

BRAZILIAN NUCLEAR PROGRAM NEAR FUTURE OPPORTUNITIES



MÁRCIO ADRIANO COELHO DA SILVA

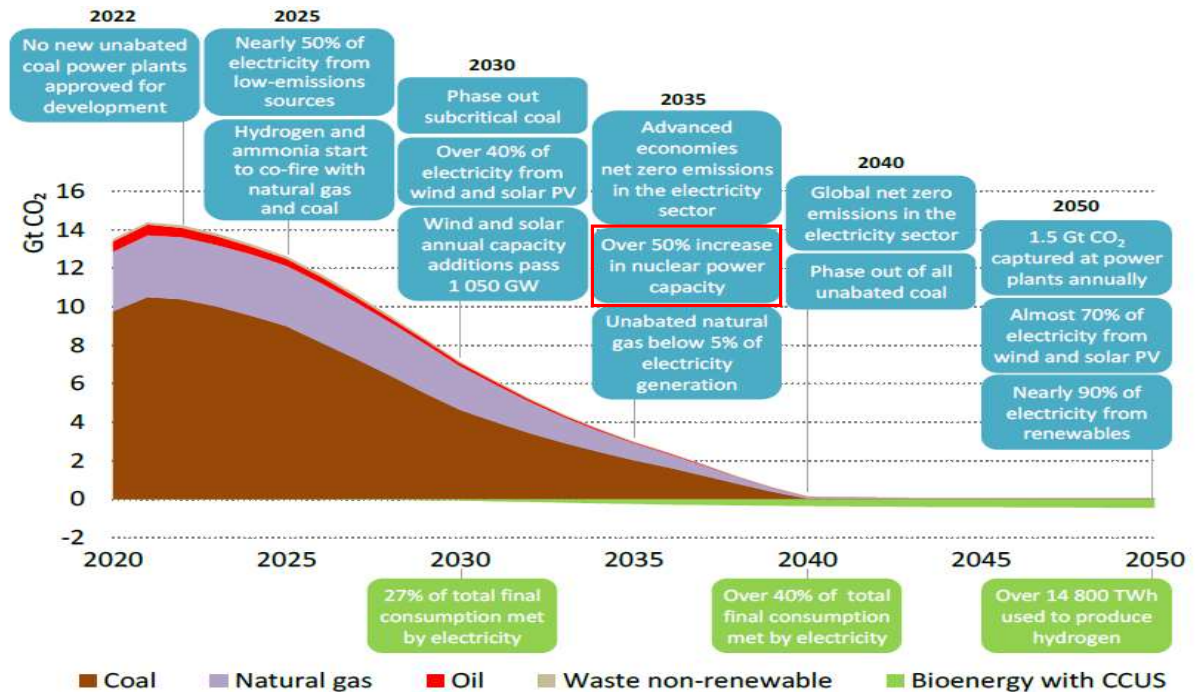
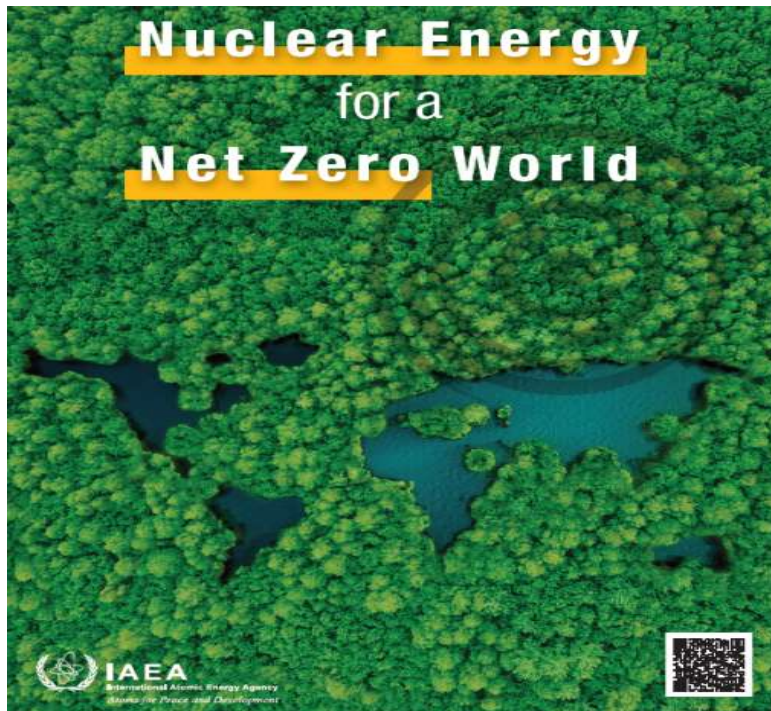
NUCLEAR FUEL PRODUCTION
INDÚSTRIAS NUCLEARES DO BRASIL - INB

BUENOS AIRES, AUGUST 23TH, 2023

Nuclear Energy and Environment



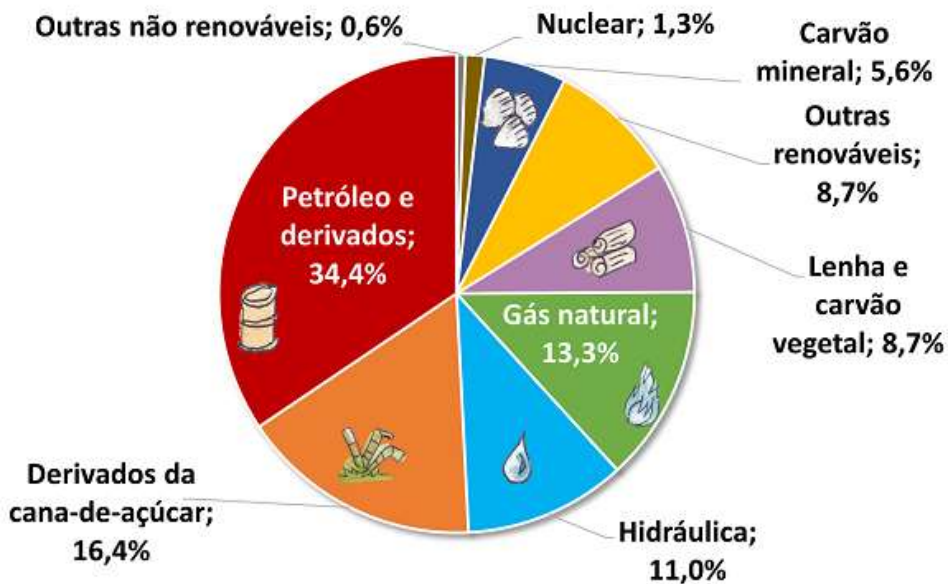
Nuclear energy is key to achieving the global targets for reducing CO₂ emissions, working in partnership with renewable energy sources, as part of a sustainable energy system to decarbonize the worldwide electrical matrix.



Source: - World Energy Outlook 2022. IEA. International Energy Agency. Website: www.iea.org
 - Nuclear Energy for a Net Zero World. IAEA.

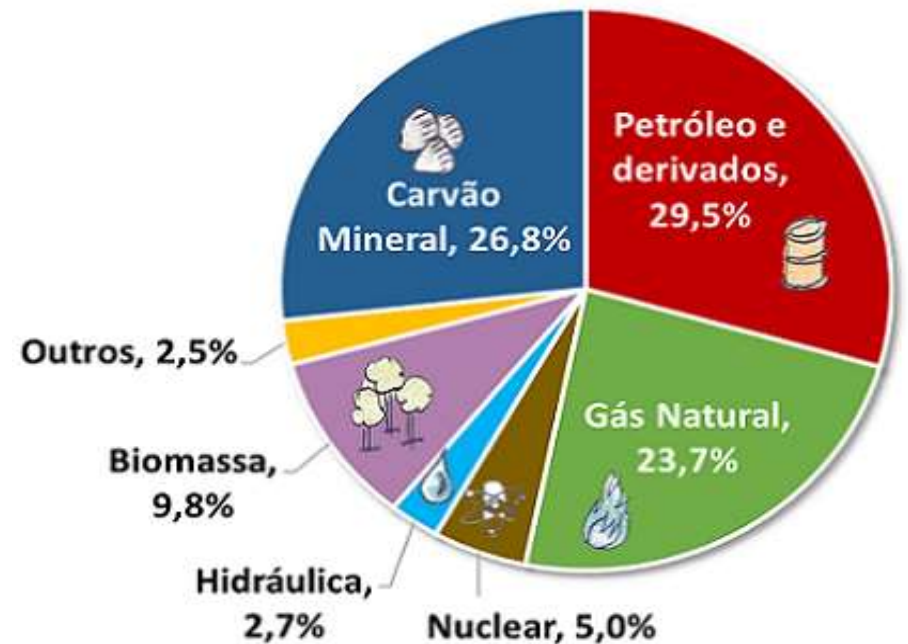
Nuclear Energy and Environment

ENERGY MATRIX - BRAZIL AND WORLD



Matriz Energética Brasileira 2021

(BEN, 2022; total: 302 milhões de tep - tonelada-equivalente de petróleo)

