Benefits and value of a flexible and responsible closed fuel cycle implementation in China

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China nuclear development and closed cycle strategy
Main features

Safe and efficient nuclear development to serve a growing fraction of energy demand

- **The Energy Development Strategy Action plan published at the end of 2014**
  - **Tackle both environmental pollution and energy security concerns,**
  - **Promote a more environmental-friendly and sustainable energy mix.**

- **Installed capacity targets to reach**
  - **58GWe in 2020,**
  - **150Gwe in 2030,**
  - **around 240GWe in 2050.**

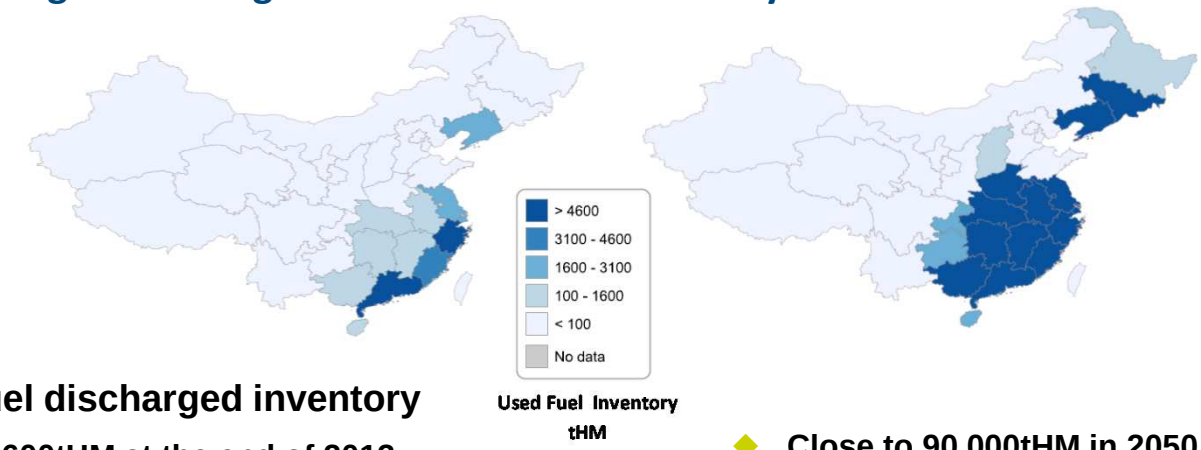
Opted closed fuel cycle with an objective of developing a sustainable fuel cycle

- **Closed cycle benefits**
  - **Responsible management of used fuel accumulation at reactor pools,**
  - **Optimization of uranium resource utilization,**
  - **Minimization of waste repository volume,**
  - **Safer disposal of radioactive waste.**

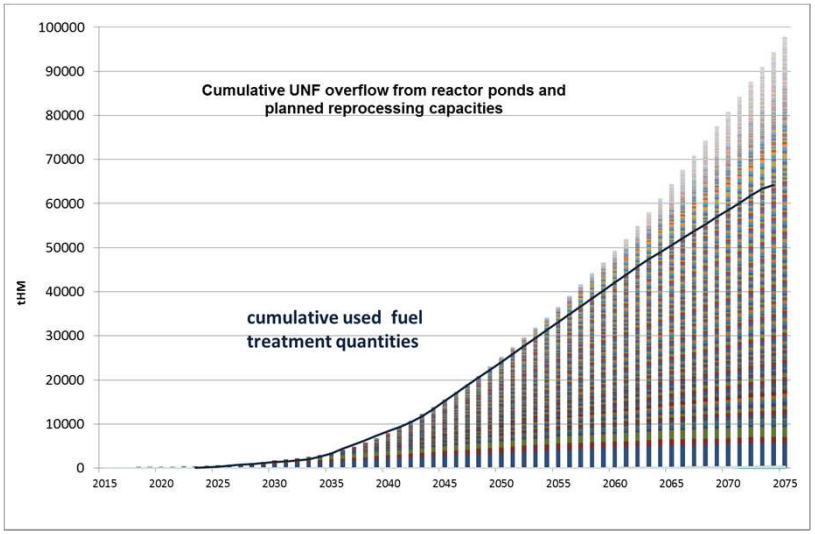
- **CNNC plans to build:**
  - **A 200 tHM/y reprocessing plant by mid 2020's.**
  - **A commercial reprocessing plant of 800 tHM/y in the early 2030's.**
  - **Beyond, additional reprocessing capacity approximately every 10 years.**

