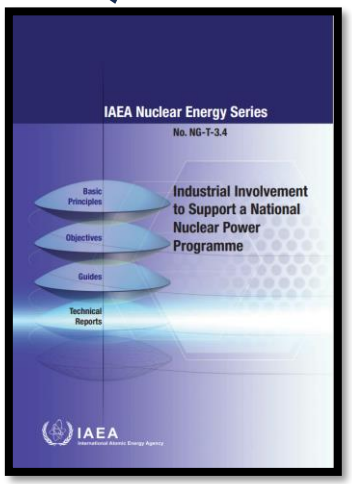
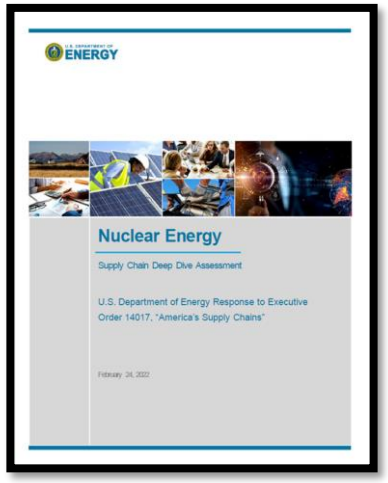


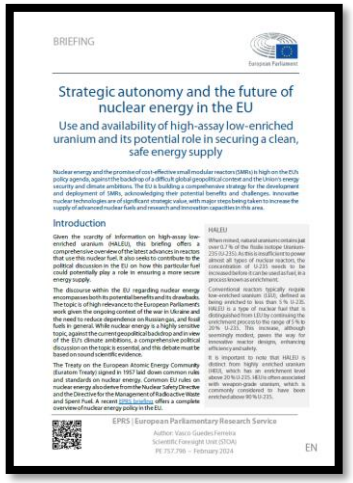
FIG. 7. Typical supplies of material and equipment [2].



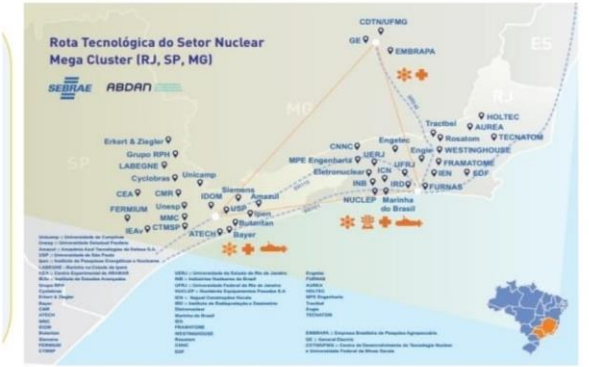
P1703_web.pdf (iaea.org)



EERE Technical Report Template (energy.gov)



Strategic autonomy and the future of nuclear energy in the EU | Think Tank | European Parliament (europa.eu)



CONSTRUÇÃO DE UMA REDE ORGANIZADA
TRANSFORMAÇÃO DO AMBIENTE DE NEGÓCIOS E TERRITÓRIOS

IAEA (2016): *National industrial involvement in emerging nuclear power States is one of the major areas of concern when developing a nuclear power programme.* ***Most States have an objective to increase national and local participation or to 'localize' those parts of industrial involvement*** *where national industries can cost effectively achieve these high standards.*

DOE (2024): ***The nuclear energy supply chain is vast and diverse*** *covering everything from uranium extraction and enrichment to general construction of buildings at a reactor site to the equipment and components required for operation.* ***The current supply chain is global*** *and relies on companies and materials located throughout the world.*

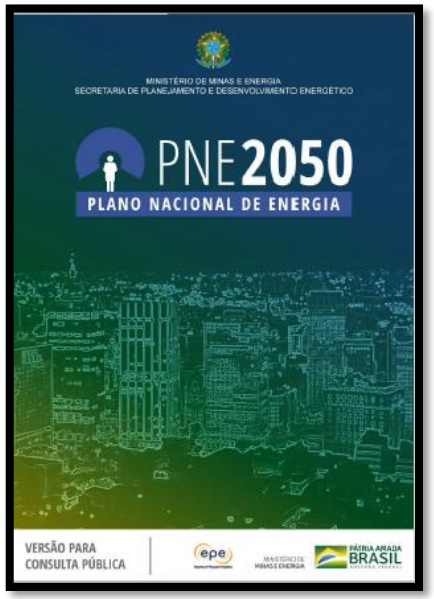
EU (2023): *Acknowledges the* ***European nuclear fuel supply chain as a strategic asset*** *and recognises the important role it will play in supporting the evolution of the next generation of reactor technology; Emphasises that a* ***robust, capable and reliable EU-based supply chain is critical for the success of producing SMRs****; recalls that the EU remains dependent on imported uranium, which poses inherent risks for its strategic sovereignty and security of supply;*

