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Fuel Cycle and the Environment

SMR and Closed Fuel Cycle

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X

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Content

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Introduction

SMR Reactor Designs–Core Sizes-Characteristics

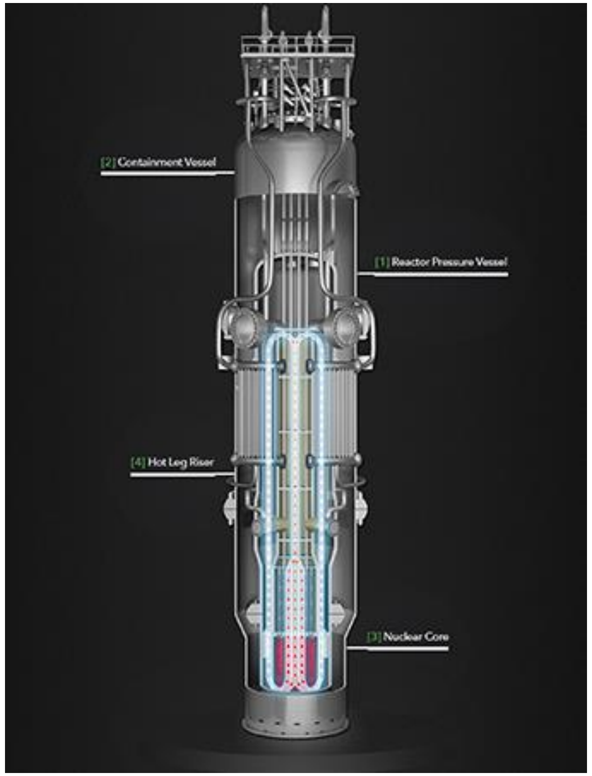
NUSCALE

HOLTEC

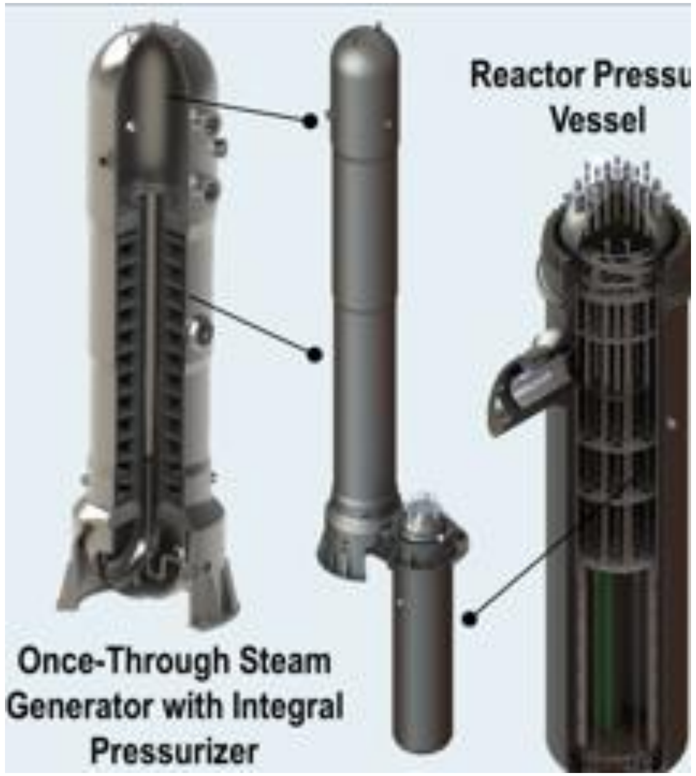
NUWARD™

SMR Reactor Designs

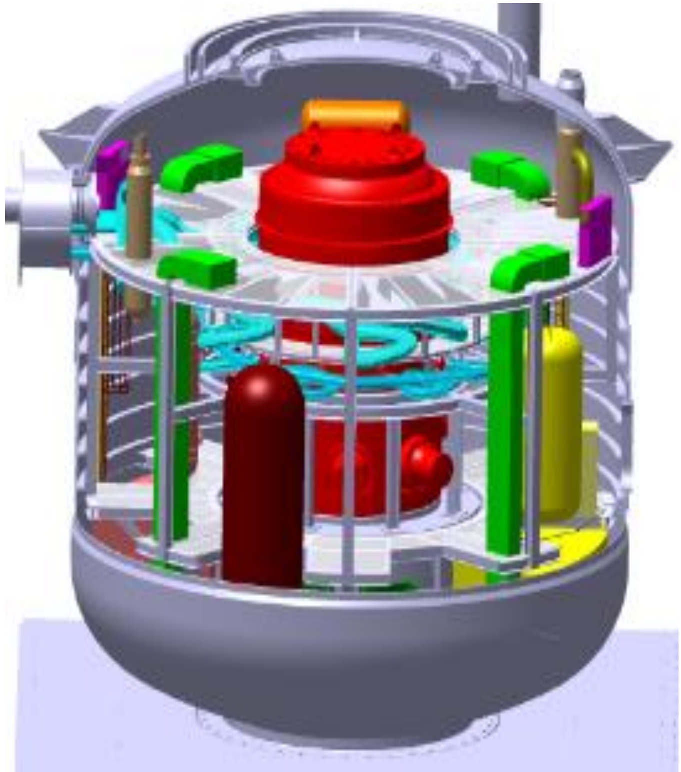
VOYGR™
NuScale



SMR-160
Holtec



NUWARD™



SMR Reactors

Core Sizes

Characteristics

REACTOR DESIGN NAME	NUSCALE (NPM160)	NUSCALE (VOYGR™)	HOLTEC SMR-160	HOLTEC SMR-300	NUWARD™	Conventional PWR
Thermal Power (MWth)	160	250	525	1050	2 x 540	2775
Electrical Power (MWe, gross)	50	77	175	300	2 x 170	900
Primary circulation	Natural			Forced		
System pressure (bar absolute)	127.6	138*	155	-	151	155
Core Flow (kg/s)	612	717*	1205*	-	-	14900
Average coolant velocity (m/s)	0.82	1.05*	1.16*	-	-	5.42
FA number in core	37	37	57	-	2 x 76	157
Fuel rod array	17x17					
Fissile column length (m)	**2.0**	**2.0**	**3.66**	**3.66**	**2.2***	**3.66**
