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Recycling - back to the future

Introduction

In the 1960s, France's energy policy mirrored those of other countries as it developed nuclear power in a bid to achieve energy independence.

This decision was borne out by the oil crises of 1973 and 1979, leading France not only to speed up its nuclear power program, but also to secure its long-term future by investing in the materials and services needed for its sustainable development.

While the reasons for the crises of the 1970s were purely economic, those of today have much wider global importance:

- the issue of global warming, mostly due to CO_2 emissions from burning fossil fuels
- the rampant development of India and China, creating huge and long-lasting energy demands.

Now, the foresight that was acted upon in the 1970s seems all the more pertinent as energy demand remains not only high, but ever-increasing. In this context, the decision to opt for nuclear fuel recycling appears to be an essential component of the nuclear renaissance.

Besides the purely economic benefits that recycling offers, in the light of the rising price of uranium, it also invites optimized management of natural resources, and responsible management of ultimate waste. With it, we are able to move into the future by developing the industrial tools and fuels of tomorrow.

1. RECYCLING: NOTHING NEW!

As soon as the civil nuclear power age got underway, it became unthinkable to imagine generating nuclear electricity without recycling nuclear material.

In every country where this form of energy was being developed, construction programs involved not only power plants, but also fuel cycle facilities, notably dedicated to recycling nuclear material. Moreover, countries were quick to embark upon national and international programs, the latter being justified by the human and capital resources to be implemented.

When we look at the energy policies of the different countries, industrial operators and R&D bodies concerned, we see that, right from the start, there was a keenness not to waste uranium, the raw material, by targeting the possibility of recycling 95% of the resources extracted a few years previously as well as the new resources created within the reactor core during electricity generation.

It was established at the start of the 1970s that our capacity to reprocess used fuel, the first key stage in fuel recycling, far outweighed demand.

2. A vision widely shared

2.1 FRANCE: "NO OIL, NO GAS, NO COAL, NO CHOICE"

Throughout the 20th century, France was forced to rely on massive imports of raw materials to satisfy its energy needs, due to its own domestic resources being limited to major hydroelectric installations and poor yet abundant coal.

Having been deemed untenable at the start of the century, energy dependence would go on to be a constant obsession of the French authorities.

Just before the first oil crisis in 1973, France was importing 75% of its energy. However, it was further back in 1956, during the Suez affair, that the French authorities were first convinced of the need for nuclear power; less than five years later, the country's first nuclear power program was under way.

Looking back, the view of two members of the energy commission have proved particularly clairvoyant [1,2]: "In the longer term, nuclear power is looking like the

Table 1. French nuclear power program (installed power in MWe net), early 1970s vision [3]

	1970	1973	1975	1980	1985	1990	2000
Foratom forecast 1973	1 470	2 400	2 900	12 700	29 500		
UNGG program (1)	1 250	2 430	2 430	2 430	1 540	0	
HWR program (2)	70	70	70	70	70	0	
LWR basic program (3)	150	150	150	15 500	46 400	70 000 ?	
FBR possible penetration			250 (4)	1450 (5)	4000 ?	10 000 ?	
HTR possible penetration					?	?	
Total power installed	1 470	2 650	2 900	19 450	52 000	80 000	120 000 ?

(1) Including the French-Spanish Vandellos Nuclear Power Station
(2) Brennilis EL4 Nuclear Power Station
(3) Including Chooz, Tihange and Kaiseraugst Nuclear Power Stations
(4) Phénix Nuclear Power Station
(5) Superphénix Project

energy that will gradually free Europe from its dependence on remote, costly and insecure supplies". However, this was quickly forgotten amid the glut of cheap oil in the 1960s.

The 1973 oil crisis changed that, and gave the French government the opportunity to put its ambitious nuclear program, on which it had been working for two years, firmly back on the agenda.

This acceleration, which came about due to the gaps between the Foratom forecasts made at the start of 1973 and those of the French program announced by Pierre Messmer on March 5, 1974, heralded the construction of fifty nuclear plants, which went online in 1985 to give the country a total installed power of over 50 GWe (*Table 1*).

The second stage of France's nuclear policy involved fast reactors, fuelled by recycled LWR fuel. The Phénix, a fast breeder reactor (FBR) pilot plant, went online in 1973 in Marcoule and the decision was taken to launch the FBR Superphénix project in 1975.

The country's recycling facilities were therefore designed to handle used fuel from its PWR fleet, i.e. 52 GWe of installed power in 1985.

Table 2 shows France's used fuel reprocessing needs, put at 1350 tHM/year in 1985 (capacity in tons of heavy metal (tHM) based on the burn up rate of the time, which was far lower than that of today).

2.2 EUROPE

By the end of the 1960s and start of the 1970s, fuel reprocessing had become a victim of its own success!

The negative effects of the then-rivalry between BNFL, Eurochemic and Wak were such that a dedicated Foratom working group recommended that the European nuclear fuel recycling players combine their efforts as part of an international collaboration.

This led to the cooperation between the CEA (and later COGEMA), BNFL and KEWA, which came together to form United Reprocessors GmbH, based in Frankfurt, Germany.