Nuclear energy in the 2050 Brazilian Energy Planning

Challenges on costs & construction time and opportunities for Small Modular Reactor

PNE 2050
Nuclear Energy

Recommendations:
To standardize projects to get scale and learning economies; To seek synergies in public policies;



***After 2030**, **new projects may be based on** PWR, **SMR** and fourth-generation reactor technologies, if the latter reach technological maturity and competitiveness.*

Small Modular Reactor - SMR

Opportunities:
Standardization, simplicity, security & safety, construction time & cost reduction, flexibility of supply, etc.

Challenges:
Technological uncertainties, many reactor concepts being proposed, quite diverse range of technological alternatives, comparisons, etc.

IAEA Coordinated Research Project – CRP
"Economic Assessment of the Potential for Small Modular Reactors on a National Level"

ABDAN Permanent Forum on SMR

USBEF Study on SMR

Nuclear energy: from Energy Planning to Policy

Legislations & Resolutions

1988 Federal Constitution,

Art. 21 The Union shall have the power to:
XXIII – operate nuclear energy services and facilities of any nature and exercise state monopoly over research, mining, enrichment and reprocessing, industrialization and trade in nuclear ores and their by-products, taking into account the following principles and conditions: (…)

Art. 225
§ 6º Power plants operated by nuclear reactor shall have their location defined in federal law and may not otherwise be installed.

Law # 14,120/2021

Establish competences to CNPE regarding authorization of Angra III; electricity price must be approved by CNPE based on a study carried out by BNDES for Eletronuclear, considering feasibility, financial conditions and affordability to consumers (EPE will be heard); Stocks from INP and Nuclep will be transferred to Union, etc.

CNPE Resolution nº 2, Feb, 10, 2021

Guidelines for energy R&DI public & public oriented funds to allocate resources in priority areas, which includes **nuclear energy**.

Law # 14,222/2021

Establish the National Authority for Nuclear Safety – ANSN and its competences.

Decree # 10,861/2021 [Law # 14,222/2021]

Associate the National Authority for Nuclear Safety – ANSN to the MME.

Decree # 10,791/2021 [Law # 14,182/2021]

Establish the Brazilian Nuclear and Binational Energy Holding Company – ENBPar.

CNPE Resolution nº 23, Oct, 20, 2021

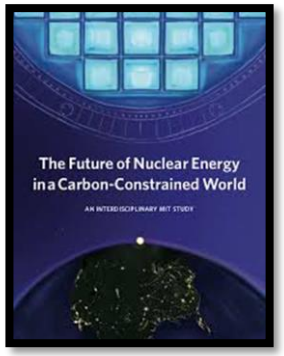
Establish directives for defining energy price for Angra 3 Nuclear Power Plant.

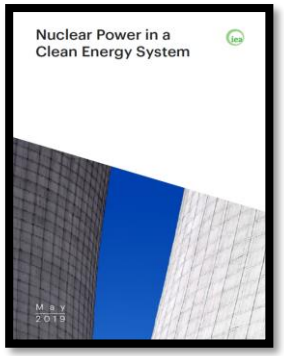
Provisory Measure nº 1,133, Aug, 12, 2022

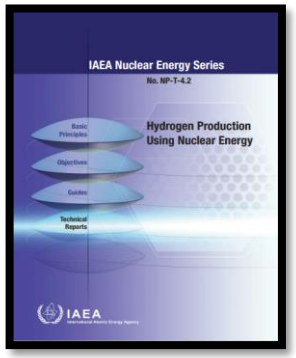
Relax the monopoly of INB on the exploration, mining, and sale of nuclear minerals, allowing for partnership with private companies.

Nuclear energy will play a key role in the energy transition

Energy security, system reliability, decarbonization, market coupling and spillovers







IAEA
International Atomic Energy Agency

Net zero needs nuclear power.
IAEA Statement on Nuclear Power at COP28 | IAEA

At COP28, Countries Launch Declaration to Triple Nuclear Energy Capacity by 2050, Recognizing the Key Role of Nuclear Energy in Reaching Net Zero

"*"We have a **viable alternative in nuclear** ... This is one of the ways in which we can achieve net-zero. **We don't get to net zero by 2050 without nuclear power in the mix.**"* In news conference at the COP27 climate summit in Egypt.
US Special Climate Envoy John Kerry