Reactivity control	Control Rods, soluble Boron			-	Control Rods only	Control Rods, soluble Boron
Fuel	UO_2, <4.95%			-	-	UO_2, <4.95% MOX

* Preliminary data

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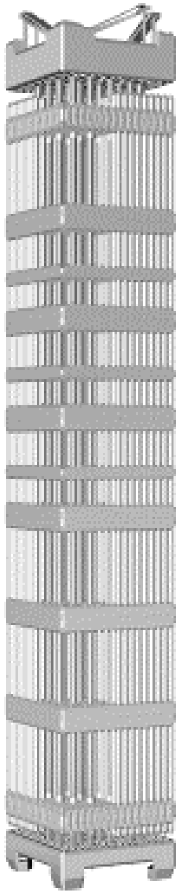
Fuel assembly designs and experience

Main SMR Fuel design differences

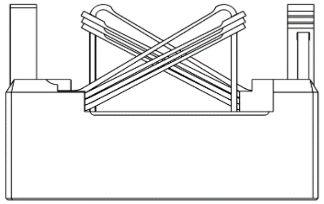
HTP operational experience

GAIA operational experience

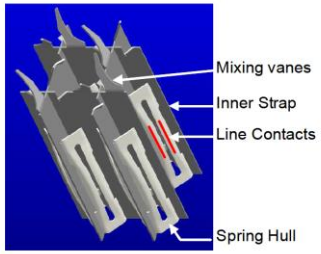
Main SMR fuel design differences



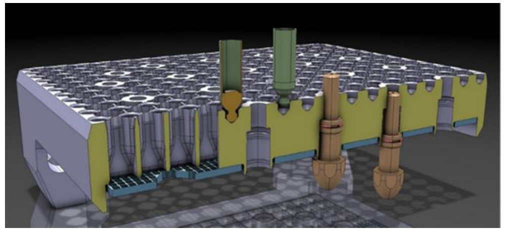
- Top Nozzle



- Spacer grid design



- Bottom Nozzle



HTP operational experience

	FA-Type	Number of Fuel Assemblies / Rods in Operation		Total		Maximum FA Burnup [MWd/kgHM]
European Plants	14x14	370	66,230	1,521	272,259	58
	15x15	294	60,270	1,288	264,040	70
	16x16	177	41,772	2,977	701,292	63
	17x17	446	117,985	5,292	1,396,177	67
	18x18	349	104,700	1,670	499,928	64
US / Far East Plants	14x14	868	152,752	3,913	688,868	63
	15x15	1,042	215,764	6,229	1,299,566	58
	16x16	417	98,412	561	132,396	53
	17x17	330	87,120	2,546	672,144	55
	Total	4,293	945,005	25,997	5,926,670	70

Huge operational experience with about 26,000 FA with up to 70 [MWd/kgHM] burnup.

