TOO LATE, TOO EXPENSIVE - THE SMR PROMISE

For the nuclear industry, one of the lessons learned from the 1986 Chernobyl disaster and 2011 Fukushima disaster was that the trend of building bigger, more robust and longer-operating nuclear power plants from the 1960s onwards needed to be replaced. It became necessary to reconsider the main direction of the design, development and construction of power and heat generation units. This is how the promise of Small Modular Reactors (SMRs) evolved and has appeared with ever more emphasis in the media since the early 2020s. The mission of SMRs, by now the main reference point for the industry's vision, is evident:

- as a new generation of technology, it should prevent the recurrence of nuclear disasters of the magnitude of Fukushima and Chernobyl,
- compared to reactors of the previous generations, it should work more safely and for longer,
- in terms of regulation, it should be more flexible,
- its construction and commissioning should be faster and more economical compared to current trends in the nuclear industry (a way to achieve this could be the mass production of key components).

The SMR promise was given an extra boost when the industry started to emphasise in its communication that this technology would be the solution for meeting climate targets and reducing global carbon-dioxide emissions. Such promises were first made mainly by Canada, China and Russia, which were then joined by the long-established US company NuScale (whose announcements, having grown in numbers recently, caused a media frenzy), and then, with other new projects, the United States, France and the UK. What is more, other countries started to make similar announcements: Belgium, which has just stated that it intended to phase out nuclear power, now finds SMRs promising; Japan, where after the Fukushima disaster there is still strong resistance to consolidating the nuclear industry again (but where politicians recently came to think that SMRs may contribute to meeting the 2050 zero-carbon objective); or Poland, which, as of yet, does not have a nuclear power plant, but in March the competition regulator issued an approval for setting up a joint venture to commercialise (as of now, only in Poland) GE Hitachi Nuclear Energy's (GEH) BWRX-300 water-cooled SMR of 300 MW and equipped with a passive safety system.

According to the International Atomic Energy Agency (IAEA), global interest has grown mainly in small modular reactors (there are also medium-sized ones), which have a capacity of minimum 10 MW and maximum 300 MW per unit, and, compared to conventional nuclear power plants of 1000-,1200- or 1600-MW units, have much lower costs and a much smaller environmental footprint. In practice, the size (design, and even the type of cooling) of SMRs may vary considerably. For example, as per IAEA categorisation, Bill Gates' TerraPower project, which has been in development since 2013, does not even qualify as an SMR, as its capacity may exceed 300 MW. However, the 300-MW limit seems to be quite flexible, given that in 2013 (they year when the company was launched) the definition of SMRs still set the capacity range between 20 MW and 125 MW. About two decades ago some calculated that SMRs could account for 40 GW of total global generation capacity by 2030, while others predicted that up to a thousand SMR units could be constructed by 2040. These projections will probably prove to be false.

According to the IAEA, there are about 50 feasible SMR plans and concepts in the world, most of them still in the development phase, while some are said to be finished in the foreseeable future. From a broader perspective, this group can also include the recent announcement of the first technological test of the US THETA, equipped with liquid metal technology; the official announcement of the completion of China's Shidao Bay project last December; or the fact that in Canada there are at least a dozen SMR development proposals stuck in the pre-licensing maze of the Canadian Nuclear Safety Commission (CNSC), but not a single project has been approved so far. In terms of completion, IAEA states that there are four major projects in advanced stages of construction. Firstly, ***Carem25*** in Argentina (initially planned for 25 MW, but now 32 MW), whose construction commenced as early as in 2014, but will still take at least 20 months to complete. Secondly and thirdly, two Chinese SMRs: the 200-MW ***Shidao Bay***, switched on in December 2021, and ***Linglong-1***, serving demonstration purposes, with a planned capacity of 125 MW, the construction of which started in summer 2021 and is proceeding rapidly. Fourthly, Russia's Yakutia Project, a facility whose planning process started in early 2021 as per Rosatom designs for an eastern Siberian location, based on the technology of floating nuclear power plant ***Akademik Lomonosov***, which has been operational since autumn 2019.