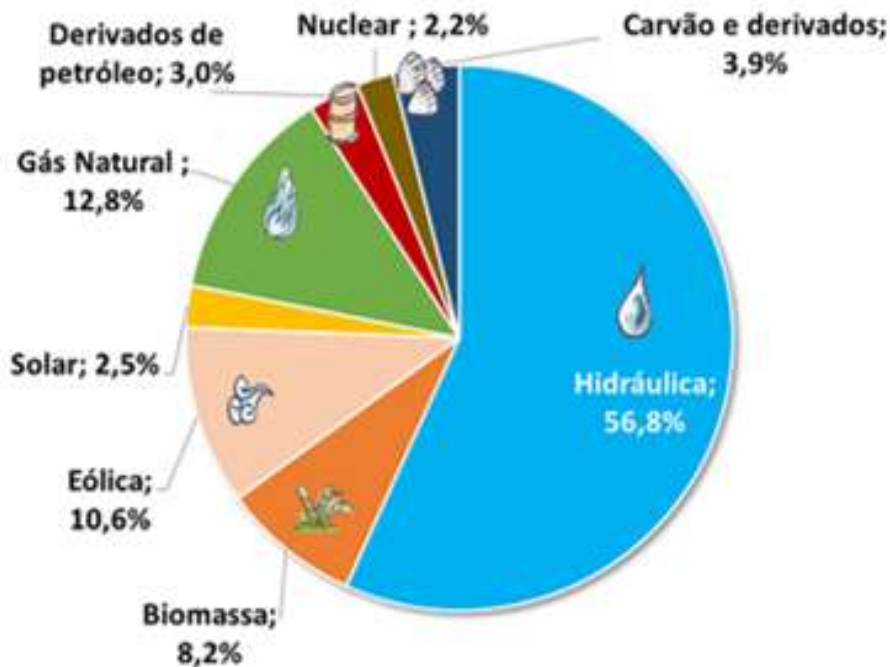


Matriz Energética Mundial 2020

(IEA, 2022; total: 585 milhões de TJ - terajoule)

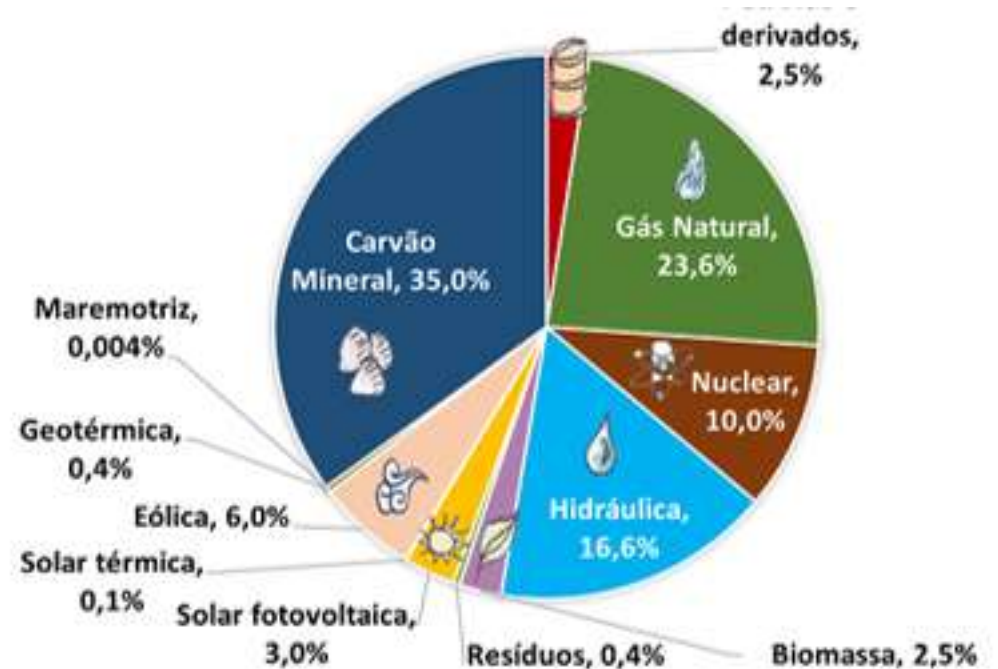
Nuclear Energy and Environment

ELECTRIC MATRIX - BRAZIL AND WORLD



Matriz Elétrica Brasileira 2021

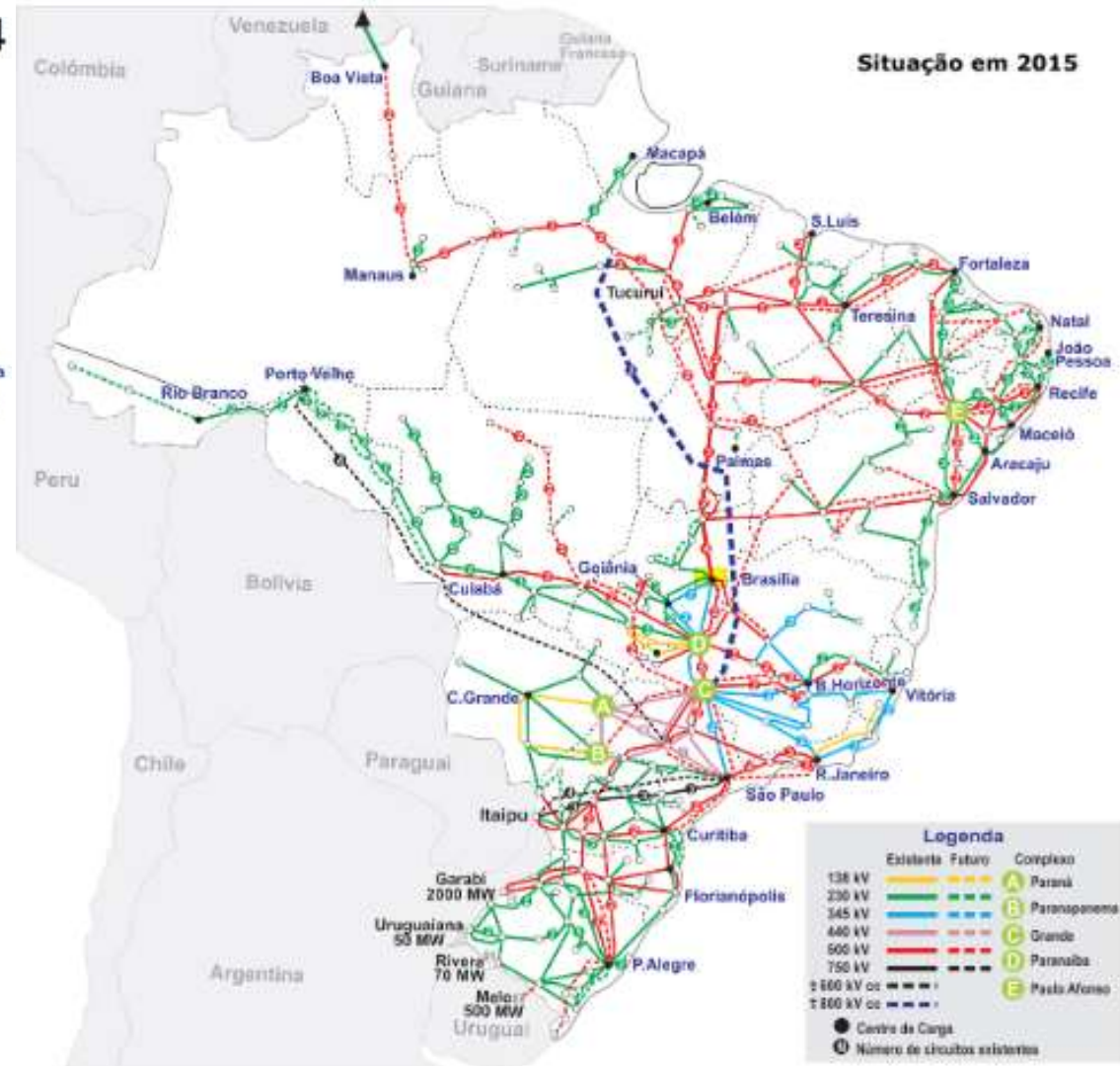
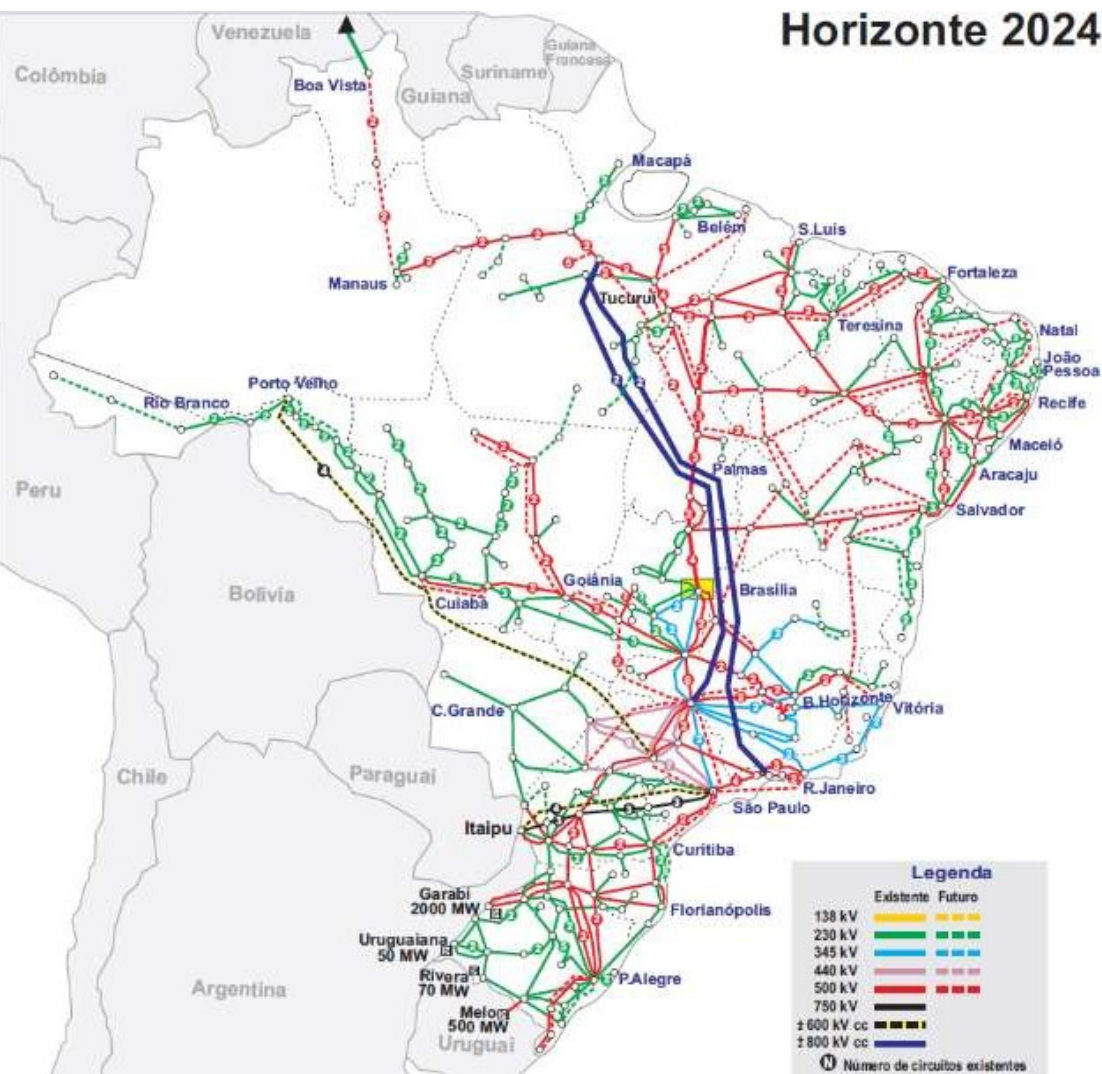
(BEN, 2022; total: 656 TWh - terawatt-hora)