Over and above each country's specific legal framework, the aim was then to:

- Rationalize investments,
- Pool sales actions to manage current and future reprocessing capacities,
- Share expertise and work together in R&D.

Table 2. Forecast French nuclear fuel needs, early 1970s vision [4]

H_1: reference scenario H_2: lower scenario H_3: Upper scenario

		1975	1980	1985	around 1990
Production U_3O_8 (tU content)	H_1	1 500	5 500	9 200	11 000
	H_2	1 400	5 000	7 700	8 500
	H_3	1 550	6 200	11 200	14 500
Conversion natural UF_6 (tU content)	H_1	1 400	4 400	8 100	10 500
	H_2	1 300	4 000	7 300	8 000
	H_3	1 550	5 000	10 600	14 000
Conversion recycled UF_6 (tU content)	H_1	-	100	700	1 300
	H_2	-	100	700	1 300
	H_3	-	-	-	-
Enrichment (tSWU)	H_1	700	2 300	5 800	8 000
	H_2	700	2 600	6 100	8 000
	H_3	600	2 100	5 400	7 500
Fuel manufacture (tU content)	H_1	600	1 200	1 900	2 100
	H_2	600	1 200	1 900	2 100
	H_3	600	1 200	1 900	2 100
Irradiated fuel reprocessing (tHM treated)	H_1	500	650	1 350	1 750
	H_2	500	650	1 350	1 750
	H_3	500	650	1 350	1 750

2.3 THE USA

The USA was one of the first countries to build used fuel recycling facilities on an industrial scale; at the start of the 1970s, the outlook was as follows:

- In 1972, after six years of operation, the NFS (Nuclear Fuel Services) facility near West Valley, NY, then owned by Getty Oil, ceased its reprocessing campaigns in order to increase capacity (from 300 to 750 tHM/year) and upgrade the facility to align it with Federal and State nuclear safety requirements.
- In 1970, AGNS (Allied Gulf Nuclear Services) began construction of a 1500 tHM/year reprocessing facility in Barnwell, SC, adjacent to the DOE's Savannah River site.
- General Electric's 300 tHM/year Midwest Fuel Recovery Plant, in Morris, Il, adjacent to the Commonwealth Edison Company Dresden Reactor site, was completed, only to be declared inoperable in 1974.
- Other initiatives should also be mentioned, from other private industrial players such as EXXON Nuclear Company and E.I. Dupont de Nemours and Company; these included "conceptual design" and/or license applications filed with US authorities.

2.4 JAPAN

With coal as its only natural resource, Japan naturally and resolutely looked toward civil nuclear power.

Japan's certainty proved accurate after the first oil crisis, prompting it to launch its "Sunshine Project" promoting solar energy applications, and issue a call, through MITI, to develop nuclear power as a matter of priority.

The PNC (Power Reactor and Nuclear Fuel Corporation, now JAEA) worked in the 1970s with SGN (now an AREVA engineering subsidiary specializing in the fuel cycle) to build a pilot 200 tHM/year reprocessing facility in Tokai Mura.

This proved insufficient to meet the needs of the country's nuclear program, and so led to the launch of a 1500 tHM/year facility, planned to be commissioned in the mid-1980s.

Table 3. Summary of used UO_X reprocessing capacity forecasts at the start of the 1970s (15- and 20-year outlooks) [5]

Capacity (tHM/year)	Around 1985	Around 1990
USA	1000	3000
UK	100	1000
France	800	1600
West Germany	-	1400
Belgium	60	300
Japan	200	1700
Other	-	400
Total capacity	2160	9700
Planned requirements	8100	-

2.5 THE USSR

Despite the Soviet Union's nuclear program being firmly governed by Cold War and weapons considerations, some of the military treatment sites began to see civil nuclear power as an additional activity and/or secondary priority.

This led the Soviet authorities to launch programs to adapt certain military sites, such as Ozersk/Chelyabinsk-65, Tomsk-7/Seversk and Krasnoyarsk-6/Zheleznogorsk, to civil nuclear fuel recycling.

The outlook for reprocessing capacity, as forecast at the start of the 1970s, is summarized in *Table 3*.

3. 1986 to 2003: Nuclear out in the cold

From a global energy perspective, this period was marked by the accidents at Three Mile Island (TMI) and Chernobyl, as well as an oil comeback that saw the price of a barrel fall back to below its pre-1973 levels!

In this context, many countries, driven by public opinion and anti-nuclear sentiments relayed in the media, put their nuclear programs on the back burner, to the point of scaling back or even pulling out of nuclear power.

In Europe, the Chernobyl disaster of 1986 had a huge impact on the way people and governments felt about nuclear power.

In the wake of the accident, several countries decided to implement moratoria or to pull the plug on nuclear power to varying degrees.

