Small Modular Reactors
An Overview Course

KEY SMR ASPECTS IN TODAY'S NUCLEAR SECTOR

Nuclear New Horizons: Fueling our Future
October 21-25, 2019 - Santos, SP, Brazil
VI ENIN

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- -Dynamics of the nuclear sector
- -SMRs entering the market

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- -Types of SMRs
- -Applications

03 What is really needed to deploy a SMR in Brazil?
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01

Introduction

Introduction

-Nuclear sustainability

-Dynamics of the nuclear sector

-SMRs entering the market

Sustainable Development Goals (SDGs)

REF: **UNITED NATIONS, SUSTAINABLE DEVELOPMENT GOALS**
HTTPS://SUSTAINABLEDEVELOPMENT.UN.ORG

01

Introduction

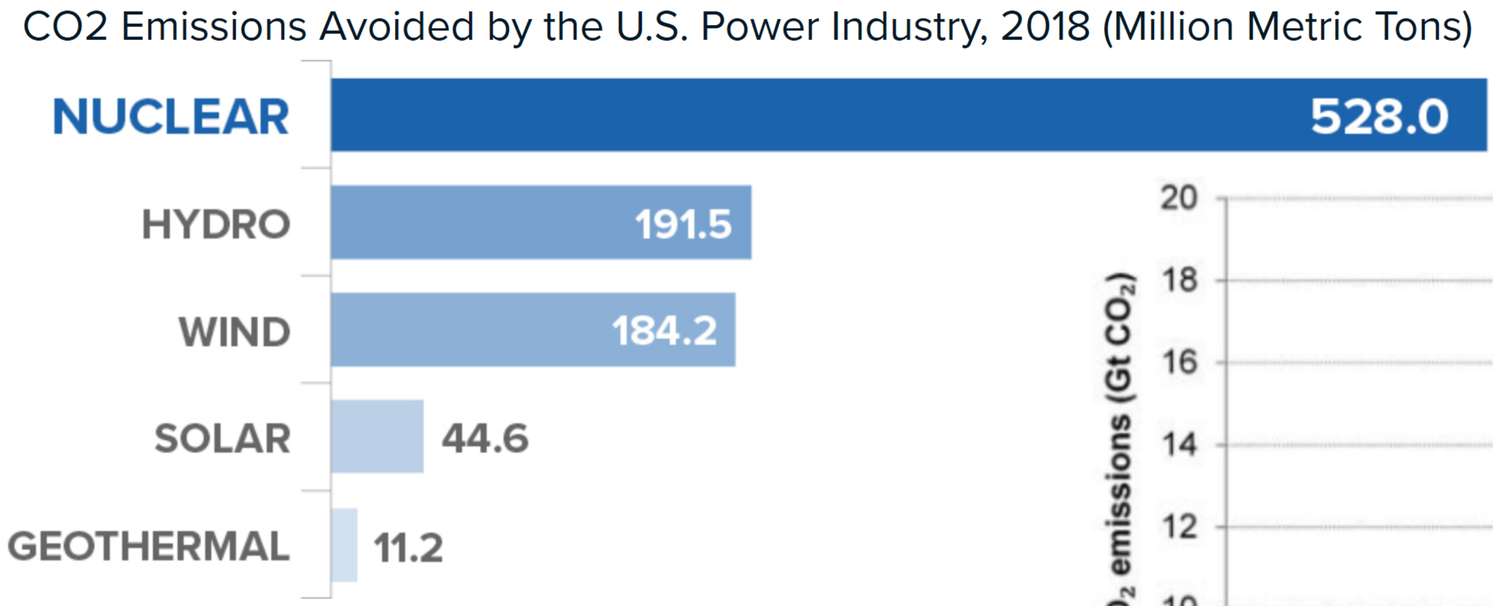
Nuclear Science & Technology can directly contribute to 9 out of 17 SDGs

REF: **INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)**
HTTPS://WWW.IAEA.ORG/ABOUT/OVERVIEW/SUSTAINABLE-DEVELOPMENT-GOALS