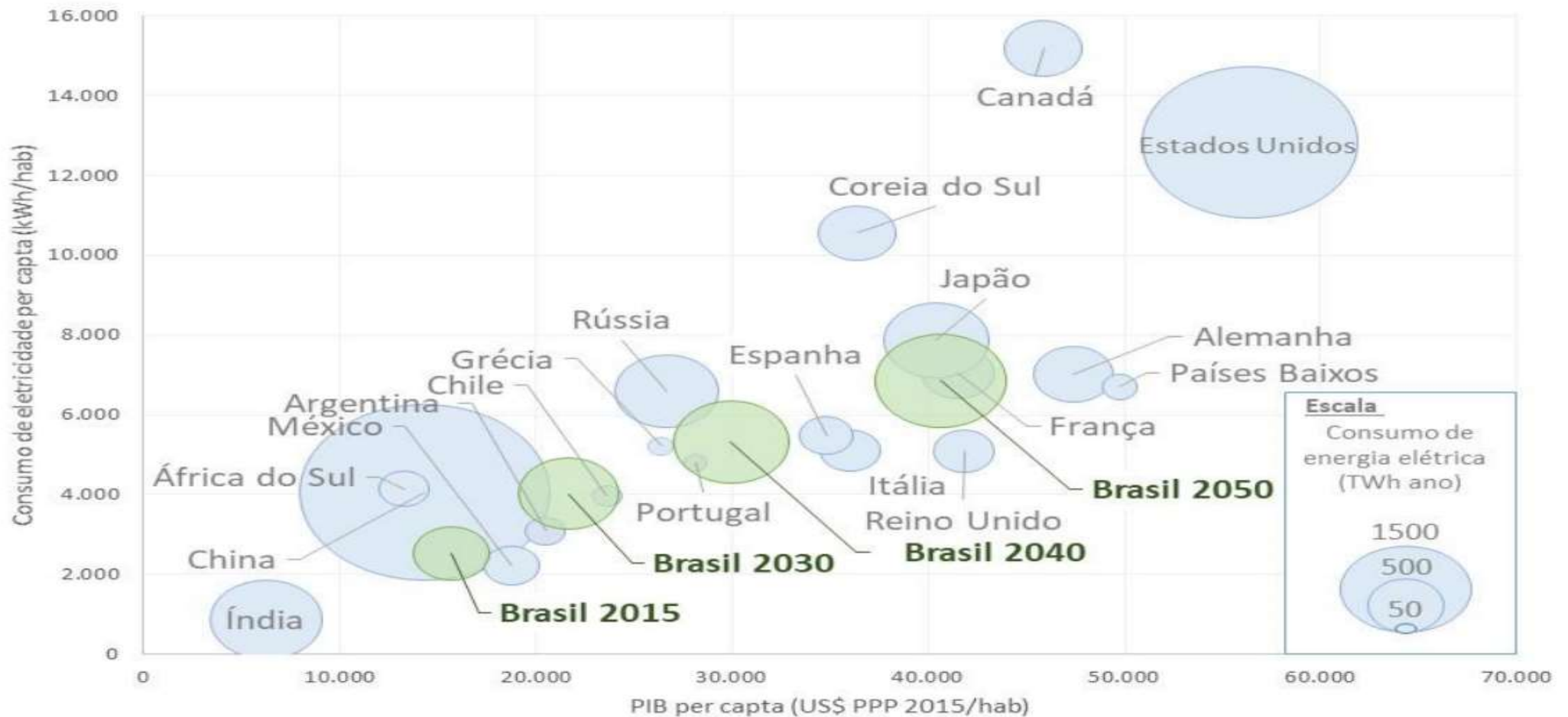
Matriz Elétrica Mundial 2020

(IEA, 2022; total: 27 milhões de GWh - gigawatt-hora)

Nuclear Energy and Environment



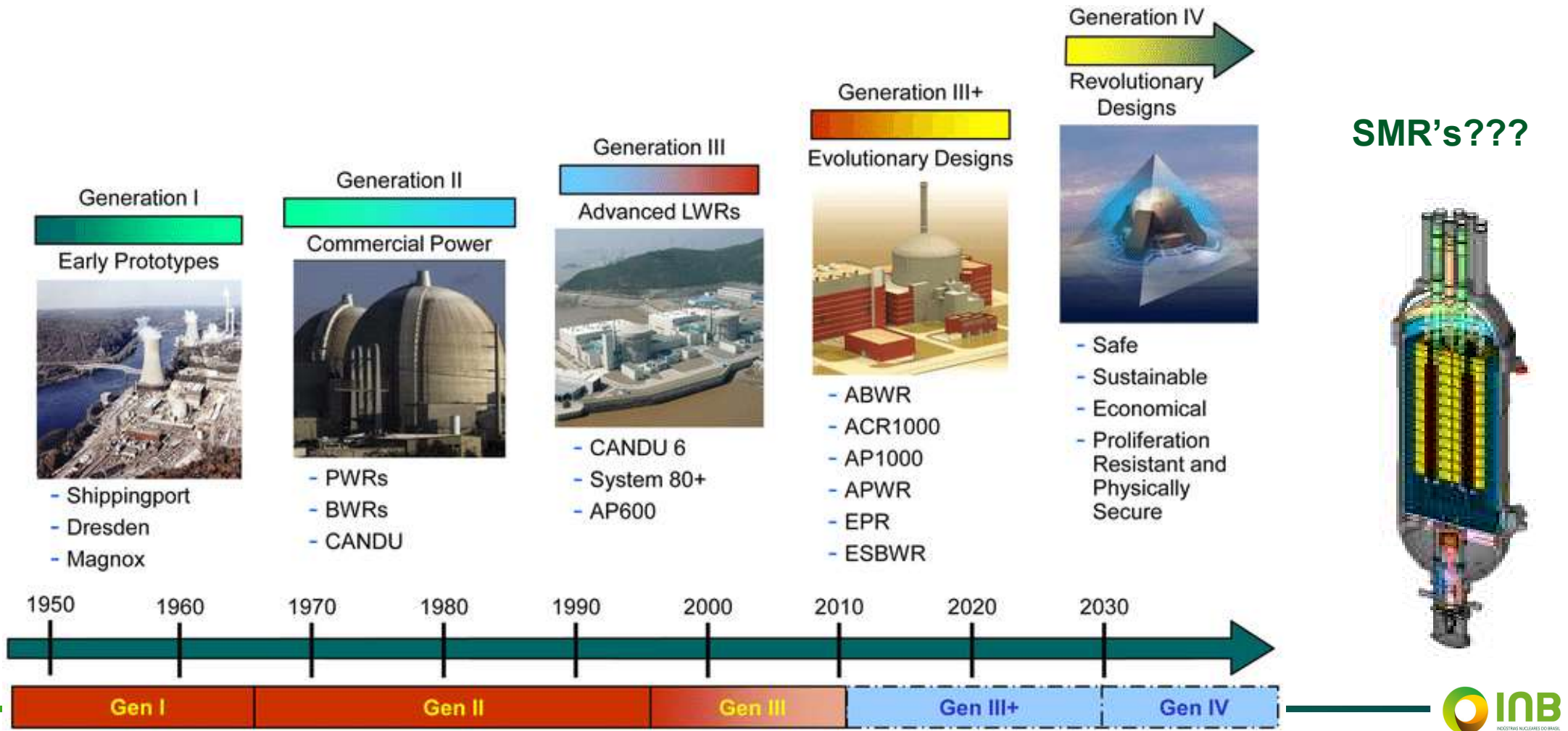
BRAZIL: Electric Consumption and GDP per Capita - Forecast