For example:

- Italy, a nuclear pioneer, suddenly decided to shut down its entire reactor fleet.
- Germany voted in a law banning all new builds nationwide, and stopped all reprocessing of unloaded fuel, thereby limiting, in the long run, the use of recycling. Despite having been a pioneer in nuclear fuel recycling, in the end Germany never got to see the Hanau MOX fuel fabrication plant in operation, despite its readiness. Instead, it was dismantled.
- France, unable to buck this trend, nonetheless limited the damage to the nuclear power industry to scrapping its fast reactor program. In 1998 it closed Superphénix, the world's first industrial fast reactor prototype, first commissioned in 1985.

In the USA, where the Carter administration had already forbidden all used fuel reprocessing in 1976, NRC delays combined with the TMI incident in 1979 and freefalling oil prices, leading to mass cancellations of reactor orders - 124 out of 259 orders were dropped.

In Japan, the capacity of the country's new used fuel reprocessing plant was scaled back from 1500 to 800 t/year.

"What doesn't kill you makes you stronger"

In the two decades nuclear power spent out in the cold, expertise and good practices were shared worldwide. This enabled the industry to reach new heights in terms of:

- Nuclear safety of global installations,
- Plant availability, yield and profitability,
- Optimization of fuel recycling facilities, with major reductions in ultimate waste residue volumes and releases.

Moreover, this is not unrelated to several countries' regained confidence in nuclear power.

4. Nuclear renaissance hand-in-hand with recycling renaissance

Since the outset of this period, the global supply-and-demand balance of energy raw materials has completely changed, giving us an entirely different situation. The economic tensions of the oil crises in 1973 and 1979 would set the scene thereafter.

Energy demands have grown in parallel to development in China and India. Moreover, 70% of the world's known oil reserves and 40% of its gas are concentrated in countries with geopolitical instability in the medium and long term. Skyrocketing prices for oil and gas (which is indexed to oil) have shaken up the hierarchy of the world's cheapest energy sources.

In addition, the issue of climate change - still totally unknown to the general public in the 1970s - has become another factor for major economies to take into account when weighing up their energy portfolios; coal, despite being cheap, has come off worst.

What remains are renewable energy sources that are incapable of meeting our major and ongoing needs.

In this context, nuclear would appear to be an essential solution for generating base-load electricity. It has been predicted that the equivalent of 250-300 EPRs will be built by 2030, in what the USA is calling the "nuclear renaissance".

To ensure the right amounts of supporting resources are also mobilized, several mining projects have also been launched. However, as in the past, analyses of our future needs suggest that extra energy resources will also have to contribute to the available mix, to support the renaissance and increase in the world's nuclear reactor fleet.

One major extra resource lies in used fuel recycling. Its intrinsic saving of natural resources could bring uranium requirements down as much as 25%, by recycling plutonium in the form of MOX fuel, and recycling reprocessed uranium in the form of ERU fuel.

Aware of the challenges they face, nuclear countries, as well as those interested in adding nuclear power to their energy mix, have lent their weight to the major international initiatives and/or projects that have been launched in recent years:

- In the USA, the Global Nuclear Energy Partnership (GNEP), launched in February 2006 by President Bush, aims at completely closing the nuclear fuel cycle.
- On November 26, 2007, China and France signed an intergovernmental agreement giving AREVA and the CNNC (China National Nuclear Corporation) the go-ahead to create a partnership that will enable China to develop its own fuel recycling platform.
- Commercial activity is due to start at Japan's Rokkasho-mura plant by the end of 2008, sealing the successful technology transfer project between AREVA's La Hague facility and Japan. This will be followed by a MOX fuel fabrication facility on the same site.

Elsewhere, India has made known its intention to develop its own fuel recycling platform once the political agreements are in place enabling it to work with other nuclear countries.

This means that unloaded used fuel, potentially reaching 400,000 tons by 2030, would give extra guaranteed supplies to nuclear power.

Having a significant proportion of utilities' energy supplies guaranteed adds weight to the oft-proven competitiveness of the "closed cycle" [6,7].

Increasing uranium prices provide further economic arguments in favor of recycling, which enables supply costs to be projected.

Finally, now sustainable development has brought climate change to people's attention the pressure is to preserve resources for future generations and to consider the environment. The solution is recycling, to which many conventional industries have already turned (e.g. paper, aluminum, glass, etc.). This now plays a significant role in the acceptance of the growing nuclear industry, especially in how it responsibly manages ultimate waste.

In choosing to recycle recoverable material since its inception, and by managing ultimate waste responsibly and optimally, civil nuclear power has prepared its own future and proven its maturity, notably to meet the challenges of the 21st century.

For a long time now, the recycling of nuclear material has been used to reduce the radiotoxicity of ultimate waste by a factor of 10, reduce disposed waste volumes by a factor of 5, and reduce natural uranium needs by a quarter.

Recycling has paved the way for us to develop the fourth generation of reactors and fuel cycle.

For all of the aforementioned reasons, the nuclear renaissance will be accompanied by an increasingly more systematic adoption of nuclear fuel recycling. This will make widespread a practice that both France's nuclear industry and research organizations have been aware of for some time, having been key figures in its development and industrialization both at home and abroad.

We therefore feel that a fitting way to sum up this journey through time would be: "NUCLEAR ENERGY IS RECYCLABLE ENERGY".

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