GAIA operational experience

14ft – 3 cycles

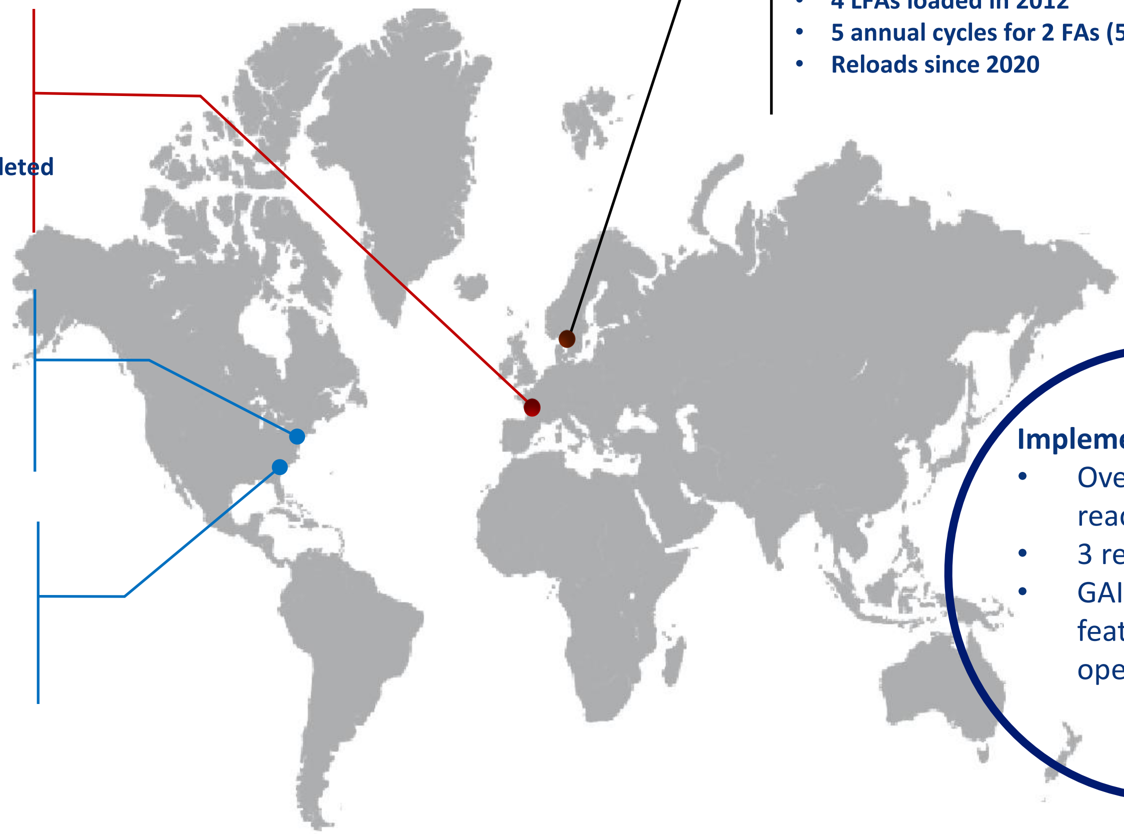
- **4 LFAs loaded in 2018**
- **3 cycles (45 MWd/kgHM) → 3 cycles completed**

12ft – 4 cycles

- **8 LFAs loaded in 2015**
- **3 18-month cycles (53.3 MWd/kgHM)**
- **Reloads since 2021**

12ft - 3 cycles

- **4 LFAs loaded in 2019 with ATF rods**
- **3 18-month cycles planned**



12ft – 6 cycles

- **4 LFAs loaded in 2012**
- **5 annual cycles for 2 FAs (57.6 MWd/kgHM)**
- **Reloads since 2020**

Implementation Status:

- Over 600 GAIA FA delivered to 6 reactors in Europe and US
- 3 reactors supplied with reloads
- GAIA assemblies with ATF features (Cr-coated fuel rods) in operation

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Fuel adaptations to the SMR reactors

Fuel designer position

SMR fuel assemblies

Further fuel adaptations

Fuel designer position

SMR developers:
specific requirements
(performance, interfaces…)

NUSCALE
Power for all humankind

HOLTEC INTERNATIONAL

nuward

framatome
(Fuel designer)