Source: Plano Nacional de Energia 2050 / Ministério de Minas e Energia. Empresa de Pesquisa Energética. Brasília: MME/EPE, 2020

NUCLEAR REACTORS TECHNOLOGY EVOLUTION

ELECTRIC POWER GENERATION



INDÚSTRIAS NUCLEARES DO BRASIL - INB



FCN – FUEL ASSEMBLY FACILITY



FCN – ENRICHMENT, POWDER AND PELLET FACILITIES

INDÚSTRIAS NUCLEARES DO BRASIL - INB

- **Public Company**
 - Brazilian Ministry of Mines and Energy – MME
- **Operates the state monopoly on Nuclear Fuel Cycle activities in Brazil**
- **Products and Services on the Nuclear Fuel Cycle**



BRAZILIAN REGULATORY AUTHORITY - CNEN



Onde Estamos

Centro Regional de Ciências Nucleares do Nordeste
CRCN-NE
 Criação: 1996
 Recife (PE)
 www.crcn.gov.br

Escritório de Brasília
ESBRA
 Brasília (DF)

Distrito de Caetité
DICAE
 Caetité (BA)

Instituto de Radioproteção e Dosimetria
IRD
 Criação: 1972
 Rio de Janeiro (RJ)
 www.ird.gov.br

SEDE
 Rio de Janeiro (RJ)

Instituto de Engenharia Nuclear
IEN
 Criação: 1962
 Rio de Janeiro (RJ)
 www.iem.gov.br

Escritório de Resende
ESRES
 Resende (RJ)

Distrito de Angra
DIANG
 Angra dos Reis (RJ)

Escritório de São Paulo
ESCSP
 São Paulo (SP)

Centro Regional de Ciências Nucleares do Centro-Oeste
CRCN-CO
 Criação: 1997
 Abadia de Goiás (GO)
 www.crcn-co.cnen.gov.br

Centro de Desenvolvimento da Tecnologia Nuclear
CDTN
 Criação: 1952
 Belo Horizonte (MG)
 www.cdtm.br

Laboratório de Poços de Caldas
LAPOC
 Criação: 1974
 Poços de Caldas (MG)
 www.cnenpc.gov.br

Escritório de Porto Alegre
ESPOA
 Porto Alegre (RS)

Instituto de Pesquisas Energéticas e Nucleares
IPEN
 Criação: 1956
 São Paulo (SP)
 www.ipen.br


CNEN
 Comissão Nacional de Energia Nuclear


CDTN
 CENTRO DE DESENVOLVIMENTO DA TECNOLOGIA NUCLEAR


IEN
 INSTITUTO DE engenharia nuclear


ipen


IRD


CRCN-NE
COMISSÃO NACIONAL DE ENERGIA NUCLEAR


CRCNCO
 Centro Regional de Ciências Nucleares do Centro-Oeste

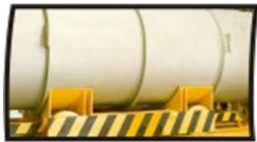

LAPOC
 Laboratório de Poços de Caldas

INB Activities on Nuclear Fuel Cycle



Uranium Mining & Mineral Processing

→ **Operating plant at Caetité – State of Bahia**



Conversion

→ **No operating industrial facilities in Brazil**



Enrichment

Operating ultracentrifuge cascades



Reconversion



Pellets Fabrication



Fuel Assembly Fabrication

Operating plants at Resende – State of Rio de Janeiro

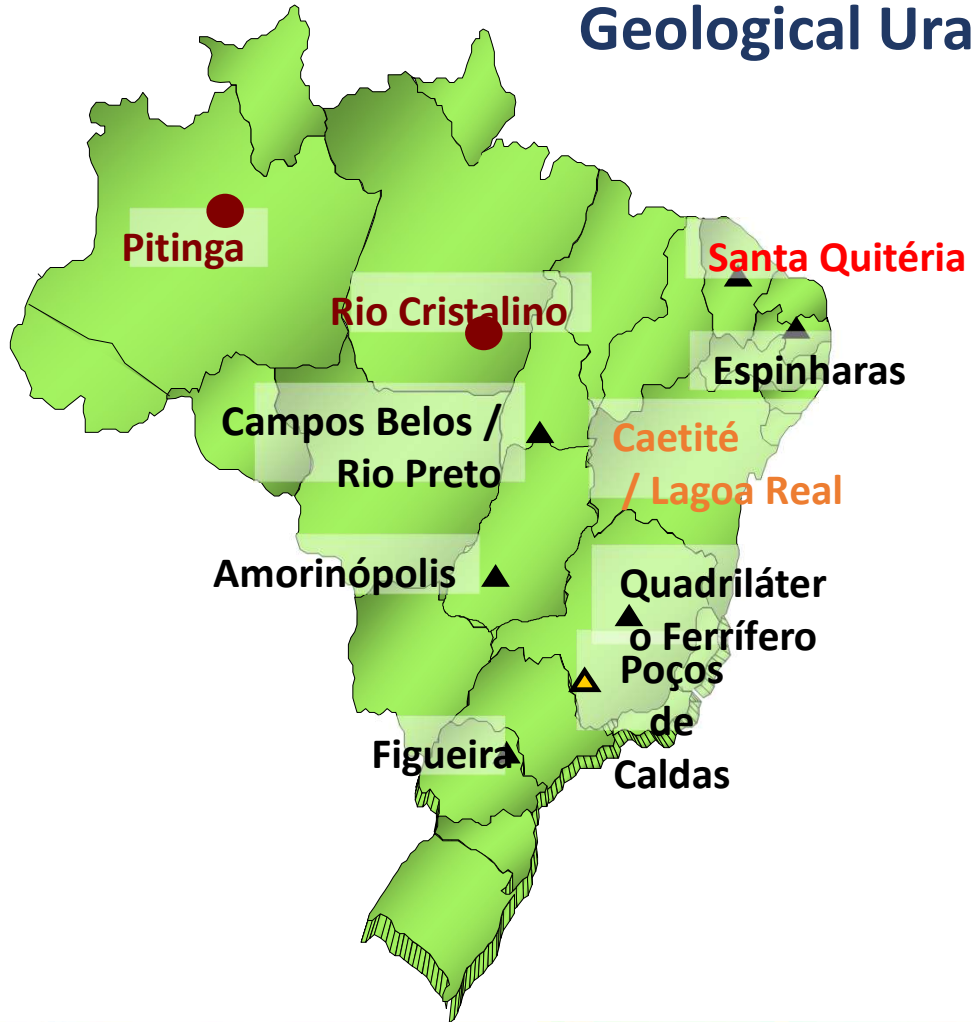
INDÚSTRIAS NUCLEARES DO BRASIL - INB

URANIUM MINING (INB- Caetité/BA)



INDÚSTRIAS NUCLEARES DO BRASIL - INB

Geological Uranium Reserves



| Deposits | Tons of U ₃ O ₈ | | |
|--|---------------------------------------|---------------|-----------------|
| | Measurements/ Indicated | Inferred | Total |
| Caetité / Lagoa Real | 94.000 | 6.700 | 100.770 |
| Santa Quitéria | 91.200 | 51.300 | 142.500 |
| Others | 39.500 | 26.600 | 66.100 |
| TOTAL | 224.700 | 84.670 | 309.370* |
| PROGNOSTICATED: Pitinga (AM): 150.000 | | | |
| Rio Cristalino (PA): 150.000 | | | |
| SPECULATIVE: 500.000 | | | |

INDÚSTRIAS NUCLEARES DO BRASIL - INB

Santa Quitéria Project, Ceará

Mineral Resource:

- Fosfate + Uranium

Consórcio Santa Quitéria



Estimated Net Capacity (Foreseen 2026)

Phosphoric Acid: 200.000 t /ano

Uranium: 2.300 t /ano (as Yellowcake)

INB – CONVERSION PLANT (USICON)