SMRs operating, under construction, under development or abandoned

Based on the latest data from the World Nuclear Association portal, which compiled an educational resource on the types of nuclear power plant technology, the following section contains the names, types, sizes and locations of projects to which have already been presented in the specialist press. [*Note*: more information and references are available via the links provided for the names and types.]

Operating small reactors

Name	Capacity	Type	Developer
CNP-300	300 MWe	PWR	SNERDI/CNNC, Pakistan and China
PHWR-220	220 MWe	PHWR	NPCIL, India
EGP-6	11 MWe	LWGR	Bilibino, Siberia, Russia
KLT-40S	35 MWe	PWR	OKBM, Russia
RITM-200	50 MWe	Integral PWR	OKBM, Russia

Small reactor designs under construction

Name	Capacity	Type	Developer
CAREM25	27 MWe	Integral PWR	CNEA & INVAP, Argentina
HTR-PM	210 MWe	Twin HTR	INET, CNEC and Huaneng, China
ACP100/Linglong One	125 MWe	Integral PWR	CNNC, China
BREST	300 MWe	Lead FNR	RDIPE, Russia

Small reactors for near-term deployment

Name	Capacity	Type	Developer

Name	Capacity	Type	Developer
VBER-300	300 MWe	PWR	OKBM, Russia
NuScale	77 MWe	Integral PWR	NuScale Power + Fluor, USA
SMR-160	160 MWe	PWR	Holtec, USA + SNC-Lavalin, Canada
SMART	100 MWe	Integral PWR	KAERI, South Korea
BWRX-300	300 MWe	BWR	GE Hitachi, USA
PRISM	311 MWe	Sodium FNR	GE Hitachi, USA
Natrium	345 MWe	Sodium FNR	TerraPower + GE Hitachi, USA
ARC-100	100 MWe	Sodium FNR	ARC with Hitachi, in the USA
Integral MSR	192 MWe	MSR	Terrestrial Energy, Canada
Seaborg CMSR	100 MWe	MSR	Seaborg, Denmark
Hermes prototype	35 MWt	MSR-Triso	Kairos, USA
RITM-200M	50 MWe	Integral PWR	OKBM, Russia
RITM-200N	55 MWe	Integral PWR	OKBM, Russia
BANDI-60S	60 MWe	PWR	Kepco, South Korea
Xe-100	80 MWe	HTR	X-energy, USA
ACPR50S	60 MWe	PWR	CGN, China
Moltex SSR-W	300 MWe	MSR	Moltex, United Kingdom

Small-scale, suspended or abandoned reactor designs

Name	Capacity	Type	Developer
EM2	240 MWe	HTR, FNR	General Atomics (USA)
FMR	50 MWe	HTR, FNR	General Atomics + Framatome
VK-300	300 MWe	BWR	NIKIET, Russia
AHWR-300 LEU	300 MWe	PHWR	BARC, India
CAP200 LandStar-V	220 MWe	PWR	SNERDI/SPIC, China
SNP350	350 MWe	PWR	SNERDI, China
ACPR100	140 MWe	Integral PWR	CGN, China
IMR	350	Integral	Mitsubishi Heavy

Name	Capacity	Type	Developer
	MWe	PWR	Ind, Japan*
Westinghouse SMR	225 MWe	Integral PWR	Westinghouse, USA*
mPower	195 MWe	Integral PWR	BWXT, USA*
UK SMR	470 MWe	PWR	Rolls-Royce SMR, UK
PBMR	165 MWe	HTR	PBMR, South Africa*
HTMR-100	35 MWe	HTR	HTMR Ltd, South Africa
MCFR	?	MSR/FNR	Southern Co, TerraPower, USA
SVBR-100	100 MWe	Lead-Bi FNR	AKME-Engineering, Russia
Westinghouse LFR	300 MWe	Lead FNR	Westinghouse, USA
TMSR-SF	100 MWt	MSR	SINAP, China
PB-FHR	100 MWe	MSR	UC Berkeley, USA
Moltex SSR-U	150 MWe	MSR/FNR	Moltex, United Kingdom
Thorcon TMSR	250 MWe	MSR	Martingale, USA
Leadir-PS100	36 MWe	Lead-cooled	Northern Nuclear, Canada