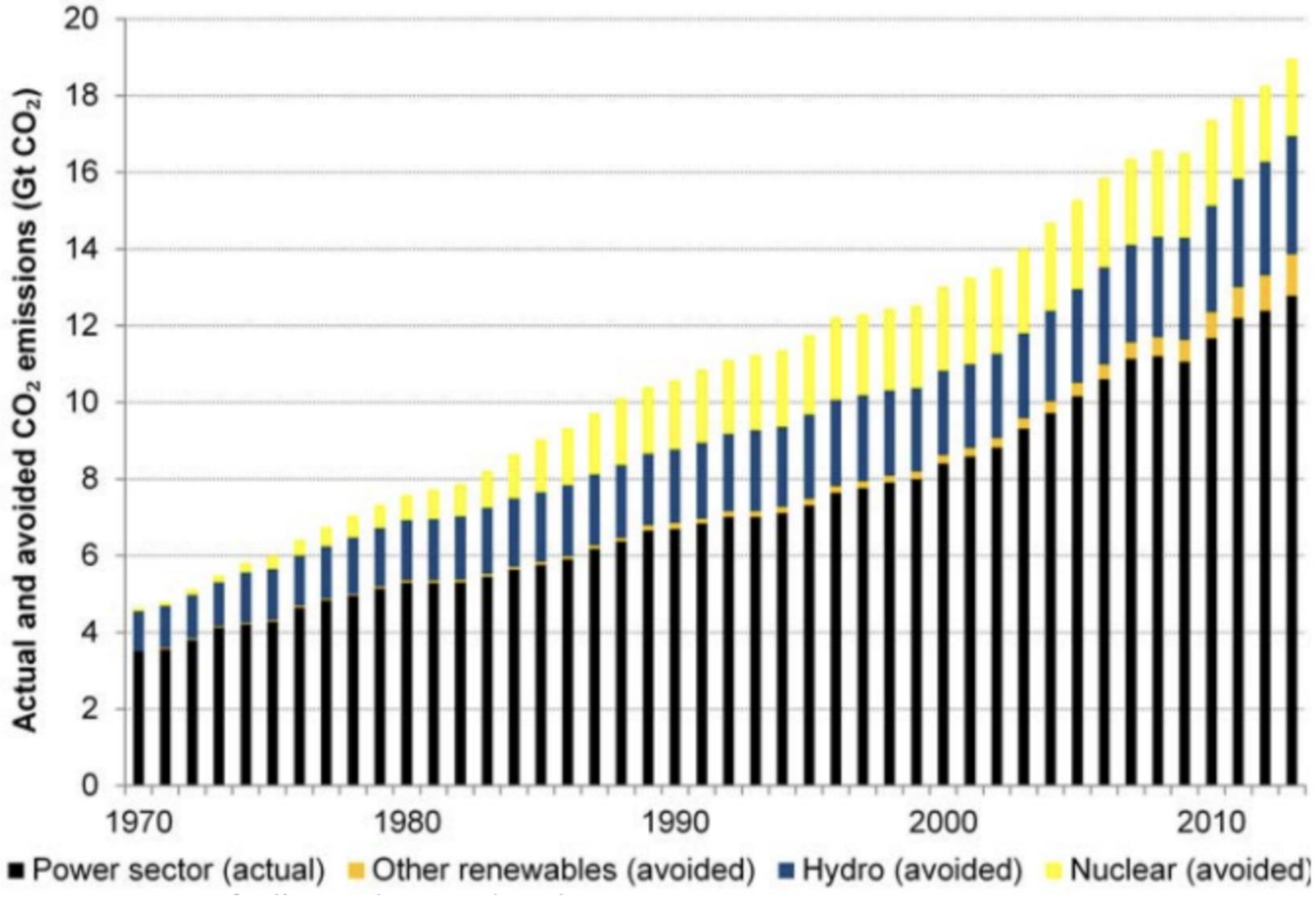
01

Introduction

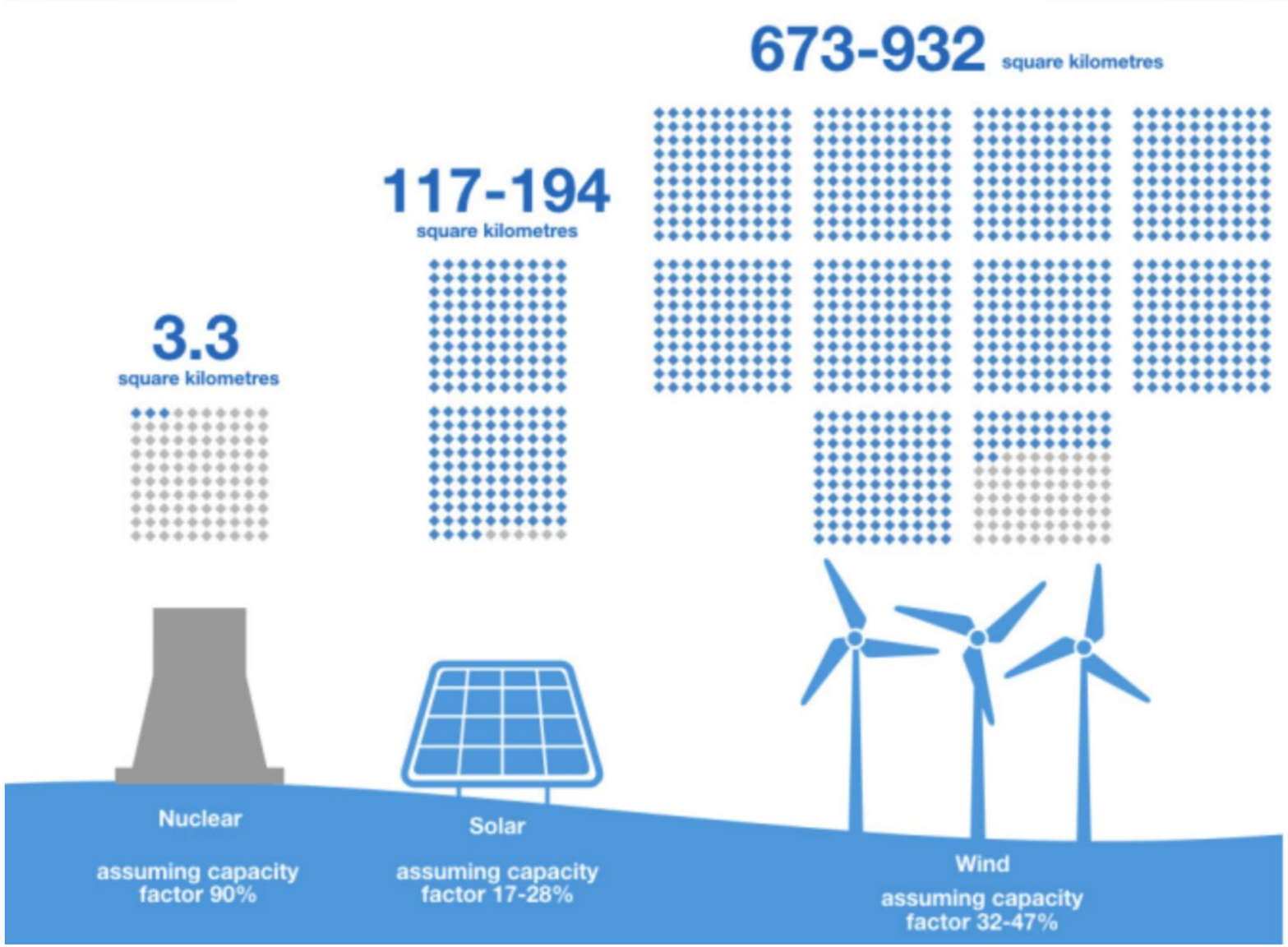
Avoided GHG emissions (US & World)



Sources: EPA and EIA. March 2019.