UO_3

$H_2 \rightarrow$

UO_2

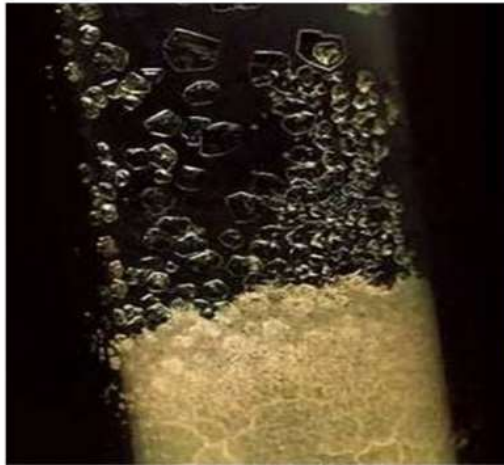
$HF \rightarrow$

UF_4

$F_2 \rightarrow$



UF_6



Cilindro 48Y



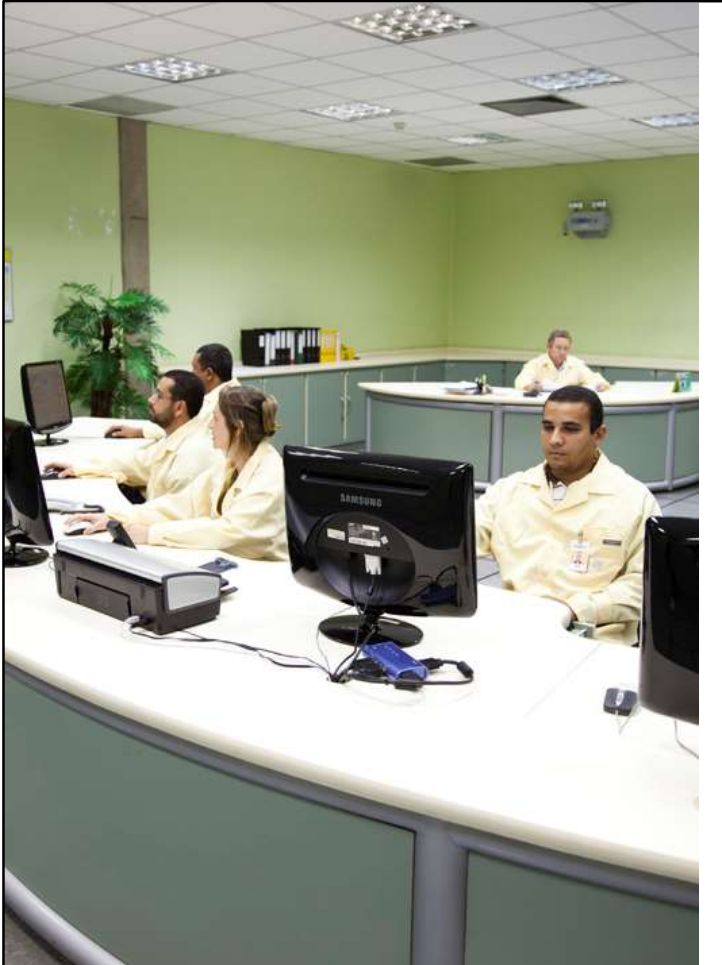
INB – USICON AND UCEU PROJECTS – MASTER PLAN



INB – ENRICHMENT PROGRAM



INB – ENRICHMENT PROGRAM



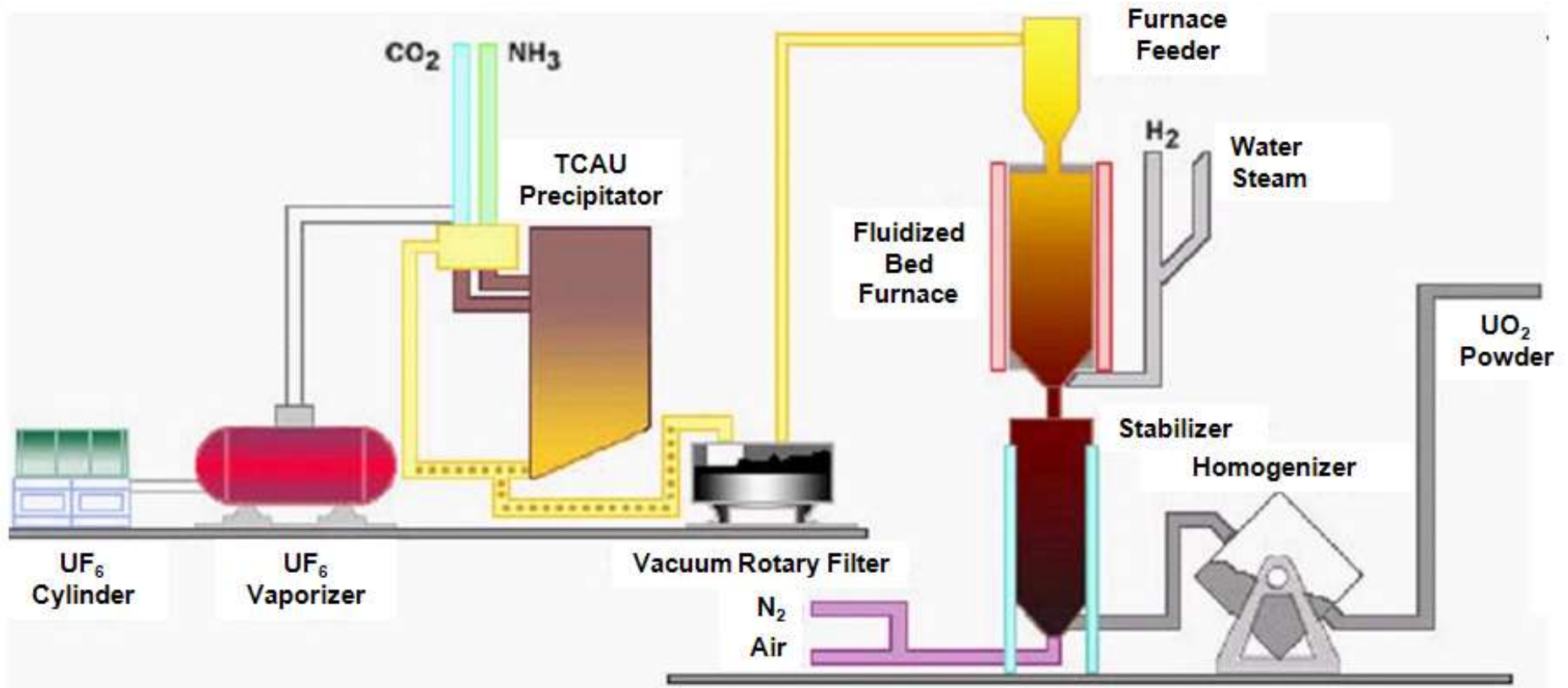
- Modular Construction at INB site
- Ultracentrifuge: Navy Technology from CTMSP - Centro Tecnológico da Marinha at São Paulo city.
- In Operation: 10 Cascades in 4 Modules.

Concluded in 2023: 1st phase 70 t UTS/y.
10 Cascades in 4 Modules.
~ 70% Angra 1 needs.
- Target 2nd phase 500 t UTS/y by 2035
100% Angra 1, 2 and 3 needs.

INB – ENRICHMENT, POWDER AND PELLET PRODUCTION



URANIUM POWDER PRODUCTION (RECONVERSION)

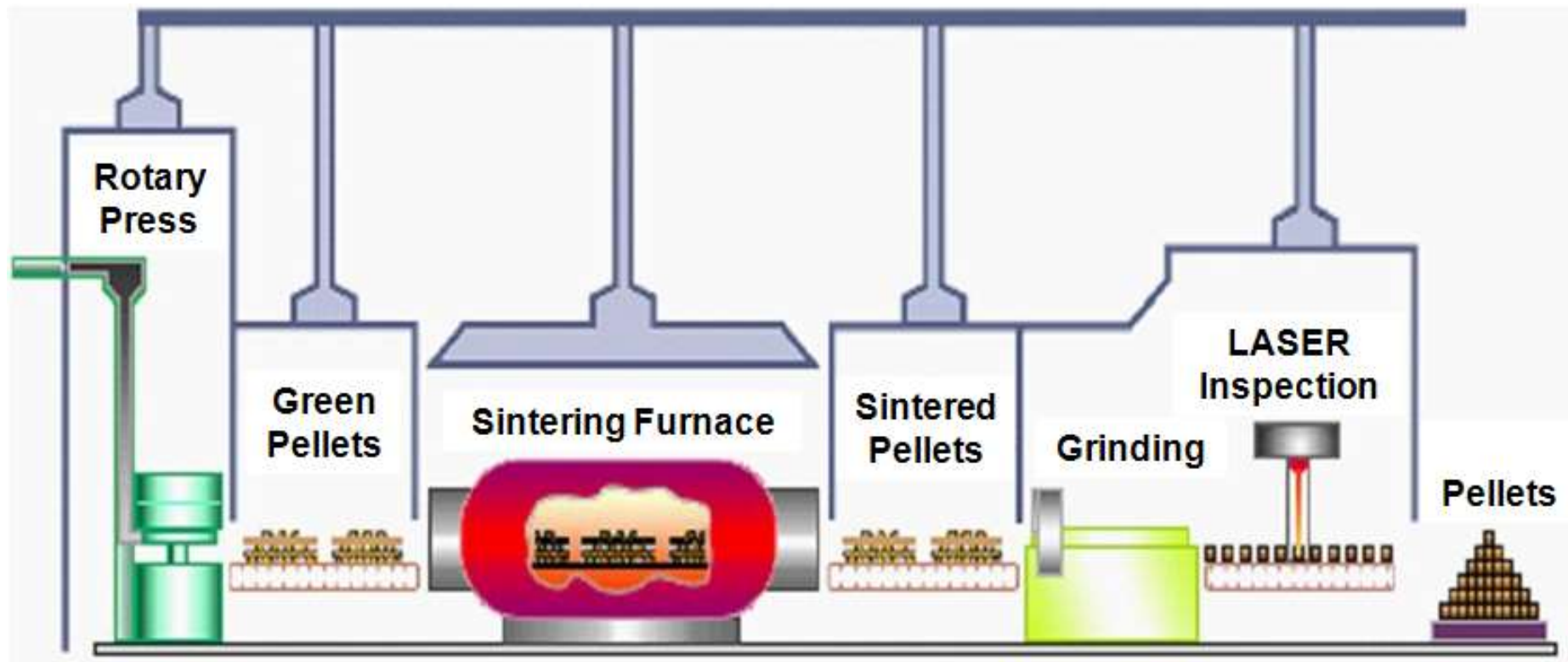


Nominal Capacity: 160 t / y UO₂

URANIUM POWDER PRODUCTION (RECONVERSION)