Used nuclear fuel inventory forecast

Regional LWR generated used fuel inventory in 2030 and 2080



- **LWR used fuel discharged inventory**
  - **Around 3600tHM at the end of 2013,**
  - **Around 22 000 tHM in 2030,**
  - **Close to 90 000tHM in 2050**
  - **Over 200 000tHM in 2080.**



- **Good correlation between planned reprocessing capacity and used fuel overflows from reactor ponds**

Achieving a responsible used fuel management = no significant delay on planned reprocessing implementation timescale

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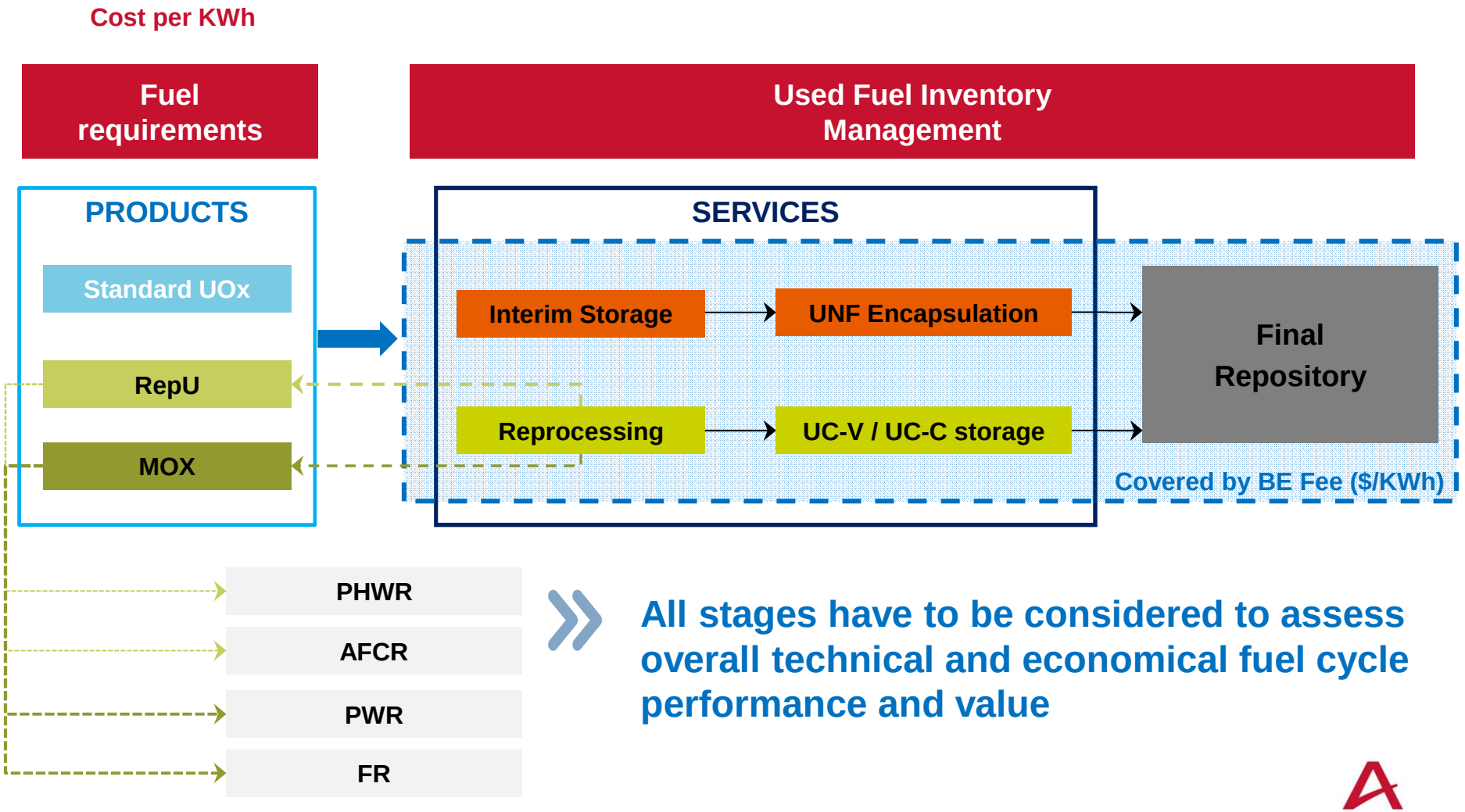
Overview of Fuel cycle elements