Land requirements 1000 MWe



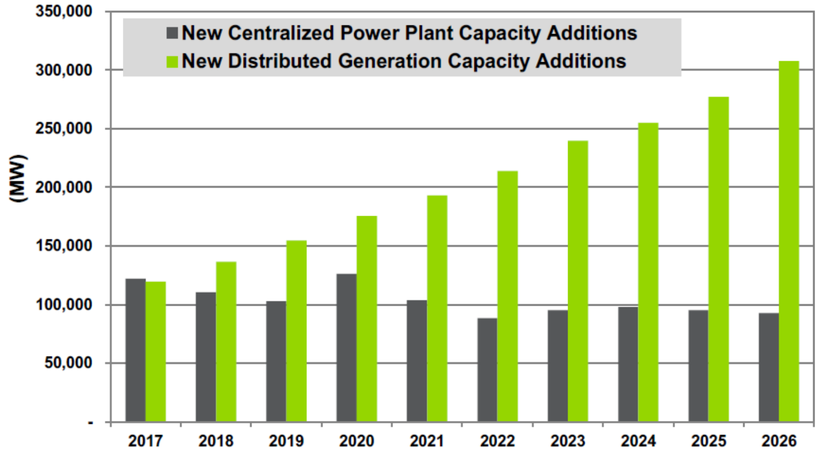
REF: **IAEA, CLIMATE CHANGE AND NUCLEAR POWER, 2016**

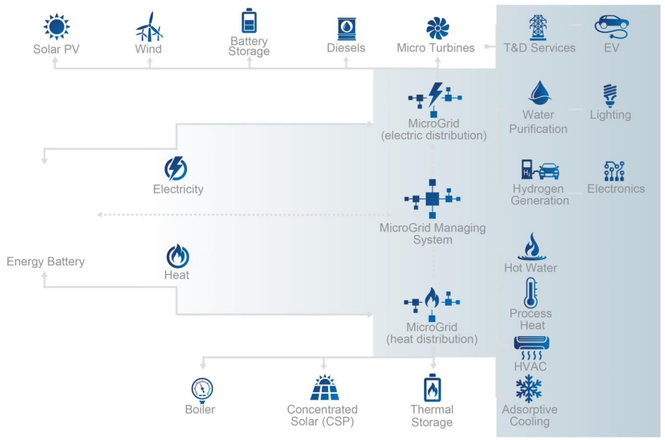
01

Introduction

Ongoing Transformation in the Nuclear Sector

- New business model for new plant development
- New power grid dynamics due to increased contribution of renewable sources
- Trend from centralized to distributed energy generation
- Different and new applications of nuclear technology





REF: **DIFFERENT SOURCES - ROSATOM, NAVIGANT RESEARCH, WESTINGHOUSE**

02

Are SMRs a suitable choice for Brazil?

Are SMRs a suitable choice for Brazil?

-SMRs definition

-Types of SMRs

-Applications

SMRs definition

The IAEA states that small modular reactors, or “SMRs”, are “newer generation reactors designed to generate electric power up to 300MW”.

SMR:	>50 Mwe (up to 300MWe)
VSMR:	10 – 50 Mwe
Micro Reactors:	< 10 MWe

REF: **IAEA: ADVANCES IN SMALL MODULAR REACTOR TECHNOLOGY DEVELOPMENTS. 2018 EDITION (VIENNA: IAEA, 2018).**

02

Are SMRs a suitable choice for Brazil?

Types of SMRs

The report of the IAEA on Advances in Small Modular Reactor Technology Developments considers SMRs in the following categories:

– water cooled (pressurized and boiling water reactors) - land based;
– water cooled (pressurized and boiling water reactors) - marine based;
– high temperature gas cooled reactors;
– fast neutron spectrum (gas, sodium and lead bismuth cooled reactors);
– molten salt reactors; and
– other.

REF: **IAEA: ADVANCES IN SMALL MODULAR REACTOR TECHNOLOGY DEVELOPMENTS. 2018 EDITION (VIENNA: IAEA, 2018).**

02

Are SMRs a suitable choice for Brazil?