URANIUM PELLET PRODUCTION



Nominal Capacity: 120 t / y UO_2

URANIUM PELLET PRODUCTION

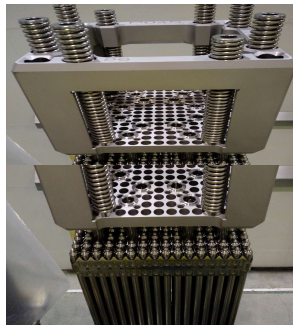
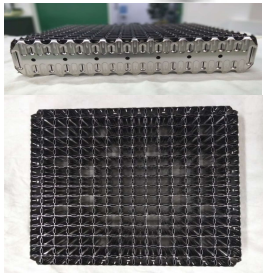
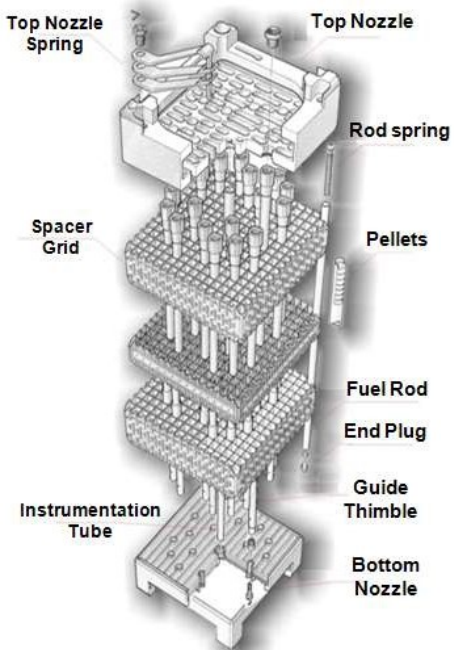


FUEL ASSEMBLY PRODUCTION

FCN – COMPONENTS AND ASSEMBLY



FUEL ASSEMBLY COMPONENTS



CERTIFICATIONS



BRTUV
CERTIFICADO

A BRTUV certifica que a Empresa:

INB - INDÚSTRIAS NUCLEARES DO BRASIL S/A
Rodovia Presidente Dutra, Km 330
27555-000 - Resende - RJ - Brasil

Implantou e utiliza um Sistema de Gestão da Qualidade para a seguinte área de aplicação:

Fabricação e comercialização de óxidos de urânio, de elementos combustíveis, componentes, itens e serviços correlatos do reator e do elemento combustível para centrais nucleoeletrônicas.

O Sistema auditado está em conformidade com a norma:

ISO 9001: 2000

Este Certificado é válido até: 16/02/2009
Nº de Registro do Certificado: Q-01042
A empresa está certificada desde 1998

BRTUV **IAF** **TUV NORD**

BRTUV
CERTIFICADO

A BRTUV certifica que a Empresa:

INB - INDÚSTRIAS NUCLEARES DO BRASIL S/A
Rodovia Presidente Dutra, Km 330
27555-000 - Resende - RJ - Brasil

Implantou e utiliza um Sistema de Gestão Ambiental para a seguinte área de aplicação:

Fabricação e comercialização de óxidos de urânio, de elementos combustíveis, componentes, itens e serviços correlatos do reator e do elemento combustível para centrais nucleoeletrônicas.

O Sistema auditado está em conformidade com a norma:

NBR ISO 14001: 2004

Este Certificado é válido até: 16/02/2009
Nº de Registro do Certificado: A-240

BRTUV **IAF** **TUV NORD**

BRTUV
CERTIFICADO

A BRTUV certifica que a Empresa:

INB - INDÚSTRIAS NUCLEARES DO BRASIL S/A
Rodovia Presidente Dutra, Km 330
27555-000 - Resende - RJ - Brasil

Implantou e utiliza um Sistema de Gestão de Saúde e Segurança Ocupacional para a seguinte área de aplicação:

Fabricação e comercialização de óxidos de urânio, de elementos combustíveis, componentes, itens e serviços correlatos do reator e do elemento combustível para centrais nucleoeletrônicas.

O Sistema auditado está em conformidade com a norma:

OHSAS 18001: 1999

Este Certificado é válido até: 16/02/2009
Nº de Registro do Certificado: A-239

BRTUV **IAF** **TUV NORD**

tuv
CERT
CERTIFICADO

A Entidade de Certificação TÜV CERT da TÜV NORD CERT GmbH certifica, em conformidade com o procedimento TÜV CERT, que:

INB - INDÚSTRIAS NUCLEARES DO BRASIL S/A
Rodovia Presidente Dutra, Km 330
27555-000 - Resende - RJ - Brasil

tem implementado e mantém um Sistema de Gestão da Qualidade, na (s) área(s):

Fabricação e comercialização de óxidos de urânio, de elementos combustíveis, componentes, itens e serviços correlatos do reator e do elemento combustível para centrais nucleoeletrônicas.

Foi realizada uma auditoria, Protocolo nº: **BR 302**

sendo-se verificado o cumprimento dos requisitos da Norma **ISO 9001: 2000 / EN ISO 9001: 2000**

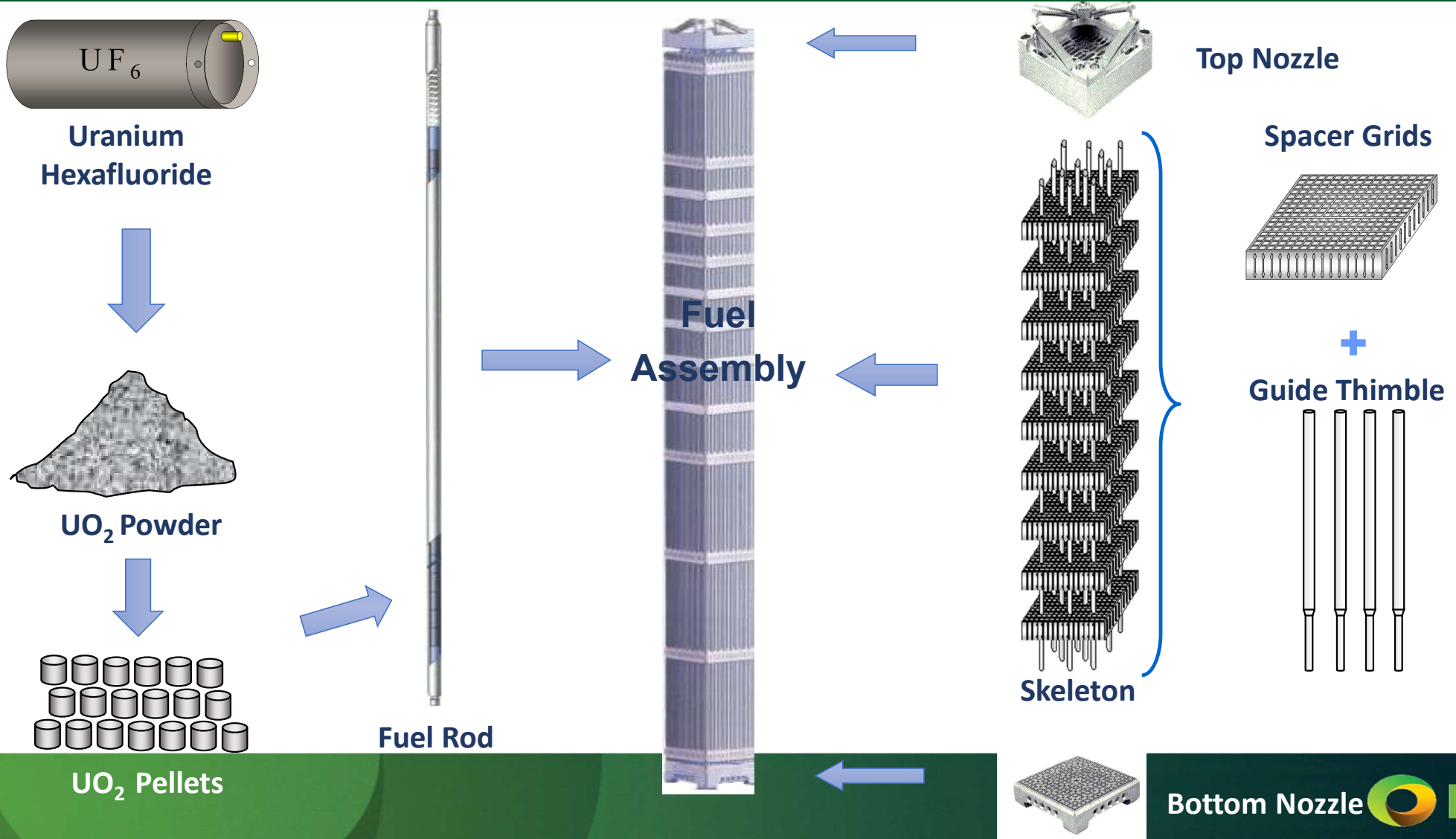
O presente certificado é válido até: **2009-02-16**