Micro-reactors under development

Name	Capacity	Type	Developer
U-battery	4 MWe	HTR	Consortium led by Urenco, UK
Starcore	10-20 MWe	HTR	Starcore, Quebec
MMR-5/-10	5 or 10 MWe	HTR	UltraSafe Nuclear, USA
Holos Quad	3-13 MWe	HTR	HolosGen, USA
Gen4 module	25 MWe	FNR	Gen4 (Hyperion), USA
Xe-Mobile	1-5 MWe	HTR	X-energy, USA
BANR	50 MWt	HTR	BWXT, USA
Sealer	3-10 MWe	FNR	LeadCold, Sweden
eVinci	0.2-5 MWe	Heatpipe-FNR	Westinghouse, USA
Aurora	1.5 MWe	Heatpipe-FNR	Oklo, USA

Name	Capacity	Type	Developer
NuScale mikro	1-10 MWe	Heatpipe-FNR	NuScale, USA

(Source of table: world-nuclear.org)

Conflicting numbers

In the light of conflicting data and numbers that is so characteristic of the nuclear industry, it is by no means surprising that when it comes to the number of SMRs of various types and of various planned sizes, the global industrial body has already published numbers other than 50. In 2020, for example, a complete catalogue was prepared that describes 73 officially existing projects, ranging from designs of fast neutron small power plants, through nuclear power plant technologies of high-temperature gas cooling or of molten salt, to micro-reactors. However, there is a problem with this SMR catalogue, as it begins with the following disclaimer: *"This is not an official IAEA publication. The material has not undergone an official review by the IAEA. The views expressed do not necessarily reflect those of the International Atomic Energy Agency or its Member States and remain the responsibility of the contributors. Although great care has been taken to maintain the accuracy of information contained in this publication, neither the IAEA nor its Member States assume any responsibility for consequences which may arise from its use."*

Still, official sources make references to the very same catalogue, which makes the content and use of the above disclaimer somewhat confusing. Another piece of information that IAEA – at least as evidenced by an article by Omar Yusuf, head of its Technical Cooperation Division, published in February 2021 – officially calculates with 70 SMR projects ongoing in 18 countries around the world. This is the number of projects currently under major development or in the preparation phase.

The number of actually existing projects is difficult to determine precisely. One of the reasons for that is that the scope of this seemingly exhaustive list (complied two years ago) does not include the mini or micro nuclear power plants under development for the US military, which have been under construction for years now but no information were published on them until recently. In 2022 April, Powermag, relying on information from the US Department of Defense, reported that the testing of a promising mobile microreactor prototype (Project Pele) was about to commence. In addition to the gas-cooled nuclear technology (tailored to the needs of the US Army and promised to be scalable from 1 to 5 MW), there is another ongoing 50-MW project by BWXT Advanced Technologies, along with yet another plan, promising a mobile nuclear power plant, scalable from 7 to 80 MW, developed by X-energy. As Powermag claims, these are likely to offer solutions ready for mass production in 2027-2028. Another reason is that most of the technical literature which gives these figures does not indicate the exact source. Although the Canadian SMR-Roadmap (which makes reference to more than 150 SMR plans) could, in theory, be included in the list, the portal does not provide the source of these data. The website states that "Canada has one of the world's most promising domestic markets for SMRs" and that "conservative estimates place the potential value for SMRs in Canada at $5.3B between 2025 and 2040", and that the global value will reach USD 150 billion, which "represents a large potential export market for Canada". Yet the credibility of these estimates is undermined by the fact that the roadmap website was set up after a major all-Canadian nuclear industry meeting in 2017, and still says that the a final roadmap will be compiled by 2018 - which has never happened.