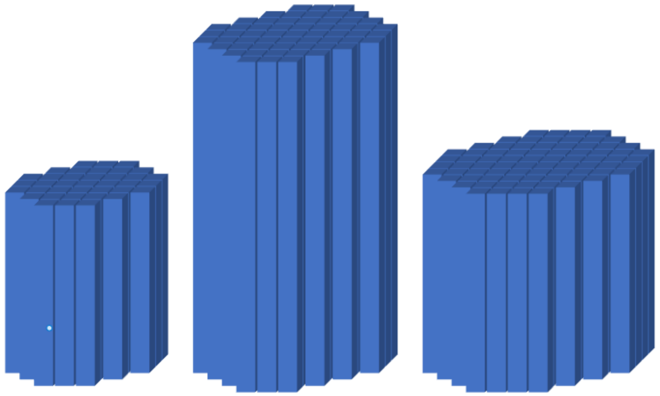
17x17 technology platform:

- Design basis
- Fabrication equipment
- Existing supply chain (materials…)
- Significant operational experience worldwide

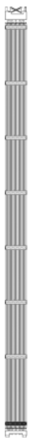
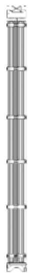
Optimum fuel and core component designs
Codes and methods
Licensing support

SMR fuel assemblies

- Framatome designs SMR fuel and core components based on 17x17 geometry.
- Variants
  - Assemblies with or without MSMGs
  - 2m to 12ft length
  - Forced or natural convection

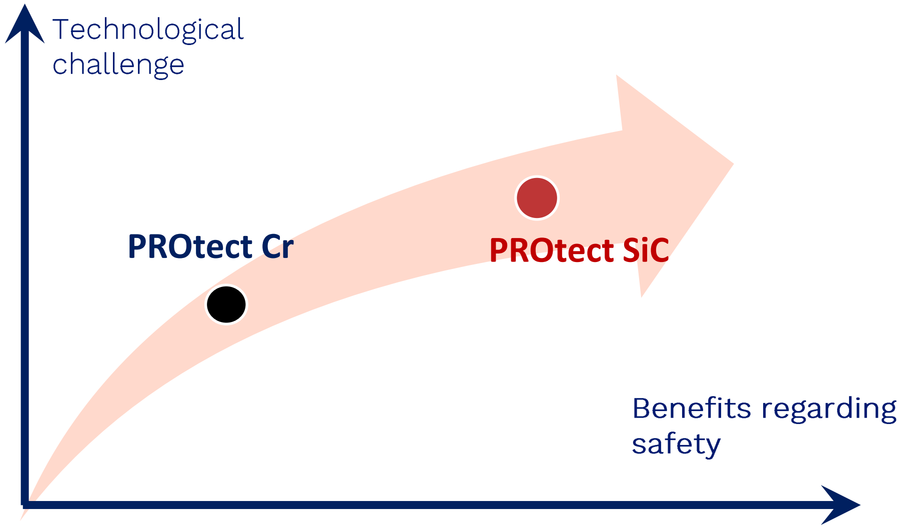


VOYGR™ SMR-160 NUWARD™

Core height	Forced convection reactors	Natural convection reactors
12ft height (3,65m)	 GAIA (typical for US market)	 GAIA (SMR-160, HOLTEC)
Shorter 7ft height (2,15m)	 GAIA (NUWARD™)	 HTP2 (NuScale)

Further fuel adaptations

- Optimization options:
  - ✓ Enhanced Accident Tolerant Fuel (E-ATF) features
  - ✓ Advanced Fuel Management (AFM) capabilities (i.e. enrichment > 5%, increased burn-ups)
  - ✓ Advanced Codes and Methods



Framatome E-ATF program will be fully applicable to the SMRs with minimum demonstration requirements.

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Framatome supply chain ready for SMR fuel