Número de registro do certificado: **04 100 065547**

A empresa está certificada desde **1998**

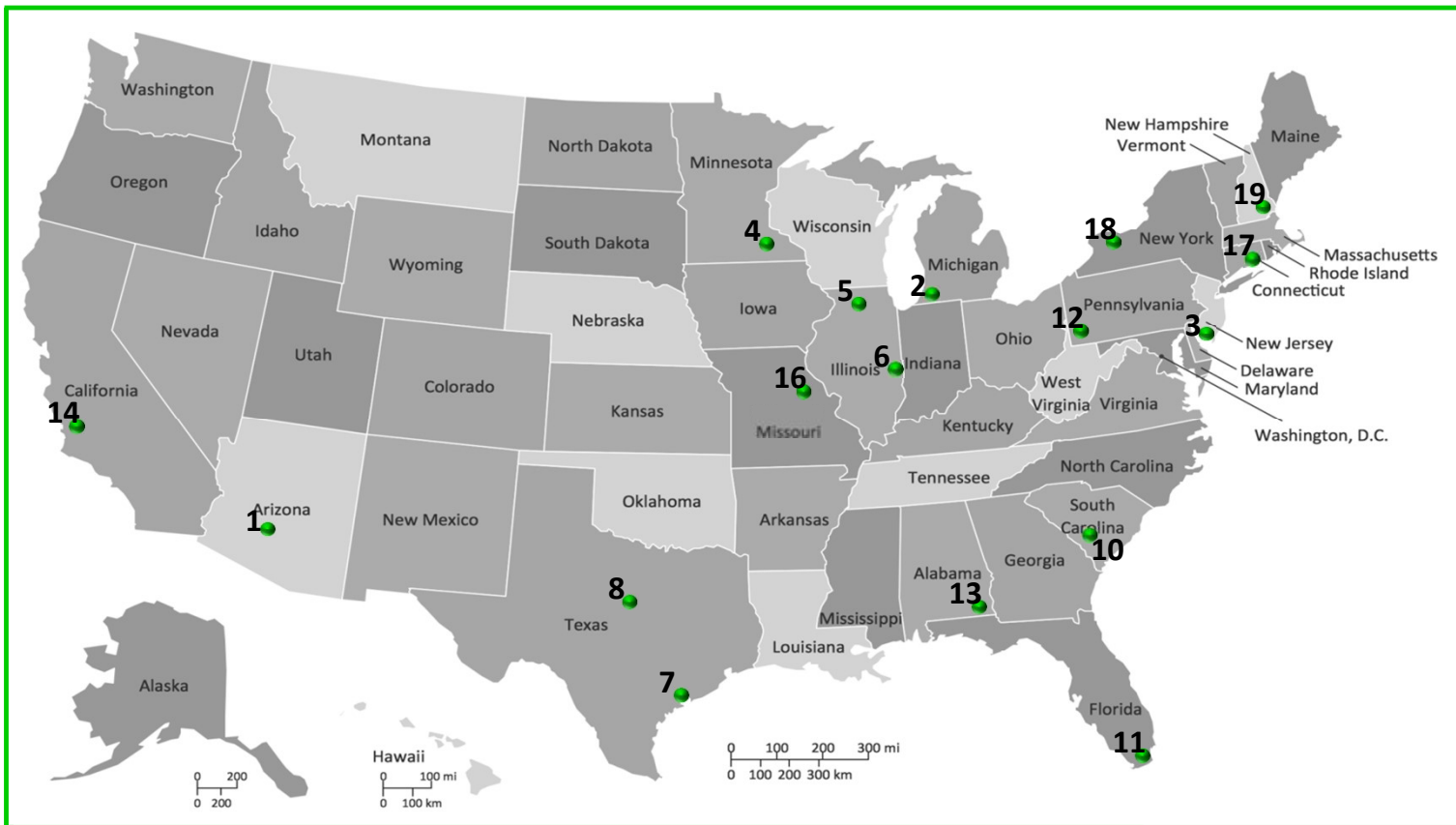
IAF **TUV NORD**

NUCLEAR FUEL PRODUCTION (DPN)



INB INTERNATIONAL ENGINEERING SERVICES

Engineering services for PWR Plants - Sub supplier of Westinghouse



Plantas PWR - EUA:

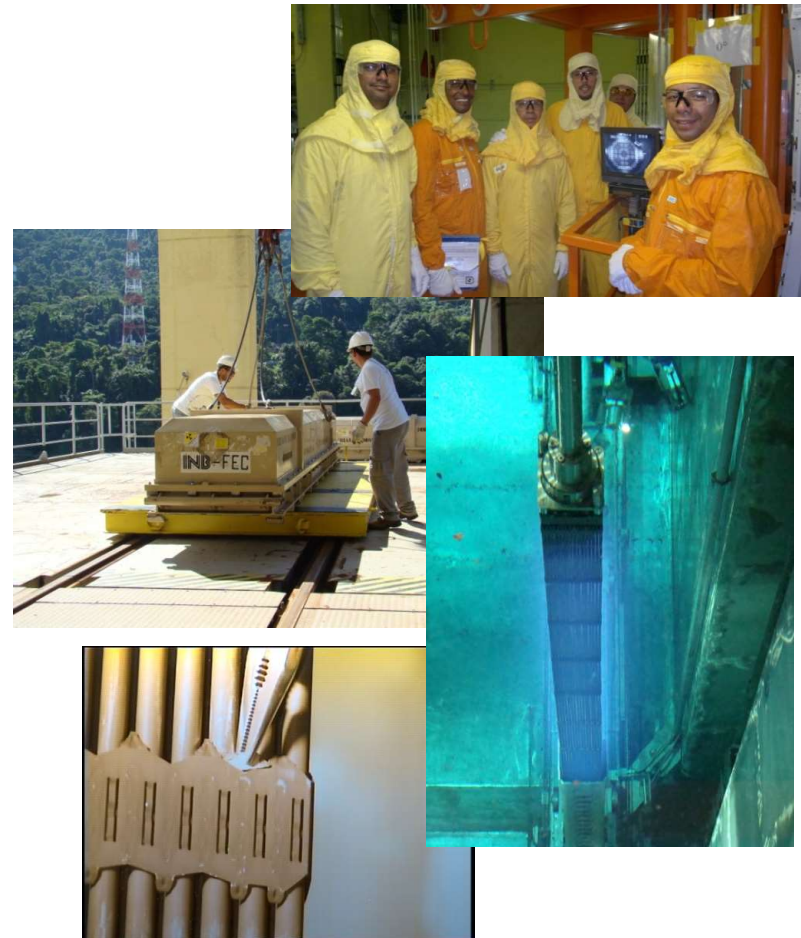
- 1 - Palo Verde
- 2 - D. C. Cook
- 3 - Salem
- 4 - Prairie Island
- 5 - Byron
- 6 - Braidwood
- 7 - South Texas
- 8 - Comanche Peak
- 9 - Vogtle
- 10 - V. C. Summer
- 11 - Turkey Point
- 12 - Beaver Valley
- 13 - Farley
- 14 - Diablo Canyon
- 15 - Indian Point
- 16 - Callaway
- 17 - Millstone
- 18 - Ginna
- 19 - Seabrook

Plantas PWR – Outros Países:

- 20 - Krsko (Eslovênia)
- 21 - Maanshan (Taiwan)
- 22 - Tihange 2 (Bélgica)
- 23 - Doel 3 (Bélgica)
- 24 - Temelín (República Tcheca)
- 25 - Koeberg (África do Sul)

FUEL SERVICES

- Fresh Fuel receipt and storage
- Fuel handling – Core loading /unloading
- Fuel Repair
- Fuel Inspection (PSE)
- Control Rods Drive Shaft
uncoupling and coupling
- Sipping Can
- Debris Removal



INB – REACTOR FLOOR SERV

South Texas



Angra 1 e 2



Comanche Peak



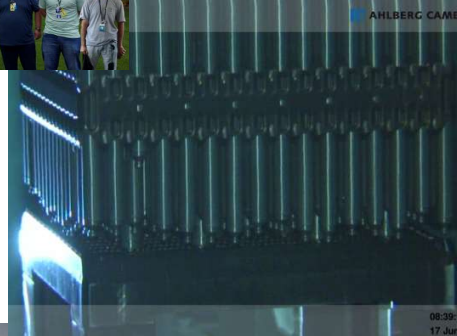
Praire Island



Beaver Valley



Vogtle



INB – ICL SERVICES



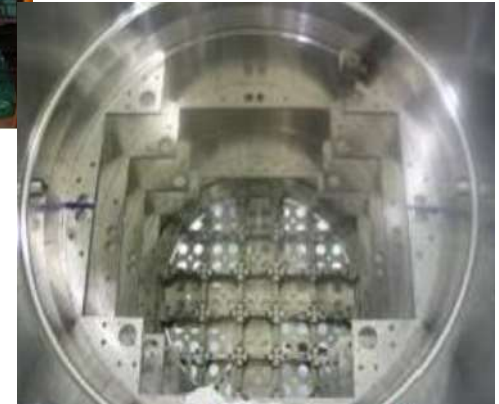
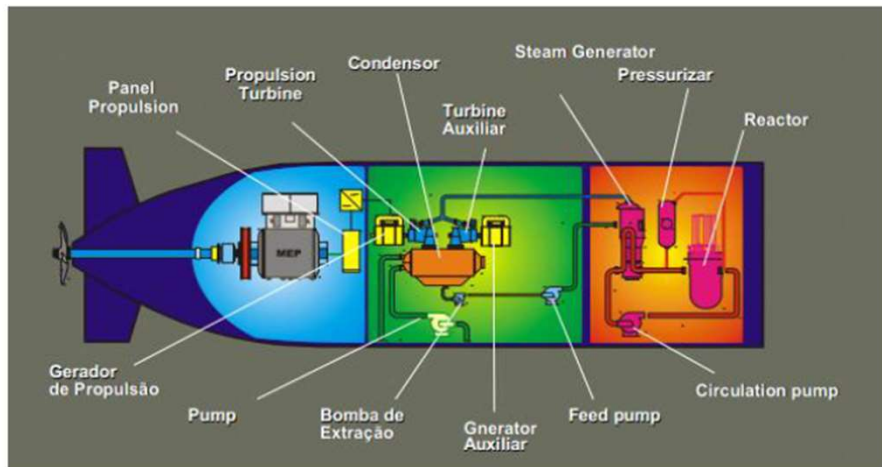
NUCLEAR POWER PLANTS ANGRA 1, 2 e 3