All stages have to be considered to assess overall technical and economical fuel cycle performance and value

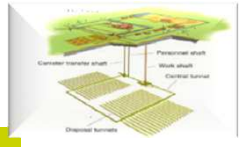
The options for used fuel management

96% of recyclable material

Treatment /recycling

UCV/UCC

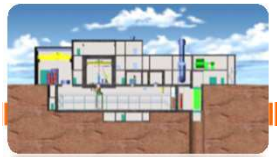
Demonstrated safe Long term storage

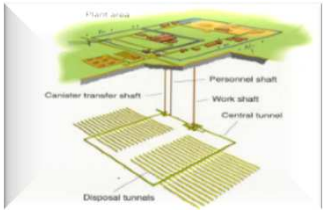


Recycling

Final disposal

Direct disposal





Intermediate storage

Extended period storage

Encapsulation

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Risks and issues with used fuel management
Major challenges for utilities

Used Fuel Management

- Significant inventories
- Scarcity of (or major delay in developing) final disposal path
  >2050
- Industrial interim systems not always capable of bridging the gap
- Uncertainty over used fuels LT behavior

Main issues

Reactors' life extension

- <u>Saturation</u> of reactors pools and constraints on operations
- <u>Safety demonstration</u>
- <u>Public acceptance</u>/LT storage
- Non proliferation issues

Reactors' shut-down

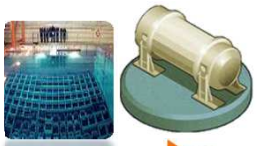
- Pool unloading for phase out
- Public acceptance
- <u>Damaged fuels</u>

New reactors

- Difficulty to get new license
- Definition and funding of back end scheme requested

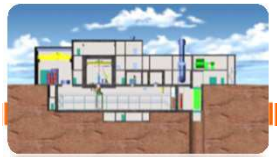
Open cycle used fuel management option requires to cover future costs and provisions

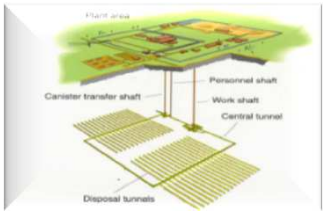
Direct disposal



Potential Reconditionning for transportation

Repacking into final disposal canisters





Intermediate storage

Extended period storage

Encapsulation

Final disposal

- *Issues with fuel integrity for extended dry storage period*
- *Fuel not self protecting*

Under design phase

No disposal in operation, nor in construction:

Most of projects in pre siting phase

High occurrence of delays

Cost for initial interim storage + **Provision for extended storage and ageing management: potential reconditionning required** + **Encapsulation costs and final waste disposal canisters costs Best estimates + provision** + **Best estimates for Development cost, construction and operation cost for final disposal + Risk fee**

(risks and uncertainties relate to the programme as a whole, such as uncertainty over site and design)

Recycling option value for used fuel management

Absence of constraints: time, footprint, safeguards

Optimisation of

- **Footprint (divided by 3)**
- **Volume (divided by 4)**
- **Radiotoxicity (divided by 10)**