Types of SMRs

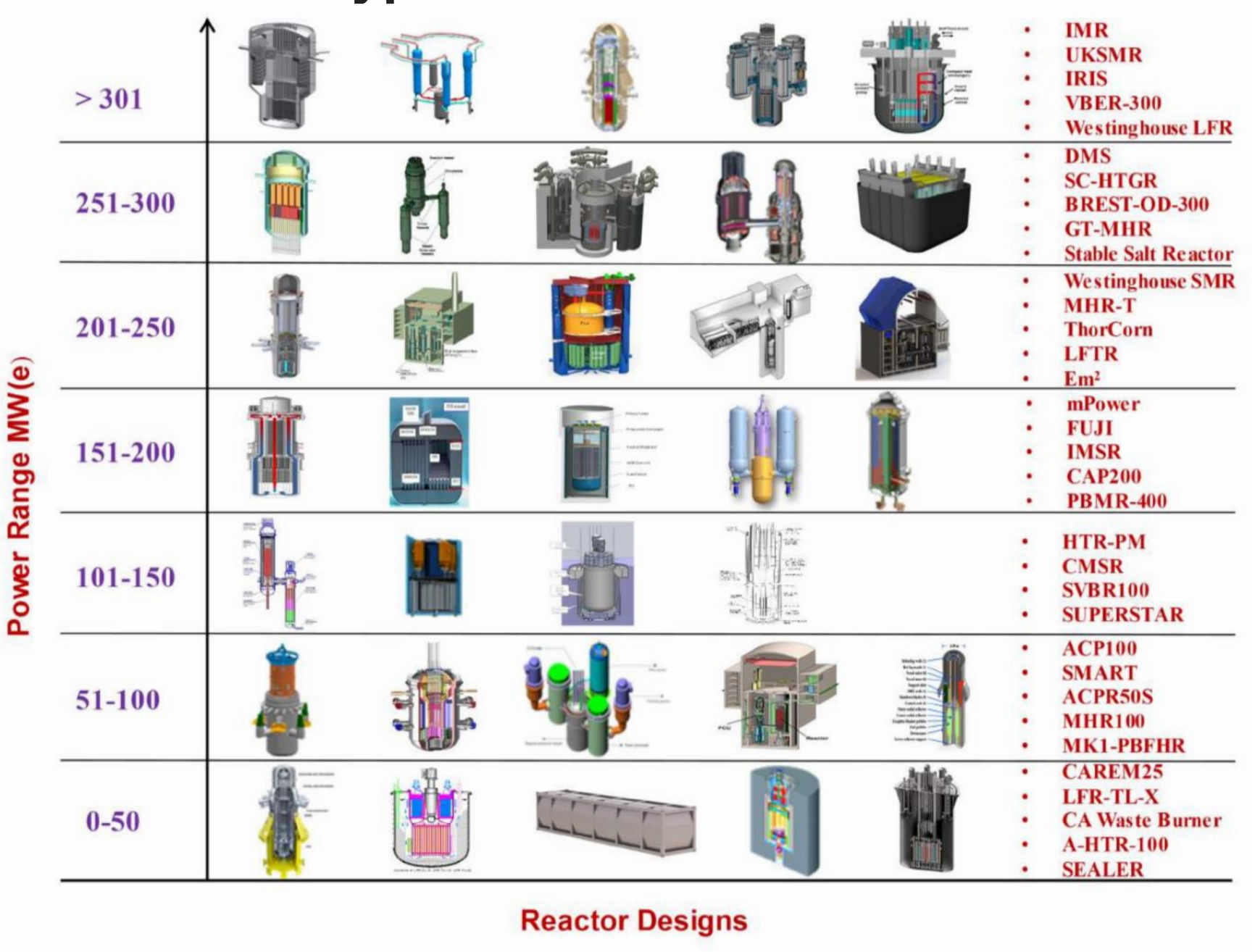
Types of SMR Technologies	Advantages	Challenges
LWR	Well known, proven technology	Limited industrial applications (no high temp)
HTGR	Safety at high temperatures Low power density	LPD = large size
Fast Spectrum – Sodium Cooled	High thermal conductivity, heat transfer Passive safety	Sodium reaction with water
Fast Spectrum – Lead Cooled	Operate at ATM Lead non reactive with water/air	High melting point of Pb
Molten Salt	Inherent safety of negative temp coefficient of reactivity Near ATM operating pressure	Molten salts are corrosive
Heat Pipes	High reliability due to minimum moving parts Inherhrent safe due to negative TCR	Limited power levels (~<20MWe) Lack of OPEX

REF: **IAEA: ADVANCES IN SMALL MODULAR REACTOR TECHNOLOGY DEVELOPMENTS. 2018 EDITION (VIENNA: IAEA, 2018).**

02

Are SMRs a suitable choice for Brazil?

Types of SMRs - Power



REF: **IAEA: ADVANCES IN SMALL MODULAR REACTOR TECHNOLOGY DEVELOPMENTS. 2018 EDITION (VIENNA: IAEA, 2018).**

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Are SMRs a suitable choice for Brazil?

Types of SMRs - Fuel

Types of SMR Fuel	Characteristics
LWR Fuel	Proven large reactor experience Readily available, fabrication capacity
Metal Fuel	Better heat transfer Targeted on fast reactors
Uranium Silicide	Higher U density, thermal conductivity Typically paired with advanced cladding materials (SiC)
Uranium Nitride	Higher U density, thermal conductivity Robust microstructure properties
Uranium Carbide	Higher U density, thermal conductivity
TRISO Fuel	Composed of encapsulated micro-particles Superior safety characteristics
Molten Salt Fuels	Flourides of Lithium, or Sodium, Berillium, Potassium, Sodium Cannot melt down

- Different geometric matrix (rods, pellets, prismatic, etc)
- Up to < ~19.5% enrichment
- Special materials
- Others

REF: **IAEA: ADVANCES IN SMALL MODULAR REACTOR TECHNOLOGY DEVELOPMENTS. 2018 EDITION (VIENNA: IAEA, 2018).**

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Are SMRs a suitable choice for Brazil?

Applications

In addition to electricity generation (including replacing old fossil- fired plants), SMRs may be suitable for:

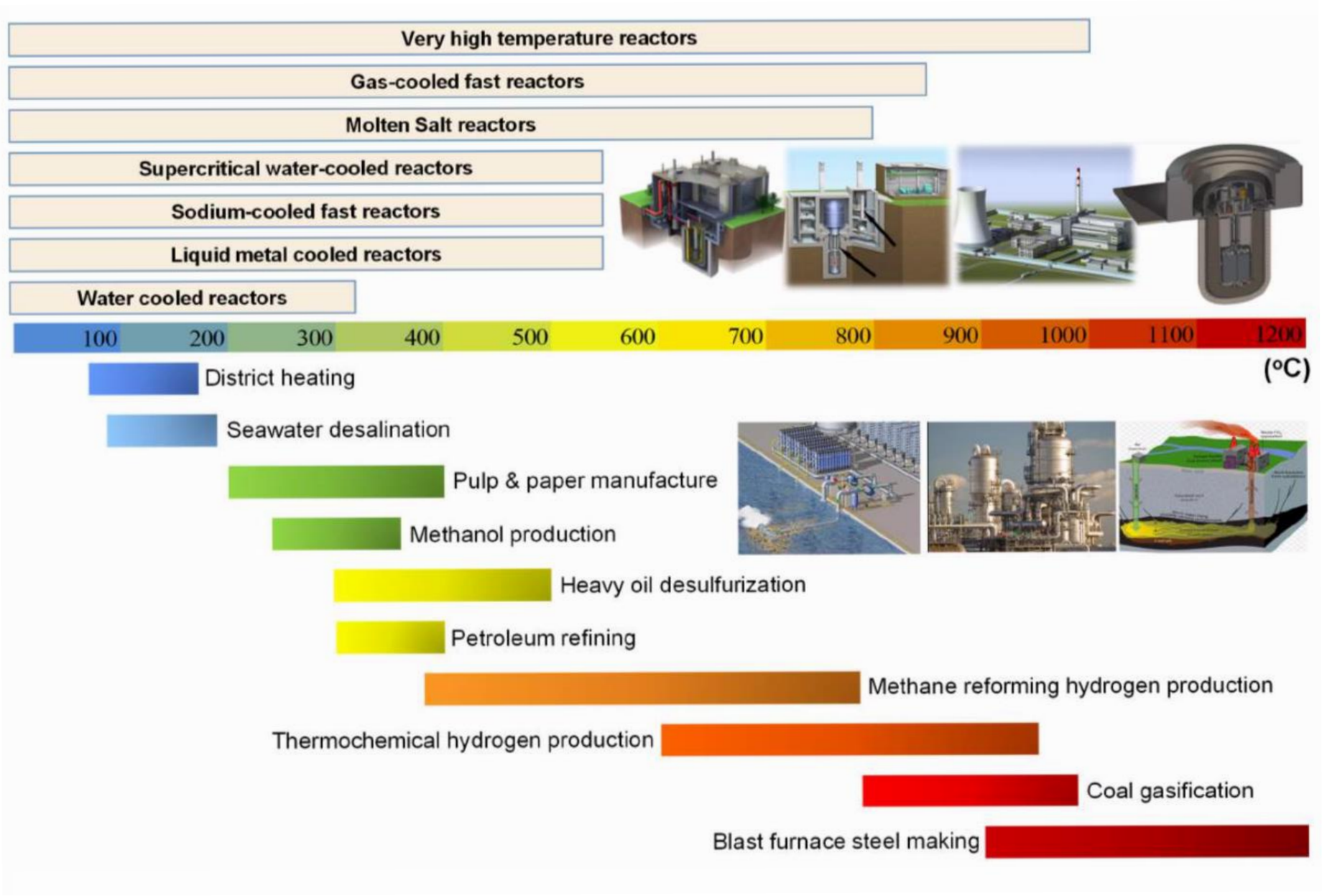
- Co-generation, including process heat for industrial uses and district heating.
- Sea water desalination.
- Hydrogen production.
- Refineries, mining installations and marine applications, such as icebreaking or shipping.

REF: **DEVELOPING LEGAL AND REGULATORY FRAMEWORKS FOR SMALL MODULAR NUCLEAR REACTORS**
HTTPS://WWW.GNEADVISORY.COM

02

Are SMRs a suitable choice for Brazil?

Types of SMRs - non electric applications



REF: **IAEA: ADVANCES IN SMALL MODULAR REACTOR TECHNOLOGY DEVELOPMENTS. 2018 EDITION (VIENNA: IAEA, 2018).**

02

Are SMRs a suitable choice for Brazil?

03

What is really needed to deploy a SMR in Brazil?

What is really needed to deploy a SMR in Brazil?

-Benefits

-Limitations

Benefits

Smaller size

- Applicable to limited grid locations
- Flexible power levels

Simplified design

- enhanced passive safety features
- fewer components, lower costs

Modularity and factory manufacture/fabricat

- standardized and factory built
- minimize site construction and focus on assembly and installation

Multi unit and incremental deployment

- flexible addition of power, phased construction/operation

Load-following

- flexible operations to better match advanced grid demands
- complementary to renewables

Safety

03

What is really needed to deploy a SMR in Brazil?

Benefits

Nuclear proliferation and security

- underground models, more resistant to hazards or interventions
- advanced fuel, resistant designs

Economics

- Smaller CAPEX upfront, economies of scale for NOAK

Operations

- Simplified and more automated designs

Siting

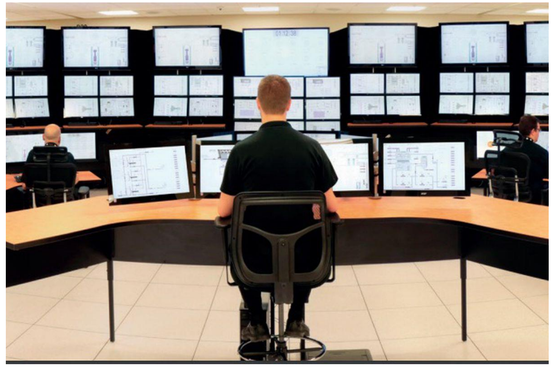
- adequate for remote areas, locations where large plants not suitable

Fuel supply

- pre-installed fuel, longer operating cycles

Decommissioning

- simplified site D&D



03

What is really needed to deploy a SMR in Brazil?

Limitations

1. Energy demand: Significant baseload capacity may be needed - are SMRs/fleets of SMRs sufficient?
2. Timescales: SMR deployment timelines vary; may be 2025-2030 for first construction – is this timescale suitable?
3. Regulatory: Even for established nuclear regulatory bodies, there may be regulatory and licensing challenges for SMRs – how can these be addressed?
4. International cooperation: Coordination and cooperation between governments (on issues of regulation, financing, export controls, international transportation) may be needed – who is actively seeking to resolve these issues?