"*Canada can be a world leader in this promising, innovative, zero-emissions energy technology, and this is our plan to position ourselves in an emerging global market. **There is no path to net-zero without nuclear power**."*
Natural Resources Minister of Canada Seamus O'Regan

"*So, from offshore wind, to **nuclear**, to a revolution in our energy infrastructure (…) We'll now have a more pragmatic, proportionate, and realistic approach that eases the burdens on families. **Pragmatism, not ideology**. "*
UK Prime Minister Rishi Sunak

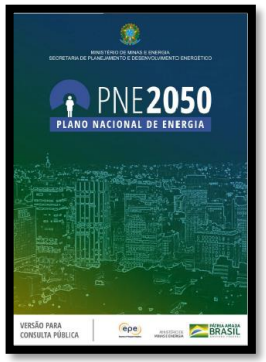
"*One of the facts in that report is in my view very pertinent. **In order to reach energy and climate goals nuclear generation needs to double compared to today**"*
Fatih Birol – Executive Director of IEA

Nuclear energy in the 2050 Brazilian Energy Planning

Energy Plans indicate challenges and recommendations

[At COP28, Countries Launch Declaration to Triple Nuclear Energy Capacity by 2050, Recognizing the Key Role of Nuclear Energy in Reaching Net Zero]

PNE 2050
Nuclear Energy



Main challenges:

Communication; improvements on institutional, legal and regulatory arrangements; implementing the National Nuclear Policy; Security & Safety; useful life and decommissioning of facilities; knowledge on related minerals resources.

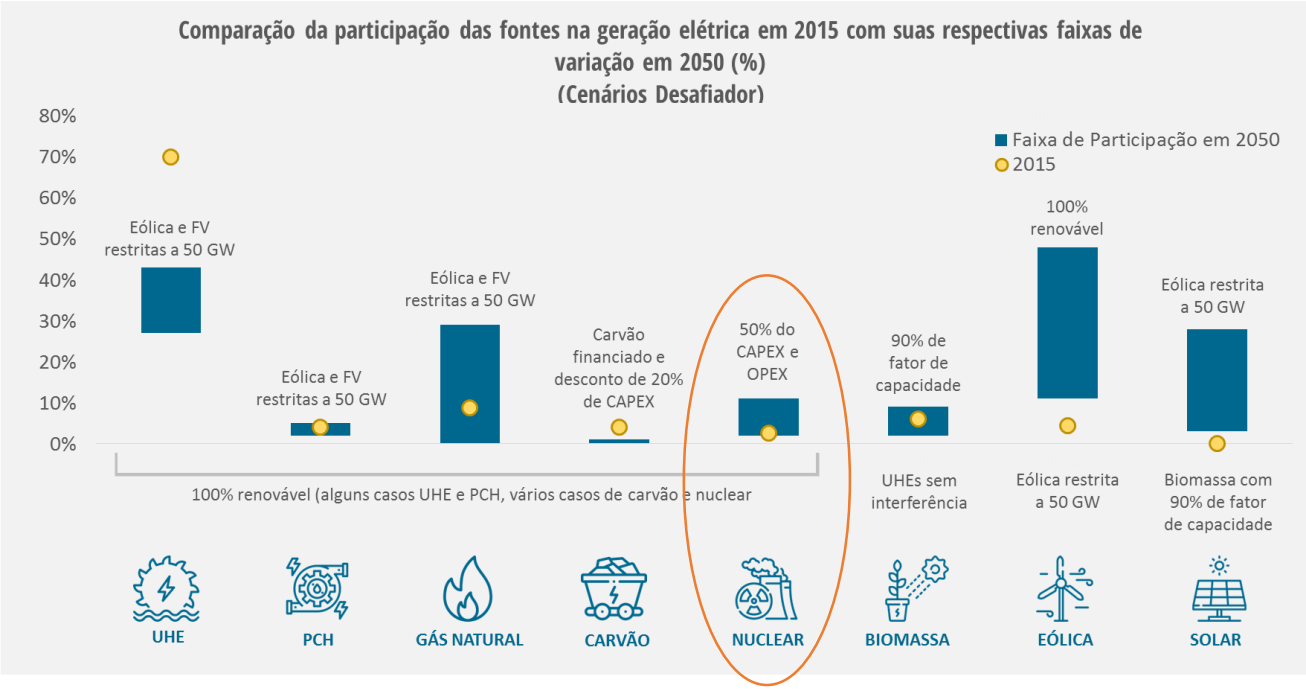
Recommendations:

To enhance communications with Brazilian society; To improve regulation framework; To estimate benefits related to spillovers and economies of scope; To standardize projects to get scale and learning economies; To seek synergies in public policies; To assure good housekeeping of waste and used fuel; To improve culture on security and safety; To guarantee fuel supply; To evaluate implications of expanding useful life.