The website of the World Nuclear Association contains a document which, in terms of scale is similar to the 350-page unofficial catalogue of the IAEA. The document, updated in May 2022, contains 17 chapters and around 250,000 characters, and takes minutes to scroll down to the end. However, it also includes an explanatory part, which says that while some of the items described are "fascinating and exciting", it is worth bearing in mind Hyman Rickover's words on the difference between a demonstration reactor unit or test reactor unit and a nuclear power plant built for energy generation. Admiral Rickover, a US pioneer in nuclear submarine development and the "father of nuclear navy", commented on the differences between the two reactor types as follows in 1953 (when the first test reactors in the USA were constructed):

- "An academic reactor or reactor plant almost always has the following basic characteristics: (1) It is simple. (2) It is small. (3) It is cheap. (4) It is light. (5) It can be built very quickly. (6) It is very flexible in purpose. (7) Very little development will be required. It will use off-the-shelf components. (8) The reactor is in the study phase. It is not being built now.
- On the other hand a practical reactor can be distinguished by the following characteristics: (1) It is being built now. (2) It is behind schedule. (3) It requires an immense amount of development on apparently trivial items. (4) It is very expensive. (5) It takes a long time to build because of its engineering development problems. (6) It is large. (7) It is heavy. (8) It is complicated."

The final conclusion is that there may be a large number of pilot projects, and even demonstration SMRs may be built, but their completion, success and transformation into a productive technology is another issue. This February, French President Emmanuel Macron promised that EdF-developed French SMRs will start to gain ground after 2030 (or rather, after 2035). In the UK, Boris Johnson hopes that Rolls Royce would come up with the same results in the next decade. At COP26, US company NuScale announced that it had concluded a contract with Romanian nuclear operator NuclearElectrica for Europe's first modular nuclear reactor. IAEA has even discussed with industry stakeholders the communication methods it deems to be useful concerning the proposals on and integration of SMRs into industrial parks and the manufacturing/service sector and the best possible ways to involve stakeholder companies in such costs and projects. But all this should not be taken for granted.

Not only because these deadlines mark only the first truly tangible phase of the hoped-for global SMR conquest of the nuclear industry, but also because SMR technology is not even close to implementation.

Why is it not a solution?

In March 2021, a dossier of analytical and explanatory articles entitled "The False Energy 'Solutions' America Doesn't Need" was opened by The Environmental Working Group (EWG), a 30 million-member group of scientists, policy experts, lawyers, communications and data specialists, probably the world's largest not-for-profit environmental organisation. One item in the dossier is about SMRs. It discusses why it is unrealistic to assume and pledge that SMR, this new favourite of the nuclear industry is capable of solving the global climate crisis and radically reducing carbon emissions, even if these are the very reasons cited by the US Department of Energy to justify the support given to SMR development.

As the article says, the answer requires a focus on two factors: time and cost. On this basis, small nuclear power plants fall into two broad categories: (1) light-water reactors based on principles similar to those of current nuclear technologies (which, in theory, can be licensed with less complexity), and (2) systems which are based on other principles and use a range of different fuel designs (such as those using molten materials flowing through the core or using coolants such as helium or liquid sodium). However, as the authors say, the prospects are poor for both groups of projects: factors like economics, mass manufacturing, manufacturing costs and the time needed show that this promise of the nuclear industry is unlikely to be ever fulfilled.