03

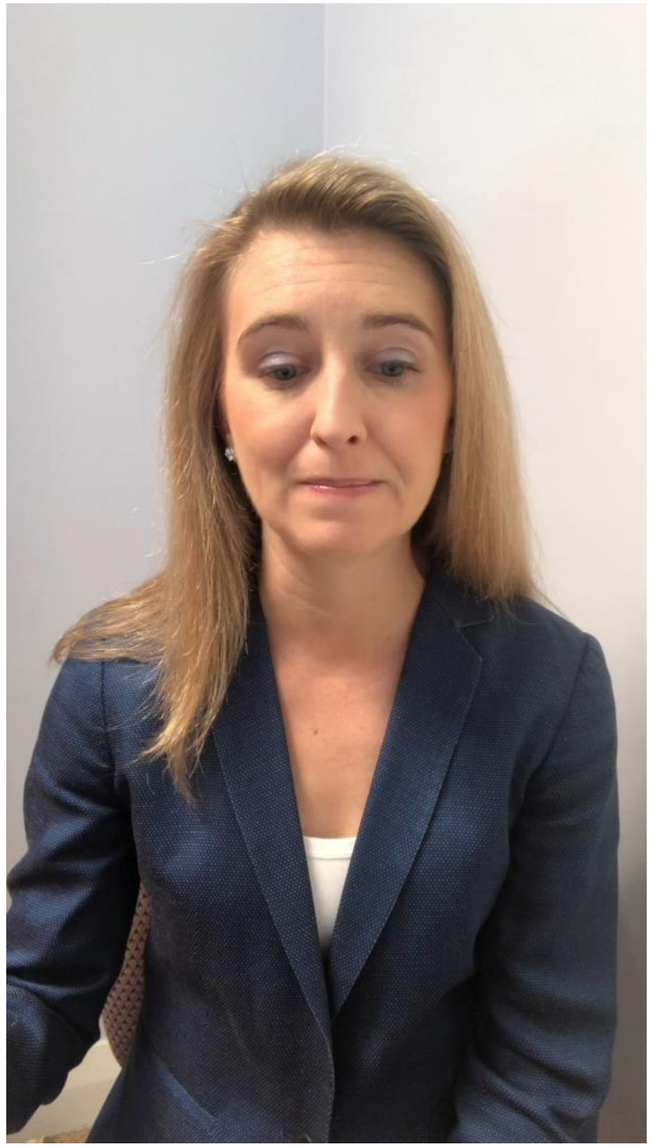
What is really needed to deploy a SMR in Brazil?

Limitations

5. FOAK risk: Likely to be considerable first-of-a-kind development risk for initial wave of SMR construction – how can FOAK-risk be mitigated?

6. Project structures: Need to understand government role and ensure bankable project structures – what government support mechanisms will be available?

7. Finance: FOAK risk increases cost; cost benefits of SMRs depend on large-scale manufacture and a fleet approach; no models yet exist for project financing and there may be market uncertainty – how will SMRs be financed?



03

What is really needed to deploy a SMR in Brazil?

04

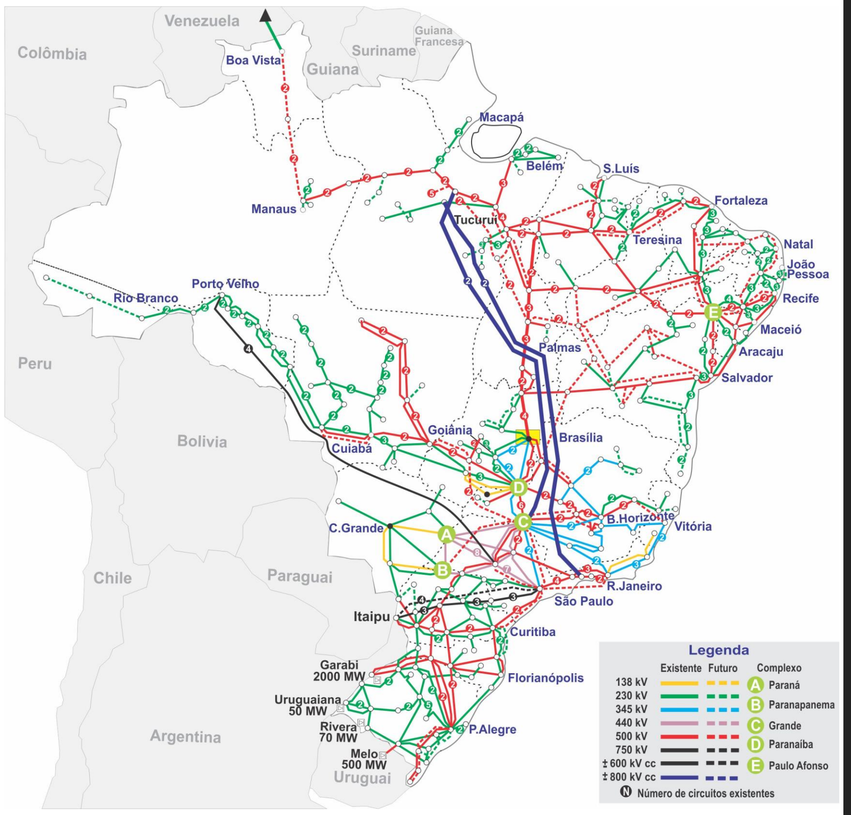
Case study

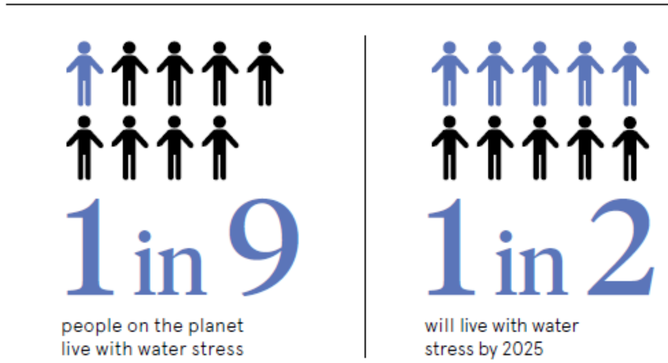
Case study

- Developing a SMR project in Brazil

Potential Applications

- Niche Areas: on-grid, off grid.
- Desalination.