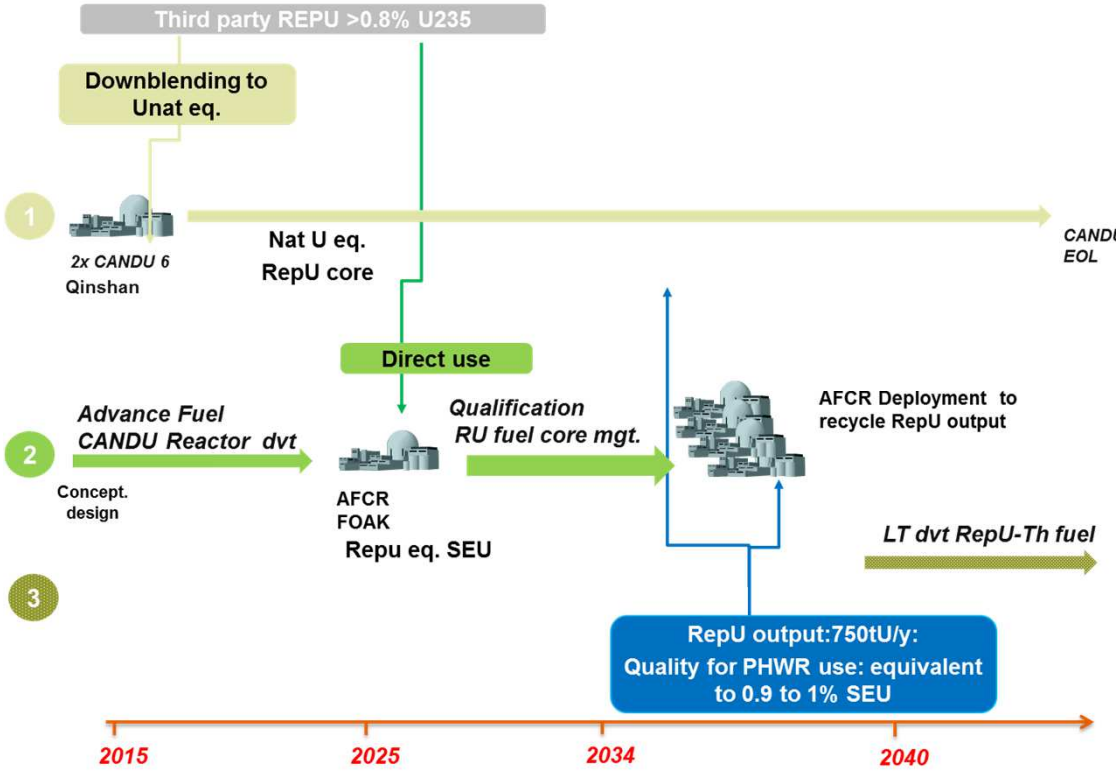
No safeguards/no proliferation risk

No safety risks

420 TWh/y nuclear fleet		Open cycle LWR	Twice Through Cycle	Closed cycle PWR/FBR	Multi-recycling FR
FR share (Gwe %)		0%	0%	5%	100%
Repository footprint	HLW (m²/TWh)	490	150	170	170
	Used fuel potential (m²/TWh)	-	180	120	0
	Global potential (m²/TWh)	490	330	290	170

Source: CEA (2015)

Chinese RePU recycling development roadmap and associated value



Benefits

1

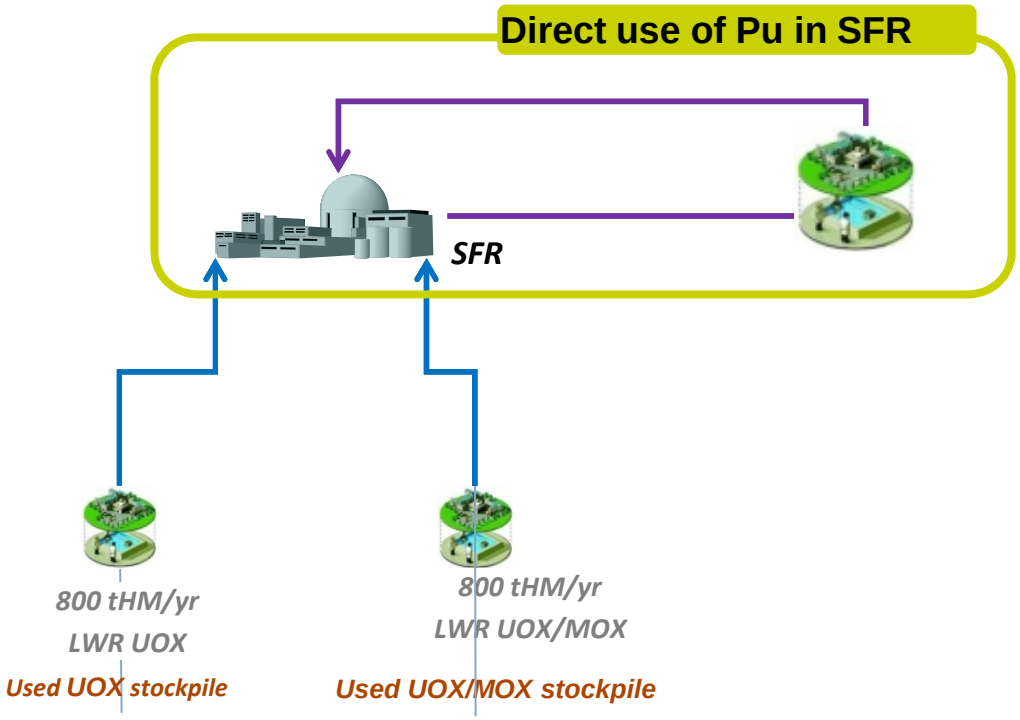
- Natural uranium savings
- Depleted Uranium storage
- RepU LT storage