Simulations for the Brazilian Power Market

Two basic cases for nuclear in 64 simulations:

1. Significant cost reductions (CAPEX and/or OPEX) for nuclear power plants
2. Public policy establishes nuclear power plants expansion of 8 GW to 10 GW by 2050



Nuclear energy & energy transition in Brazil

Energy security, system reliability, decarbonization, market coupling and spillovers

https://agenciagov.ebc.com.br/noticias/202311/alexandre-silveira-destaca-a-importancia-da-pluralidade-de-fontes-energeticas-do-pais-durante-evento-do-setor-nuclear

"***Developing and adapting the wide range of low-carbon technologies to local realities is the great challenge of energy planning.*** *This, in fact, is one of the main objectives of my tenure at the Ministry: to stimulate the plurality of sources, without technological lock-up and seeking the best energy costs for our population. We will foster a market that is always looking for new opportunities, helping the country to follow a path that focuses on energy transition and security.*

We must keep a firm eye on ensuring the security of service, with a plan based on the supply of clean, cheap, safe and accessible energy for all. ***And nuclear power is part of that scenario.*** *Because there is no universal recipe or a single set of technological solutions.*

Building consensus is not easy*. But it is what we pursue day and night, listening to everyone, dialoguing, acting with pragmatism and rationality.* ***And our development of the sector has shown that the mastery of nuclear activities and technologies can generate great advances for our country in the field of peaceful use.*** *We work to ensure that our actions are part of a broad spectrum of consistent energy policies, with an efficient energy transition, based on security, predictability and transparency.*

Alexandre Silveira, Minister of Mines and Energy of Brazil

[Speech at Nuclear Legacy 2023, Brasilia - Brazil]

Brazil is seeking engagement of stakeholders, communication with civil society and International Cooperation on Nuclear

Nuclear projects need wide consensus to increase social acceptability

Lula recebe Macron em Brasília no último dia da visita do líder francês ao Brasil — Planalto (www.gov.br)

Presidents Lula and Macron signed key deals in 2024

https://veja.abril.com.br/coluna/radar/deputado-apresenta-plano-nuclear-brasileiro-na-franca/

Brazilian Congressman Julio Lopes in the World Nuclear Exhibition

https://agenciagov.ebc.com.br/noticias/202311/brasil-e-franca-avancam-em-dialogos-para-consolidar-parceria-no-campo-das-geociencias

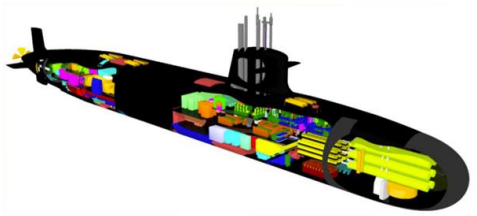
President-Director of Geologic Survey of Brazil Inácio Melo in the WNE

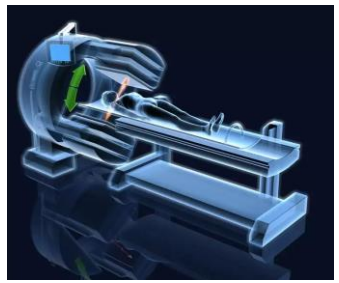
New Action Plan of the Brazil-France Strategic Partnership