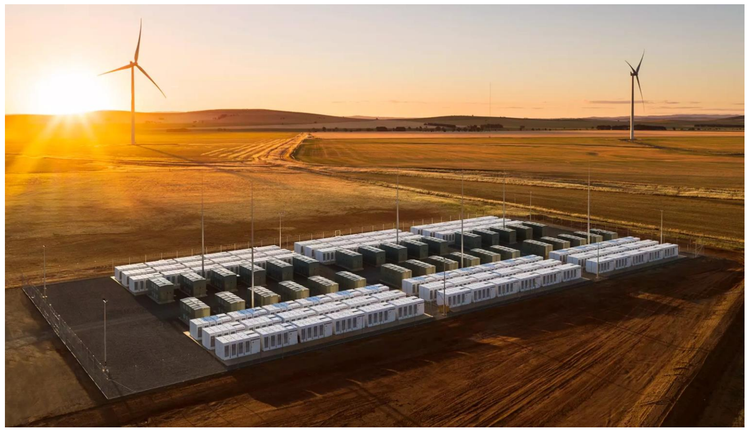
Ref: United Nations Convention to Combat Desertification
https://knowledge.unccd.int/

04

Case study

Potential Applications

- Complementary to Renewables
- Industrial Process Heat (H2 Production, etc)



Ref: https://www.teslarati.com/tesla-powerpack-farm-australia-energy-storage-movement/

Ref: Dupont

04

Case study

Building a project - Developing a SMR Roadmap for Brazil

Ref: https://smrroadmap.ca/

04

Case study

Building a project - Developing a SMR Roadmap for Brazil

Canada Status

- Demonstration Program
    - Government & Private Sector Cost Share
    - Demonstrate technology readiness
    - confirm benefits, mitigate uncertainties
- Supply Chain
    - Incentives for supplier investment
    - Identify gaps, solutions
- Licensing
    - process reform
    - pre-approval, evaluation
- Public Engagement
    - New stakeholders
    - acceptance

04

Case study

Building a project - Developing a SMR Roadmap for Brazil

United States Status

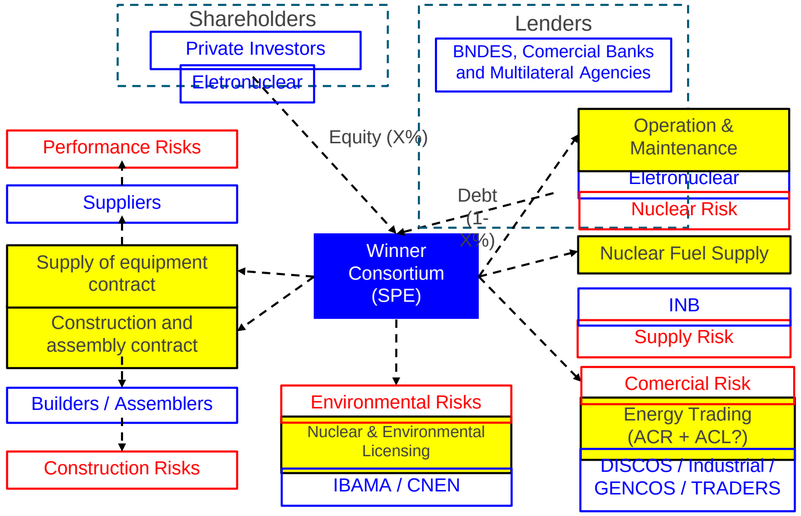
- Demonstration Program
    - Government & Private Sector Cost Share
    - Led by DOE Idaho National Lab (INL)
- Technology Testing & Validation
    - Materials, I&C, Fuels, Simulation, etc
- Regulatory Process
    - Address SMR challenges
- DOE US$700M Budget for Nuclear Energy, including SMRs (part of $1.9B budget for energy R&D)

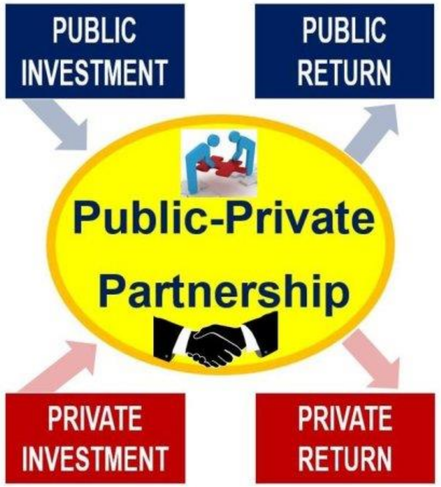
04

Case study

Building a project - Financing a Business Model

- Contracts
- Auction/Direct Bid
- SPE Models
- Public/Private Banks and Investment Funds





Ref: Different Sources - Wikipedia, ANEEL, Market Business News

04

Case study

Building a project - Sitting on SMRs

- Site Selection and Evaluation and Prioritization
- Infrastructure: local, remote, grid connection