ANGRA 3 CONSTRUCTION



LABGENE PROJECT – FUEL PRODUCTION



- Pellet - done
- Fuel mechanical components - 10 % done
- INB Fuel Assembly Plant preparation – Starting 2024
- First Fuel transport – scheduled for MAR/2028 [preliminary target]
- Criticality – to be defined by Brazilian Navy Research Institute (CTMSP)

Nuclear Fuel Brazilian Scenario

- INB has intention to make part of international fuel cycle market (uranium first)
- Initially to meet internal demand

| Time Line | Demands | Fuel Fabrication |
|--|---|---|
| • Actually | <ul style="list-style-type: none"> • CNAAAA • CTMSP | <ul style="list-style-type: none"> • Angra 1 + Angra 2 + Angra 3 first core • LABGENE (Navy Technology Center - SP) |
| • As of 2028 | <ul style="list-style-type: none"> • CNAAAA | <ul style="list-style-type: none"> • Angra 1 + Angra 2 + Angra 3 (Fuel Reloads) |
| <ul style="list-style-type: none"> • By 2032 (PNE 2032) | <ul style="list-style-type: none"> • CNAAAA • New site | <ul style="list-style-type: none"> • Angra 1 + Angra 2 + Angra 3 + NPP 4 • RMB (Brazilian Multipurpose Reactor) |
| <ul style="list-style-type: none"> • By 2050 (PNE 2050) | <ul style="list-style-type: none"> • CNAAAA • New Site(s) | <ul style="list-style-type: none"> • Angra 1 + Angra 2 + Angra 3 + NPP 4 + NPP 5 + NPP 6 ... • Small Modular Reactors |

Internal Demand for Uranium and Fuels

- Angra 1 (PWR 640 MW) e Angra 2 (PWR 1.350 MW) = under operation
- Angra 3 (PWR 1.405 MW) = under construction (commercial operation: 2027)

| | | Scenario 1 Demand Angra 1/2 (actual) | Scenario 2 Demand Angra 1/2/3 (2027) | INB - Capacity (Current) |
|---|---------------------------------|---|---|-----------------------------|
| Yellow-cake U ₃ O ₈ | t U ₃ O ₈ | 400 | 700 | 200 |
| Conversion to UF ₆ | t UF ₆ | 390 | 620 | Service hired abroad |
| Enrichment | t SWU | 280 | 460 | 70 |
| UO ₂ Powder | t UO ₂ | 45 | 70 | 160 |
| UO ₂ Pellets | t UO ₂ | 45 | 70 | 120 |
| Fuel Assembly | units | 100 | 150 | 500 |

Internal Demand for Uranium and Fuels

- PNE 2050 – insertion of 8 GW to 10 GW nuclear
- Equivalent to 6 times Angra 3 (1.4 GW) = 8.4 GW

| Scenario 2 Demand Angra 1/2/3 (2027) | Scenario 3 Demand + 8 – 10 GW (2050) | Scenario 2 + 3 Demand (2050) | INB - Capacity (long time) |
|---|---|------------------------------------|-------------------------------|
|---|---|------------------------------------|-------------------------------|

| | | | | | |
|---|---------------------------------|-----|---------|-------|---------------------|
| Yellow-cake U ₃ O ₈ | t U ₃ O ₈ | 700 | + 1.700 | 2.400 | 800 + 2.300 = 3.100 |
| Conversion to UF ₆ | t UF ₆ | 620 | + 1.400 | 2.000 | Localization |
| Enrichment | t SWU | 460 | + 1040 | 1.500 | 500 |
| UO ₂ Powder | t UO ₂ | 70 | + 150 | 220 | 160 |
| UO ₂ Pellets | t UO ₂ | 70 | + 150 | 220 | 120 |
| Fuel Assembly | units | 150 | + 280 | 420 | 500 |

Scenario Transition (10 to 30 years)

Nuclear Fuel Production Technologic Capability

- **ATF (Accident Tolerant Fuel)**
- **LABGENE (48 MW_{th})**
 - Contract between INB and CTMSP to produce 25 Nuclear Fuels
- **SMR**
 - MOU between INB and Holtec International (Develop and produce fuel for the SMR-160 in Brazil)
 - Complementary capabilities of INB, Navy Technology Center and Federal Institutes for HALEU production
 - INB: Uranium mining, Uranium enrichment (up to 5% U235), commercial and logistic experience on international services acquisition, nuclear material transportation and national authorities permissions obtaining process
 - Navy Technology Center (CTMSP): Uranium enrichment up to 20% U235
 - CNEN/IPEN Institute: U metal and oxide production, nuclear fuel manufacturing for SMR, research and medical isotopes reactors

Nuclear Fuel Production Technologic Capability

- Fully licensed and safeguarded installations
- Ready availability of main supply chain facilities (with exception of UF6 conversion)
- **RMB (Brazilian Multipurpose Reactor)**
 - Brazilian nuclear industry, Navy Technology Center and Federal Institutes jointly production (HALEU)

▪ Thorium Fuel

- Three times more abundant in Earth than Uranium

BIGGEST THORIUM RESOURCES

| | |
|--------|---------|
| India | 846 500 |
| Brazil | 632 000 |
| USA | 595 000 |

*No data available
from China and
Russia*

*Source: IAEA-
TECDOC-1877*

- Intrinsic proliferation resistance of thorium fuel cycle due to lower Plutonium production
- Not for now – Necessary more research and developments

Investments on Nuclear Fuel Cycle - Mining

- **Uranium concentrate production – Caetité**
 - Current Capacity: 200 t/y U_3O_8
 - Chemical Plant Expansion (for 800 t U_3O_8 /year)
 - Underground mine project (Cachoeiras mine)
- **Santa Quiteria Project – Uranium and phosphate**
 - Expectation: 2.300 t U_3O_8 /year (2026)
- **Geological research for new deposits**
 - Caetité (BA), Rio Cristalino (PA), Pitinga (AM), others

Investments on Nuclear Fuel Cycle - Enrichment

- **Ultracentrifuge Technology Developed in Brazil by CTMSP**
- **December 2022:**
 - First Phase completed → 70 t SWU/year (70% Supply of Angra 1 needs)
 - 10 Cascades in 4 Modules
- **Future**
 - Ultracentrifuge Fabrication Expansion
 - Second Phase → 500 t SWU/year (100% Angra 1, 2 e 3)
 - 30+ Cascades in 10 Modules (about 15 years)

(*) UCEU – Commercial Uranium Enrichment Plant

Investments on Nuclear Fuel Cycle - Fuel Conversion

- **Commercial → 5% of total fabrication cycle**
- **International market saturation by 2035**
- **INB USICON → Conceptual bases**
- **INB and CTMSP cooperation on USEXA pilot plant**

Planning and Challenges on Nuclear Fuel Production

Angra 3

- First core and coming reloads
- Increase INB financial sustainability
- Small investments (oppose to production plants aging and modernization of fuel fabrication process)

14.514 Law

- Recent improvements in Brazilian regulatory framework – Legal security for attraction of private investments in partnership with INB, specially in uranium resources exploration
- Allows INB to carry out the exploration, mining and trading of nuclear ores and their concentrates, associates and derivatives
- In order to carry out above referred activities INB is allowed to sign contracts with legal entities (internal or external markets) and establish parentships
- Under Government Regulation

Planning and Challenges on Nuclear Fuel Production

Licensing

- Santa Quitéria uranium deposit
- Currently under discussion and documents application - U_3O_8 production capacity around 2300 t/y (reasonable costs)
 - Preliminary License (2023)
 - Construction Permit License (2024)
 - Operation License (2026)
- Looking for partners in order to explore new uranium deposits on the Brazilian territory

Business Models

- Consolidate and establish new Business Models according 14514 law
- Establish partnership for exploration of new uranium deposits on the Brazilian territory
- Became a player in the uranium international market
- CAPEX generation for INB further investments (UCEU, Caetité mining expansion capacity, Conversion plant, etc.)

Planning and Challenges on Nuclear Fuel Production

HALEU
And SMR Fuels

- Production for LABGENE
- Current production capacity enough to meet Brazilian internal demand
- Increase production capacity to make part of the international Market

BRAZILIAN NUCLEAR PROGRAM NEAR FUTURE OPPORTUNITIES



Thanks!

¡gracias!

QUESTIONS???

DPN@inb.gov.br