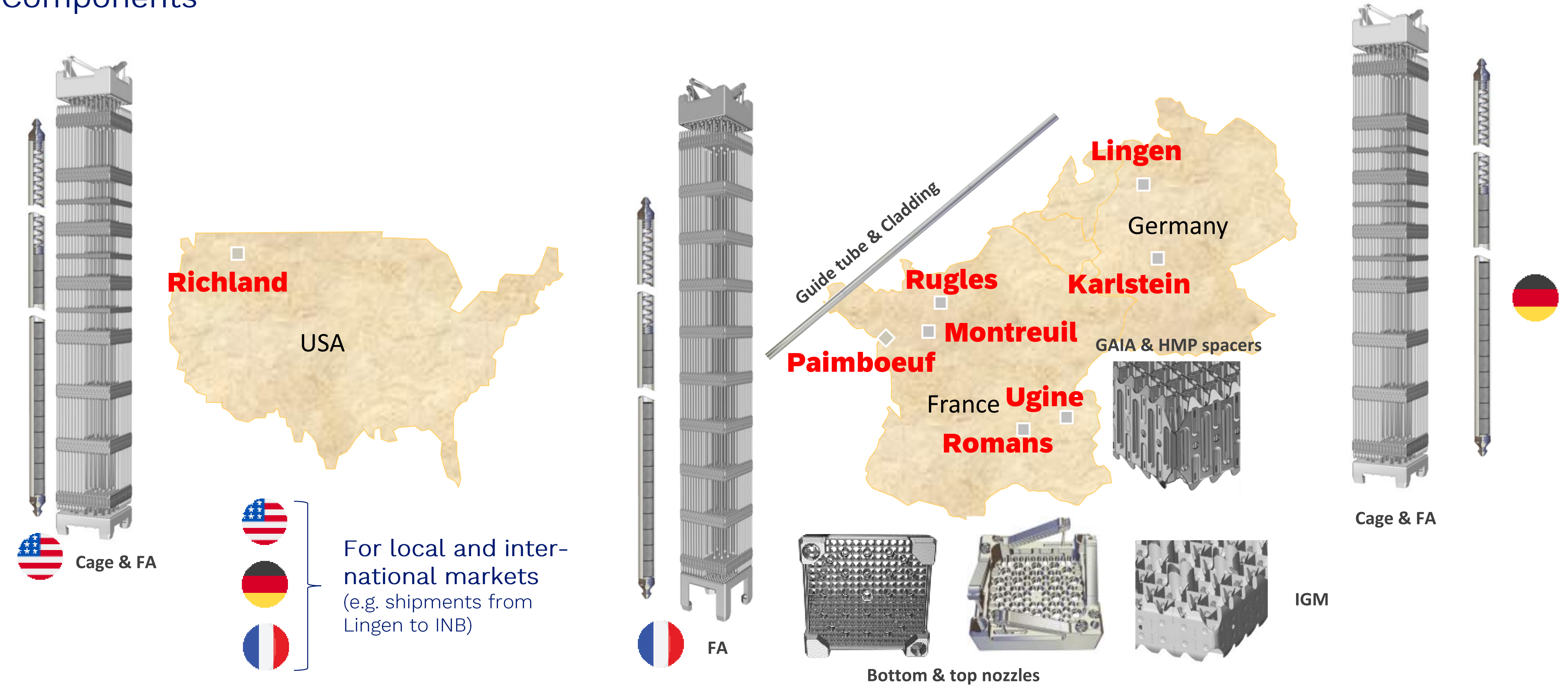
Current manufacturing route

SMR Fuel impact on Fabrication