2

- Fuel efficiency: Burn Up double
- Conversion and SWU savings
- No tails management
- Used fuel inventory divided by 2 leading to intermediate storage, transportation and final disposal cost savings

Chinese Pu recycling development roadmap and associated value

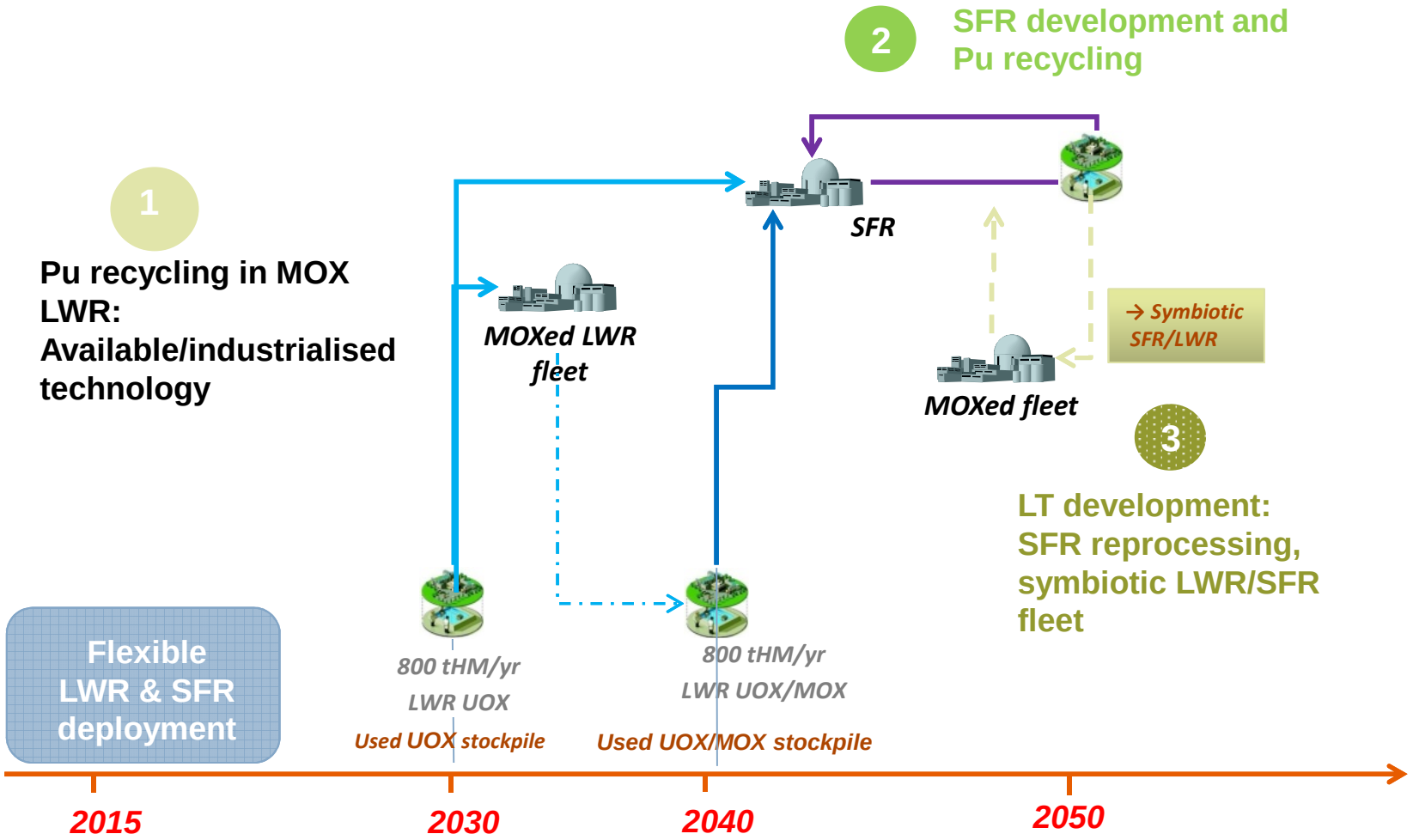
- **Chinese reference scenario:**
  - **Mixed uranium plutonium oxide arising from reprocessing plants recycled in SFRs**
  - **Commercial SFRs foreseen to be implemented from early 2030's**