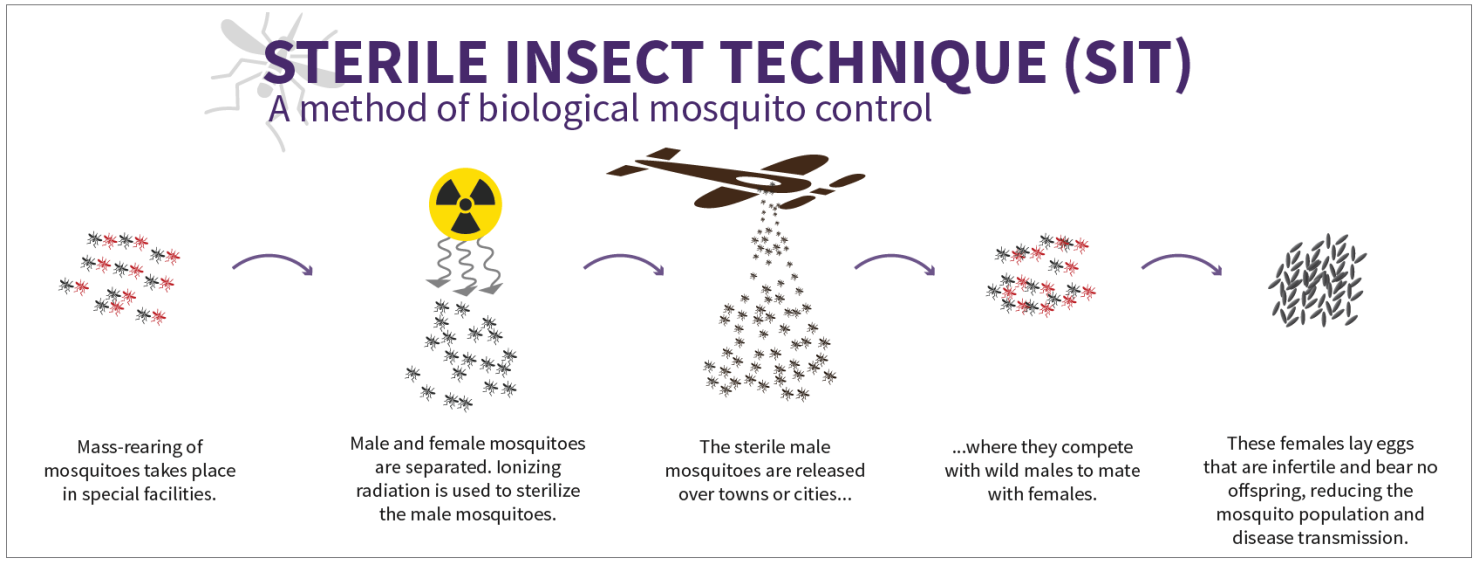
IX – Cooperation in energy and mining: 49. The two countries wish to deepen their cooperation lin the areas of energy transition, **notably civil nuclear energy**, critical minerals, renewable energy sources, decarbonised hydrogen, eectricity grids, energy efficiency, low-carbon transport as well as essential services of the sustainable city, notably in the areas of urban infrastructure, public-private partnerships and concessions low-carbon mobility).

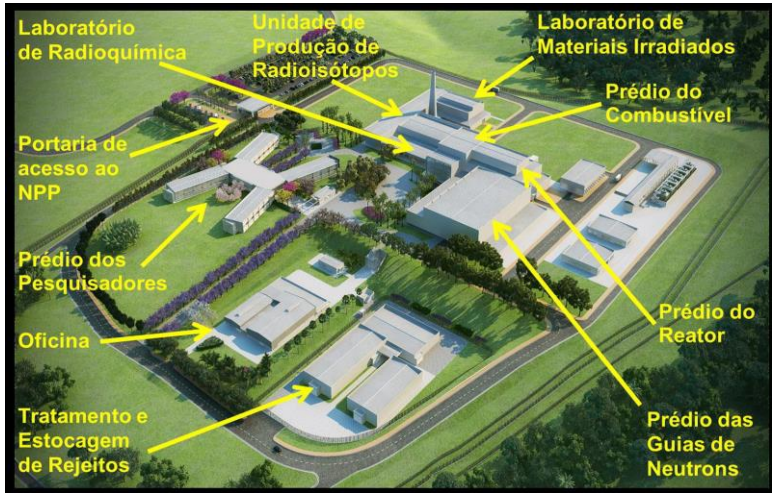
Nuclear industry & other uses: externalities & spillovers

Food irradiation, nuclear medicine, defense, industrial heating, etc.