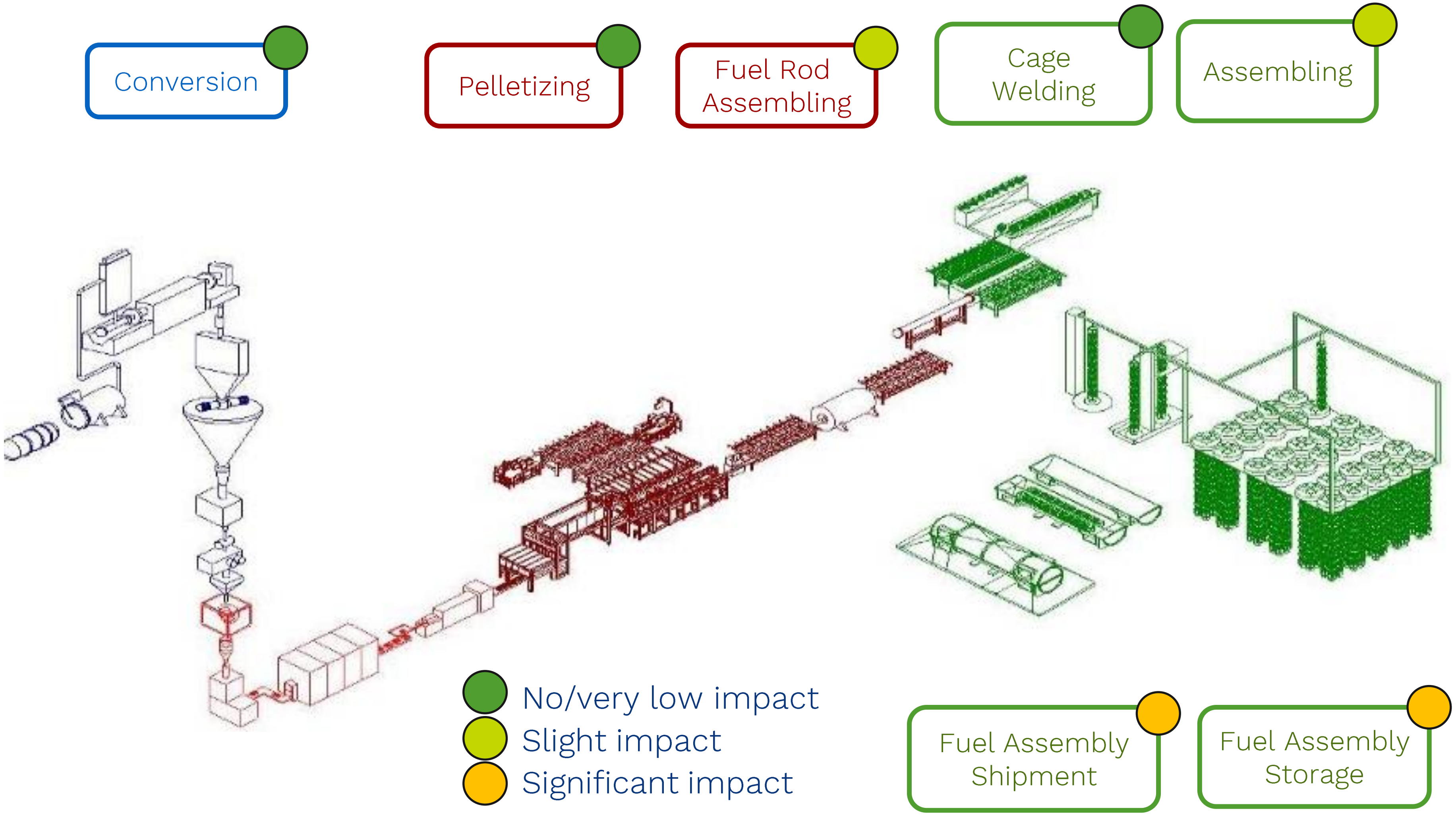
Framatome supply chain ready for SMR Fuel