IAEA Safety Standards

for protecting people and the environment

Site Survey and Site Selection for Nuclear Installations

Specific Safety Guide

No. SSG-35

IAEA

International Atomic Energy Agency

Ref: IAEA, Eletronuclear

04

Case study

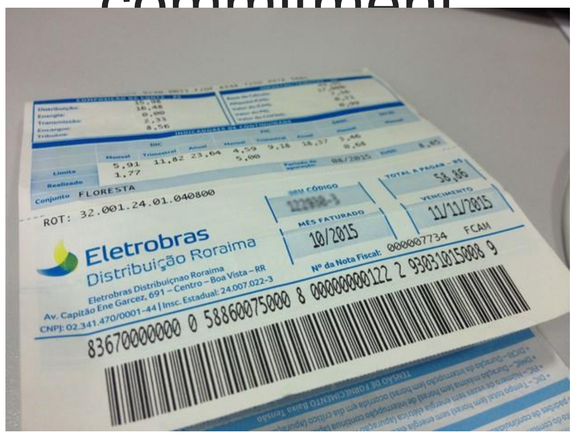
Building a project - Project Stakeholders

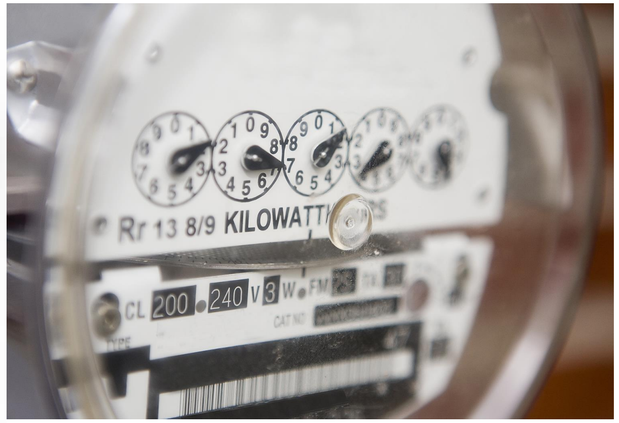
- Government: Federal, State and Local
- Utilities: Eletrobras Eletronuclear, Regional Utilities
- Supply Chain: manufacturing, assemblers, import/export, local content
- Technology Providers: SMR developers, partners, collaborators
- Banks, investment funds: BNDES, ECAs, etc.
- Licensing: CNEN, IBAMA, others
- Constructors: civil, erection, commissioning, O&M
- FOAK & NOAK Models: tech transfer

Ref: IAEA, Eletronuclear

Building a project - Generation

- Electricity Rate structure: baseload, reserve, spot
- PPAs: contract length, adjustment, etc.
- Tax Structure: incentives, initial and phased subsidies, MWe commitment





Ref: Petronoticias, Globo

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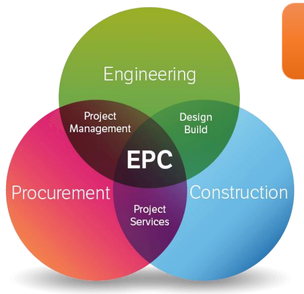
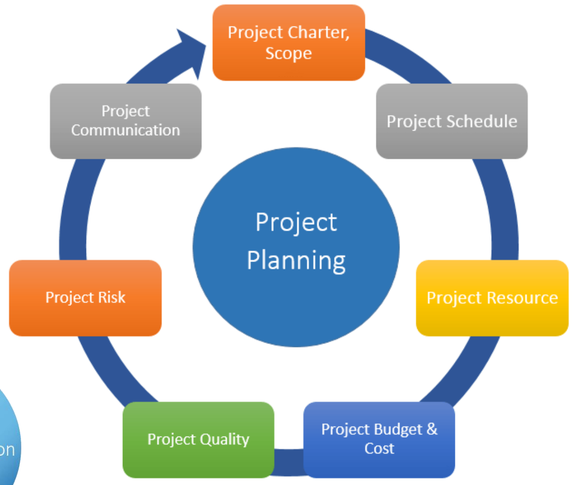
Case study

Building a project - Construction

- Contract Models
- Engineering
- Civil works
- Manufacturing and supply chain
- Schedule vs. Risk
- Share of International vs. Domestic contribution





Ref: STRVision, INB, NUCLEP, Westinghouse

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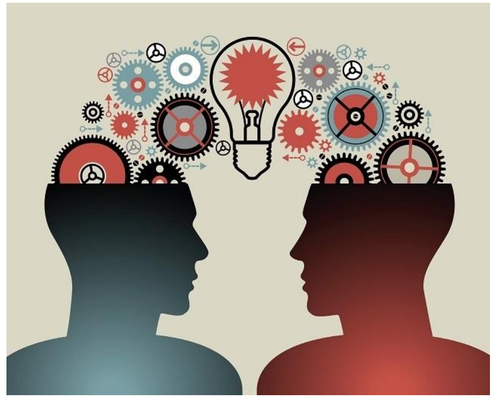
Case study

Building a project - Human Resources

- Knowledge Transfer
- New Professionals/technicians
- Universities and Trade Schools
- Labor Issues and Challenges
- Training and qualification



Ref: ATD, ASME

04

Case study

05

Summary

Summary

05

Summary

Key Takeaways

- Nuclear technology will continue to have an important role to play in the global energy matrix.
- SMRs have the potential to revolutionize the energy sector with its flexible, attractive, modular, multi-purpose application characteristics.
- There remains key challenges to overcome to enable the full potential of SMR development.
- Brazil has the potential to benefit from SMRs as complementary to a broader nuclear growth strategy to ensure the the Brazilian energy matrix remains clean, reliable, competitive and robust to meet the demands of the next decades.

Reference:

Developing legal and regulatory frameworks for small modular nuclear reactors

Helen Cook and Federico Puente-Espel

Download a copy at:

https://www.gneadvisory.com

Thank you

Helen, Federico, Carlos