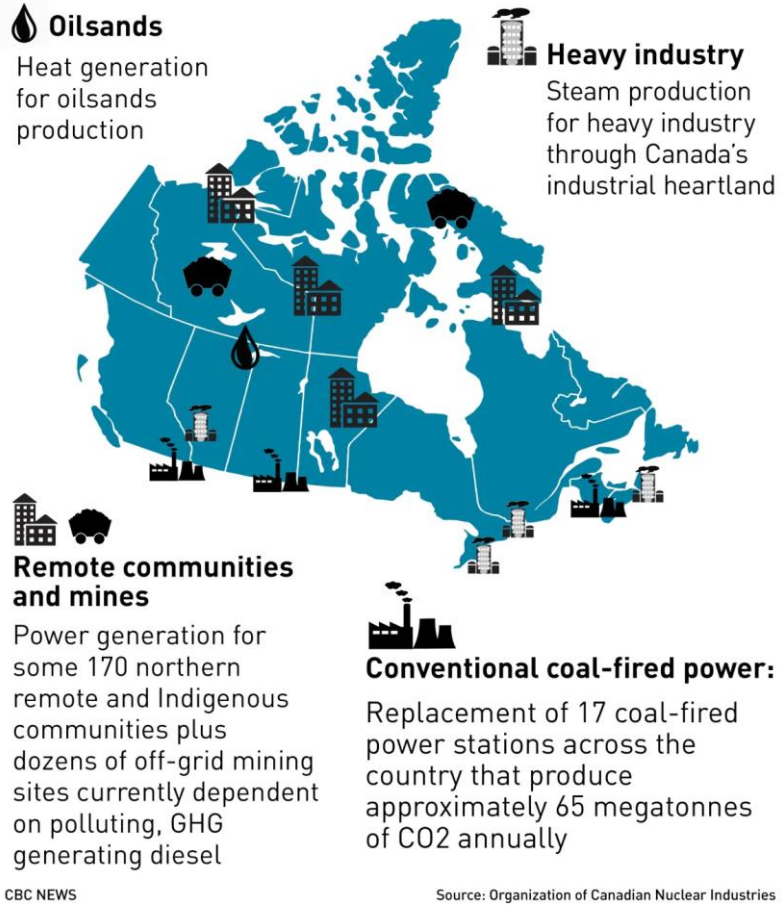


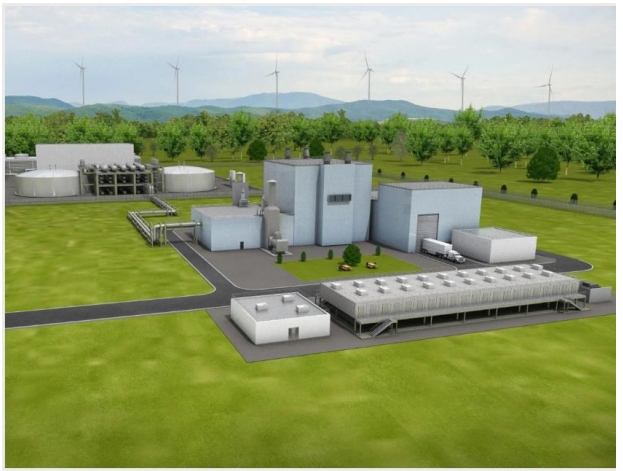


Nuclear industry & other uses: sectorial coupling

Heavy industrial, power in remote area, replacement of coal power plant, oil industry

Small modular reactors are designed to be factory-built then transported, as in this illustration. *(Supplied: NuScale)*



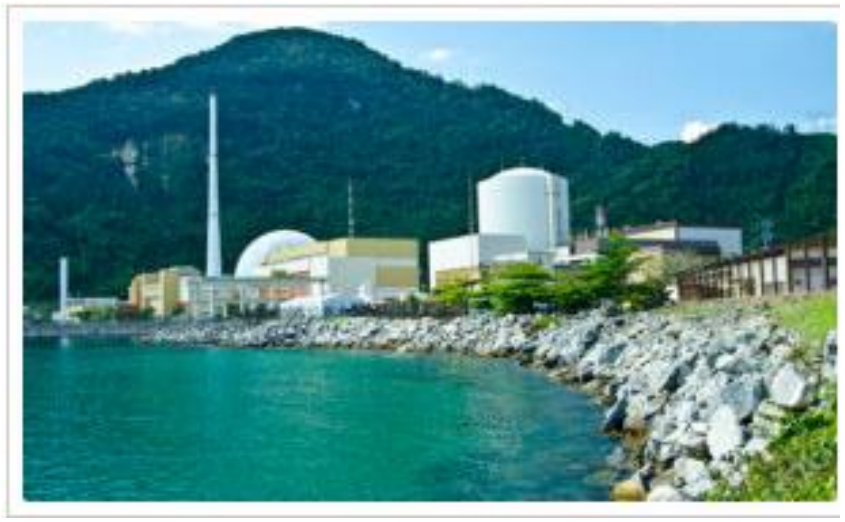


This illustration shows TerraPower's Wyoming project, which aims to retrofit an existing coal plant with a sodium fast reactor. TERRAPOWER

Hydrogen production from nuclear in Brazil

On-going projects ...