Current manufacturing route

Main Components



SMR Fuel impact on Fabrication



Framatome supply chain ready for SMR Fuel

- SMR fuel assembly Fabrication
  - SMR fuel assembly components are identical to the proven 17x17 design.
  - Some components are adapted (e.g. length).
  - Use of proven fabrication equipment and technologies.

- Conventional 12ft fuel component fabrication can be used with minor adaptations for SMR design
  - Supply chain readiness checked (mock-ups).
  - Shipment and storage need adaptation

Framatome supply chain ready for SMR Fuel

- Fuel fabrication localization at INB:
  - HTP Fuel Assembly design is successfully manufactured for Angra 2 and 3.
  - With the close collaboration between INB and Framatome, INB is progressing towards full scope component manufacturing depth for HTP Fuel Assemblies in Brazil.
  - Similar modifications necessary in Framatome’s plants for SMR fuel may be implemented.
  - INB, Brazil will achieve to manufacture SMR Fuel on Framatome’s quality level.

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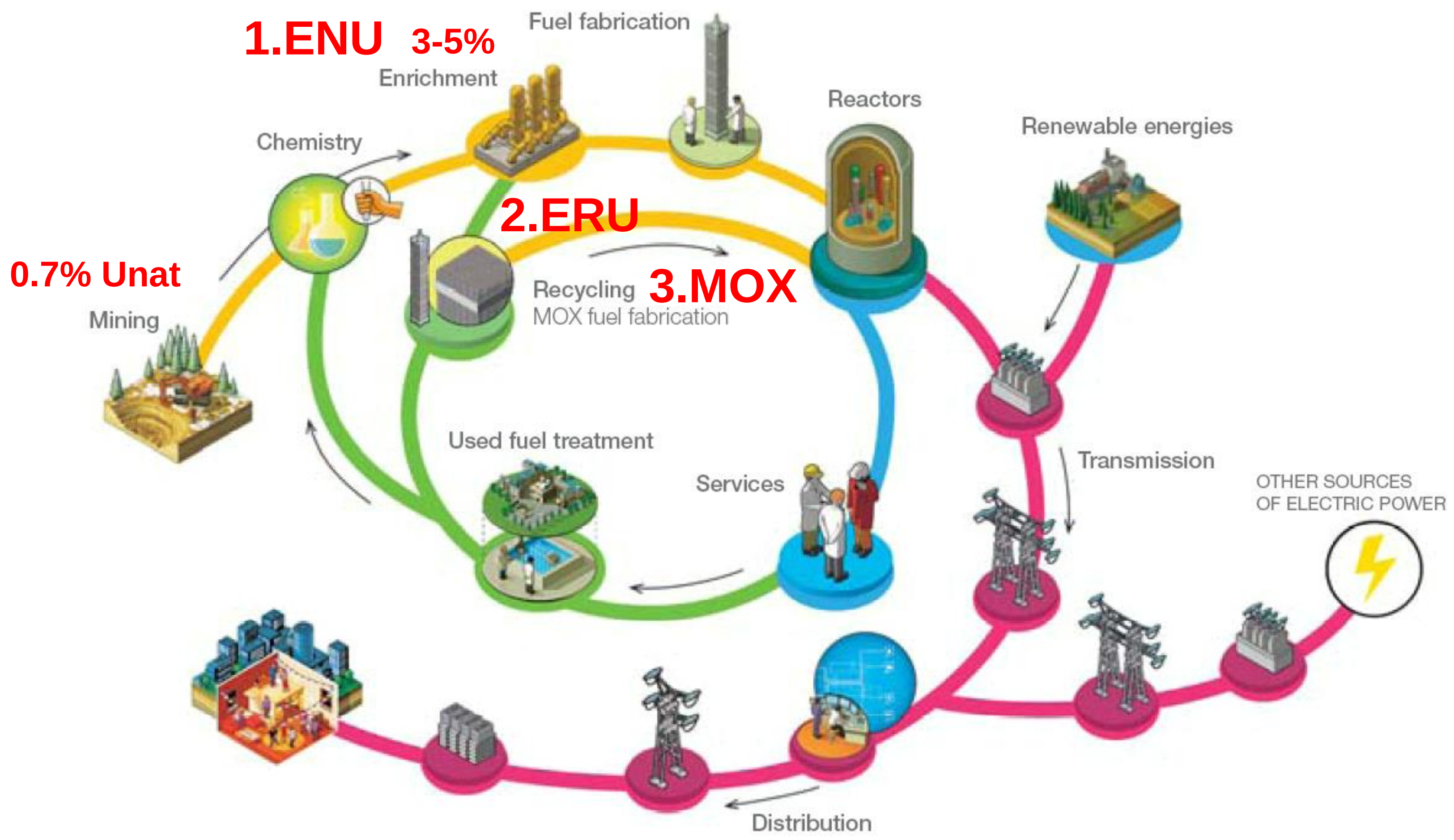
Outlook / Conclusions

Outlook:

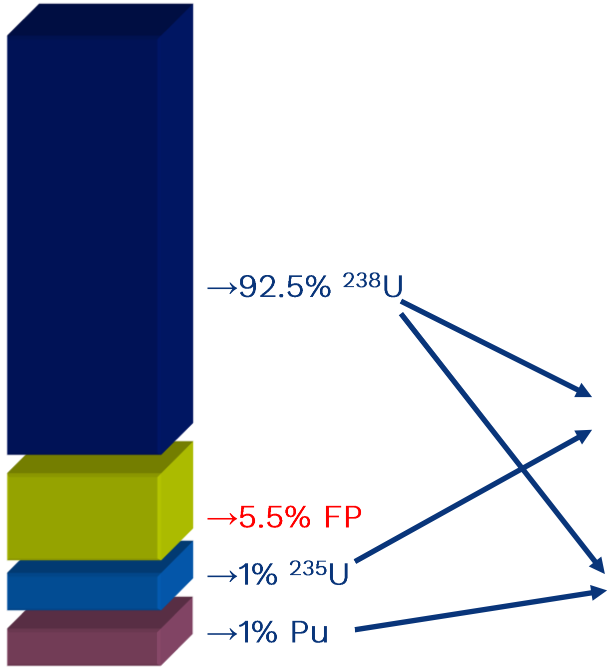
- 3 Different Fuel to close the Fuel Cycle
- Closed Fuel Cycle to reduce Uranium and Waste

Conclusions

Outlook - 3 Different Fuel to close the Fuel Cycle



Outlook - Closed Fuel Cycle to reduce Uranium and Waste



1. ENU (Enriched Natural Uranium)
2. ERU (Enriched Reprocessed Uranium)
3. MOX (Mixed Oxide, UO_2 and PuO_2)

-> 5.5%	Waste for final storage
-> 94.5%	Material further processed in case of closed Fuel Cycle
-> 10 to 20%	Reduction of Nat U Consumption with ERU and MOX
-> Up to 40%	Reduction of Nat U Consumption with MOX reprocessing in addition