Benefits

- **Increased Pu Fuel efficiency: thus NatU and SWU savings**
- **Allow Pu multi-recycling**
- **Allow flexibility to manage Pu inventories**
- **Optimisation of Final disposal footprint and design constraints: radiotoxicity safeguards…**

Pu recycling
a possible valuable back up approach



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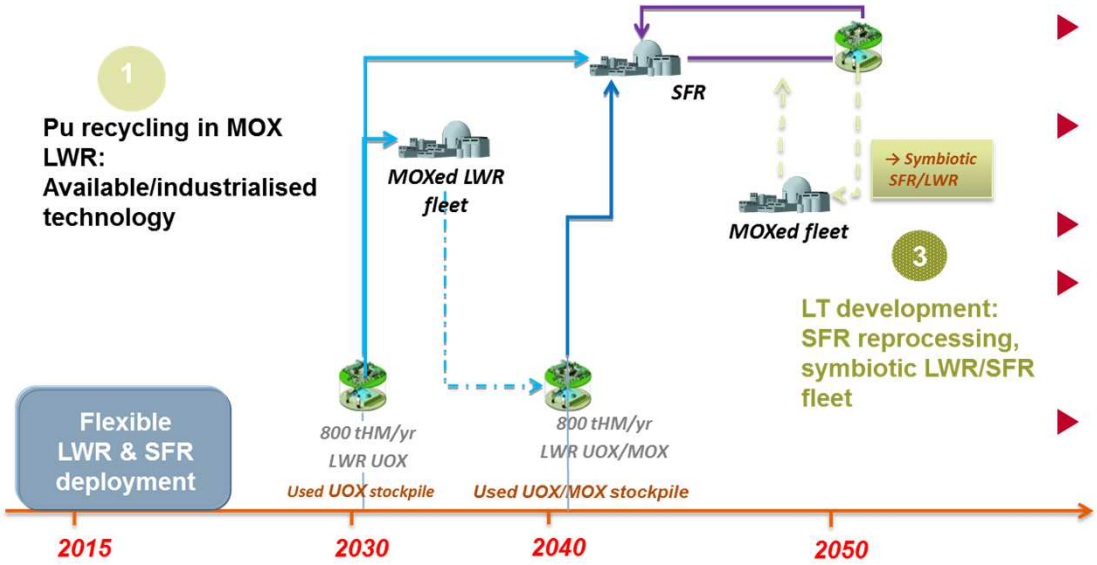
Value of the Pu recycling back up approach

Benefits



1

- Mitigate any delays in Chinese foreseen SFR installed capacity
- Lower investment on interim storage system
- Use of Pu to generate electricity instead of storing it
- Savings of Nat U and SWU
- Provision of early experience in MOX fuel fabrication and reactor operations with recycled fuel
- LWR used MOX is the safest and most optimized way to use and store Pu for GenIV reactors: higher Pu throughput for treatment plant

2

- Flexible deployment of FR/LWR
- Lower capital investment SFR/LWR nuclear system
- Flexibility on energy independence level

3

- Optimisation of Final disposal footprint and design constraints: radiotoxicity safeguards…

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Key take aways

- **Open cycle option for used fuel management encounters many risks to be covered by provisions**
  - Extended period of interim storage
  - Storage of high burn-up fuels
  - Damaged fuels
  - Uncertainties related to the whole GDF programme such as uncertainties over site and design
- **Recycling option mitigates those risks while offering additional benefits:**
  - Industrially demonstrated technology for a responsible used fuel management especially for marge inventories
  - Demonstrated safe long term storage of final waste
  - Reduction of waste volume and both design and operational constraints on GDF
  - Natural resource and SWU savings
  - Flexible deployment of FR/LWR
  - Flexibility on energy independence level

Closed cycle : from comparable to preferable!