Project in Angra Nuclear Complex by Eletronuclear



Eletronuclear plans to purify the hydrogen gas (currently at 96% concentration) produced in Angra I & II (potential 150-300 kg of H2/day, raising to 500 kg/day with Angra III in the future)

Hydrogen separation facilities in Angra Nuclear Complex

Angra I

Angra II

The chlorination system was replaced from a process based on chlorine gas with on-site generation of sodium hypochlorite from seawater electrolysis. Hydrogen is a by-product currently vented to the atmosphere.

https://inis.iaea.org/search/searchsinglerecord.aspx?recordsFor=SingleRecord&RN=30041651

Texts adopted - Small modular reactors - Tuesday, 12 December 2023 (europa.eu) 8. **Encourages the exploration of the potential use of SMRs for low-carbon hydrogen production, both for its direct use in industry, as well as for the production of sustainable synthetic fuels; recalls that vast amounts of new electricity capacity is needed to ensure the expected scale of hydrogen production required to decarbonise European industry, considering the predicted global expansion of hydrogen demand;**

Recent news on nuclear from Brazil

Strategic Decisions

DIÁRIO OFICIAL DA UNIÃO

Publicado em: 07/11/2022 | Edição: 210 | Seção: 2 | Página: 3

Órgão: Presidência da República/Gabinete de Segurança Institucional/Comitê de Desenvolvimento do Programa Nuclear Brasileiro

PORTARIA Nº 101, DE 3 DE NOVEMBRO DE 2022

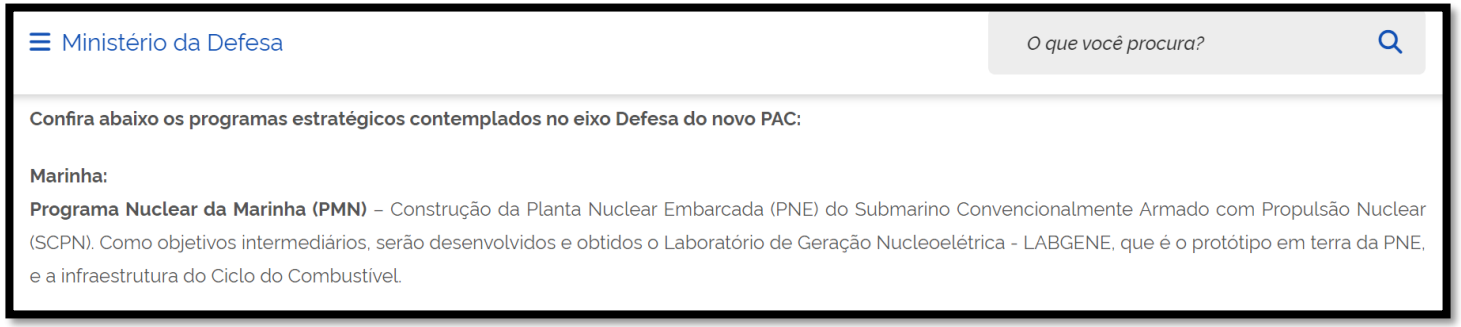
O MINISTRO DE ESTADO CHEFE DO GABINETE DE SEGURANÇA INSTITUCIONAL DA PRESIDÊNCIA DA REPÚBLICA, na condição de COORDENADOR DO COMITÊ DE DESENVOLVIMENTO DO PROGRAMA NUCLEAR BRASILEIRO, no uso das atribuições que lhe confere o art. 87, parágrafo único, incisos I e IV, da Constituição, e tendo em vista o disposto no artigo 9º, incisos I e II, do Decreto nº 9.828, de 10 de junho de 2019, no art. 2º do Anexo da Resolução CDPNB nº 20, de 15 de setembro de 2022, e nos §§ 1º e 2º do art. 21, do Anexo da Resolução CDPNB nº 21, de 15 de setembro de 2022, resolve:

Art. 1º Designar os seguintes representantes, titulares e suplentes, indicados pelos órgãos que integram o Grupo Técnico do Comitê de Desenvolvimento do Programa Nuclear Brasileiro, com o propósito de analisar aspectos direcionadores para a escolha de novos sítios nucleares, onde serão construídas as próximas usinas termonucleares no Brasil:

Jan 2023

Guidelines to select sites for new nuclear plants in Brazil

Eletronuclear



GERAÇÃO DE ENERGIA

Modalidades	Quantidade	Valor - R$ Bilhões	Tipo
Térmica Nuclear	1	1,9	Estatal
Térmica a Gás	3	6,7	Privado
Térmica Renovável	2	2,1	Privado
Hidrelétrica	1	0,2	Privado
Eólicas	120	22,0	Privado
Fotovoltaicas	196	41,5	Privado
Pequenas Centrais Hidrelétricas	20	1,3	Privado
TOTAIS	**343**	**75,7**	

Decree # 9,600/2018: the Brazilian Nuclear Policy

Directives for the Brazilian Nuclear Policy

Art 1°. ***The Brazilian Nuclear Policy has the purpose of guiding planning, actions and nuclear and radioactive activities in the homeland***, according to the national sovereignty, focusing on the development and on the protection of the human health and of the environment.


DIÁRIO OFICIAL DA UNIÃO

DECRETO Nº 9.600, DE 5 DE DEZEMBRO DE 2018

Consolida as diretrizes sobre a Política Nuclear Brasileira.