Reduction of Nat U Consumption ~ CO_2

Conclusions

- Framatome fuel design, analyses and testing for NuScale licensing for DCA* NRC approval
- Framatome provides code licenses, training and training to SMR developers
- Framatome has 2 proven Fuel Assembly designs for all different SMR reactor types:
  - HTP design, manufacturing and operational experience with outstanding reliability
  - The GAIA design was developed based on HTP and AFA technologies with further improvements
  - Both technologies are compatible with reprocessing (ERU, MOX)
- Framatome technologies and resources can serve all SMR need and load requirements for:
  - Engineering
  - Supply Chain
  - Manufacturing
- -> We are prepared and ready for all mentioned and other new SMR technologies, for a

  “closed Fuel Cycle as the reliable Solution for the Environment”

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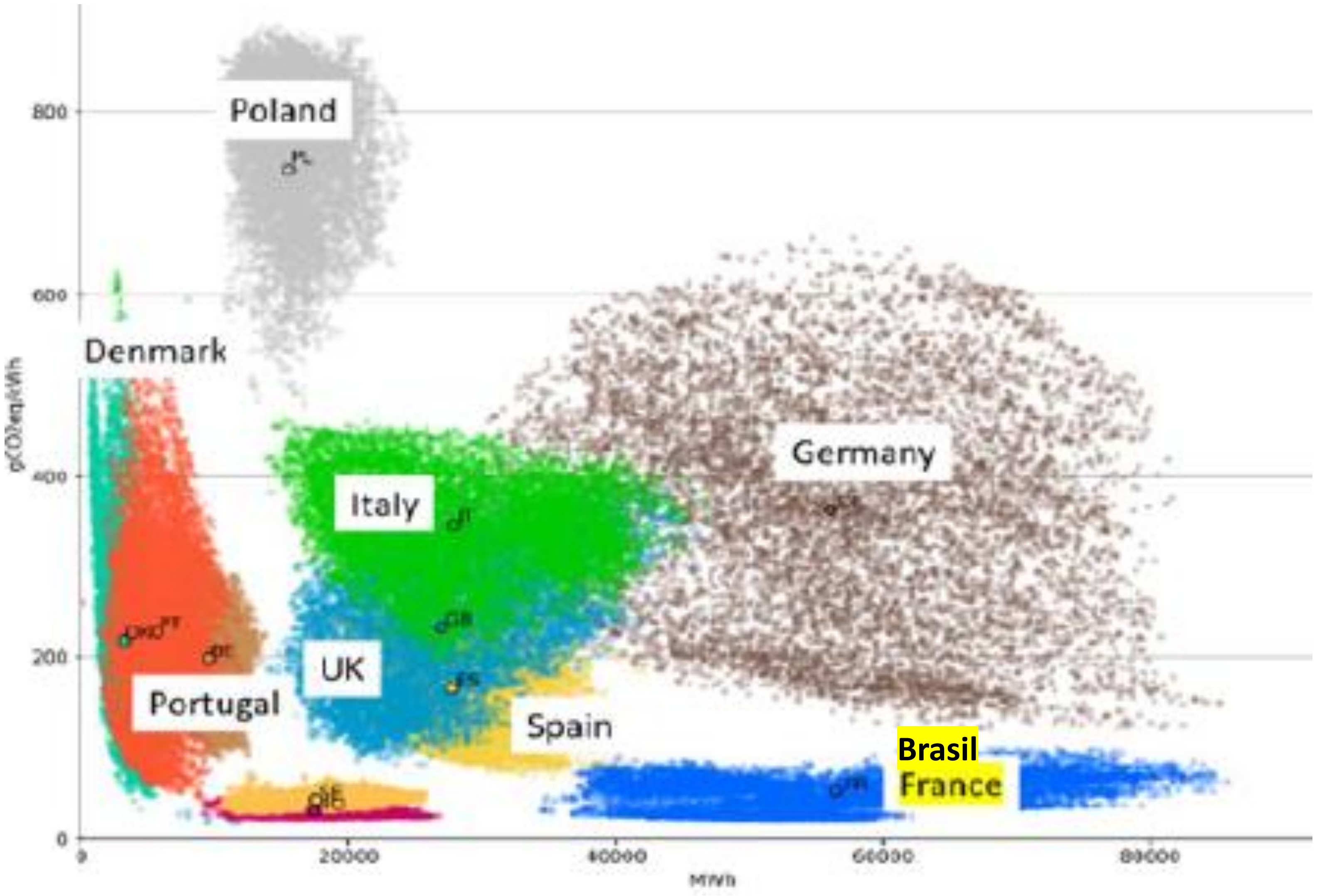
* DCA = Design Certification Application

CO2 emissions (g/kWh) per electricity production



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Thank you