O PRESIDENTE DA REPÚBLICA, no uso das atribuições que lhe confere o art. 84, caput, inciso VI, alínea "a", da Constituição,

D E C R E T A:

CAPÍTULO I

DISPOSIÇÕES PRELIMINARES

Finalidade

Art. 1º A Política Nuclear Brasileira tem por finalidade orientar o planejamento, as ações e as atividades nucleares e radioativas no País, em observância à soberania nacional, com vistas ao desenvolvimento, à proteção da saúde humana e do meio ambiente.

Definições

Art. 2º Para fins do disposto neste Decreto, considera-se:

I - combustível nuclear - dispositivo capaz de produzir energia, por meio de processo autossustentado de fissão nuclear;

II - combustível nuclear usado - combustível nuclear utilizado no reator nuclear e removido de seu núcleo, que será armazenado em local apropriado para futura reutilização;

III - elemento nuclear - urânio, tório, plutônio ou qualquer elemento químico que possa ser utilizado na produção de energia em reatores nucleares;

IV - estoque estratégico de material nuclear - estoque constituído pelo volume de material nuclear necessário para atender por determinado período, à demanda do Programa Nuclear Brasileiro;

V - material nuclear - compreende os elementos nucleares ou os seus subprodutos em qualquer forma de associação;

VI - material radioativo - material que emite, espontaneamente, radiação ionizante;

VII - mineral - substância sólida, de ocorrência natural, homogênea e com composição química e estrutura cristalina constantes e definidas;

VIII - mineral nuclear - mineral que contém em sua composição um ou mais elementos nucleares;

IX - minério nuclear - concentração natural de mineral nuclear, no qual o elemento ou elementos nucleares ocorrem em proporção e condições tais que permitam sua exploração econômica;

X - Programa Nuclear Brasileiro - conjunto de projetos e atividades relacionados com a utilização, para fins pacíficos, da energia nuclear sob a orientação, o controle e a supervisão do Governo Federal;

XI - proteção física - conjunto de medidas destinadas a:

a) evitar atos de sabotagem contra materiais, equipamentos e instalações;

b) impedir a remoção não autorizada de material, em especial material nuclear;

c) estabelecer meios para localização e recuperação de material desviado; e

d) proteger o patrimônio e a integridade física da pessoal que integra a instalação nuclear;

D9600 (planalto.gov.br)

Art 5°. The objectives of the Brazilian Nuclear Policy are:

I - **preserve the domain of nuclear technology** in the country;

II - **meet future decisions of the energy sector regarding the supply of clean and firm energy through the generation of nuclear power**;

IV - **to promote the awareness of Brazilian society**, in a transparent manner, regarding **the benefits of the use of nuclear technology and the measures that allow its safe use**;

V - expand the medical use of **nuclear technology as a tool to improve the health** of the population;

VIII - **to foster research, development and innovation in nuclear technology**;

X - to promote **research and prospecting for nuclear minerals** in the country;

XI - **to encourage the domestic production of nuclear ores and their by-products**, including those associated with other mineral goods, with a view to meeting domestic demand and exports;

XIII - **guarantee autonomy in the production of nuclear fuel**, on an industrial scale and in all stages of its cycle, with a view to ensuring the supply of domestic demand;

XIV - promote national self-sufficiency in the **production and supply of radioisotopes and their export**;

XVII - **stimulate technical, scientific and industrial training** compatible with the needs of the nuclear sector;

(...)

Key messages

- ✓ Nuclear role in energy transition
  - ✓ Energy security, system reliability, decarbonization and spillovers
  - ✓ Possibility of coupling to other markets (carbon market, industrial heat, hydrogen, etc.)
- ✓ Energy plans, legislations and CNPE resolutions are dealing with challenges for nuclear in Brazil
- ✓ Particularly, SMR brings new opportunities to nuclear industry
  - ✓ Standardization, simplicity, security & safety, construction time & cost reduction, flexibility of supply, etc.
  - ✓ Market coupling: electricity, industrial heat, hydrogen, carbon, etc.
- ✓ Nuclear-Hydrogen nexus improves economics of both!

Engagement and communication still matter!

Market pricing usually does not value externalities and spillovers, but total value might be estimated:

Total value of nuclear (benefits) = value of use + value of option + value of precaution + value of synergy

Mathematical expression of Decree 9,600/2018

www.epe.gov.br

MINISTÉRIO DE
MINAS E ENERGIA

GOVERNO FEDERAL
BRASIL
UNIÃO E RECONSTRUÇÃO

Thank you!