The EWG article states that nuclear reactors are large because of economies of scale and this is a principle that the Americans unsuccessfully tried disprove in the 1960s. The reason for the early shutdown of small reactors was that the smaller size had turned out to generate higher construction and operating unit costs. The problem with mass production (expected by the proponents of the technology to make SMRs cheaper and faster to build) is that:

- given that throughout the history of nuclear power plant construction the capital cost per kilowatt has never decreased, it is difficult to believe that it would happen in this case, where the capacity of a conventional nuclear power plant could be achieved by constructing 4-6 or even 12 modules side by side;
- it is hard to believe that the technology is capable of solving the chicken-and-egg problem, where economies of scale and lower product prices require manufacturing plants; however, costs can only be reduced if there are orders, which, is unlikely to happen while prices are high. Consequently, it is doubtful whether it is possible to encourage investments necessary for setting up the supply chain.

Additionally, there is another problem: mass production inevitably (and practically always) leads to production problems or faulty batches. And while product recalls (or repairs or replacements) were possible in cases such as the problems detected relatively late for Toyota airbags or the Boeing 737 Max jetliners (even if at considerable extra cost and loss), such a solution is impossible for a nuclear reactor unit isolated from the external world. If a component of a mass-produced reactor unit malfunctions or gives rise to safety problems, the production of the entire series will have to be stopped and the defective component recalled. It is possible to implement recalls for products ranging from smartphones to jet aircraft. But how would it be possible for an SMR completely isolated from the external world? This is the question posed by the authors, who also call attention to the fact that "these questions haven't been addressed by the nuclear industry or energy policy makers".

As for the timeframe, EGW recalled that, according to the forecast issued by the US Department of Energy (DOE) in 2001, nearly 10 SMR designs "could be made available for deployment before the end of the decade". Albeit - along business and industry investors - the US government has long been actively supporting SMR projects (it has already allocated USD 314 million to the SMR projects of NuScale; DOE also granted an amount over USD 100 million to Babcock & Wilcox for its mPower, which was simply halted in 2017), in 2022 the only promise they can make is that the first SMR openings may take place in 2029-2030. In fact, analysts write, this idea of DOE seems idealistic, given that reliability problems to be solved keep occurring. This means that reaching the 2050 target of reducing carbon pollution to zero cannot be based on SMRs.

The Institute for Energy Economics and Financial Analysis IEEFA IEEFA), having analysed the chances of NuScale (which is probably the most widely reported project in the media in relation to the SMR vision), came to the same conclusion in February. IEEFA analysts identified four risk factors:

- rising construction costs (albeit NuScale claims to be able to build SMRs at less than USD 3000 per kW, the official estimate exceeds USD 6800 per unit);
- a longer construction period (in 2018, NuScale expected the reactor unit to be switched on in 2026; now, even according to optimistic estimations, the completion date is 2029);
- the unattainable capacity factor (c.f. NuScale calculates with a factor of 95% for the entire 60-year lifetime, while none of the 93 nuclear reactor units currently operating in the USA have ever been able even to approximate it, given that even the best ones achieved a capacity rate of only slightly above 85% and only in the first decade of operation);
- higher costs for project investors (project investors have to pay all costs and expenses that arise from the final costs of the future project above the price of USD 58/MWh. This liability arises even if the SMR is never built, or is damaged, shut down or destroyed).

This is what was summed up by analysts as "too late, too expensive, too risky and too uncertain."

PowerPoint reactors

We invited Mycle Schneider to provide an opinion on the nuclear industry's SMR promises and the actual achievements and potential. Schneider, researcher, editor and the author of the World Nuclear Industry Status Report WNISR, a top-ranking independent annals of the nuclear industry, reacted as follows :
What do you think about the SMR promises?

"SMR promoters have pointed to two key characteristics of their ideas: SMRs would be much smaller, thus require less capital and fit better with small power grids, they would be easy to build and thus much faster to implement. Those basic ideas have been around for decades. So far, only Russia and China have connected prototypes to the grid.

"The construction of Russia's Akademik Lomonosov twin "floating" 30-MW reactors was planned to take 3.7 years. In reality, it took 12.7 years—3.5 times as long—to connect the units to the grid. So, obviously, the final costs sky-rocketed as well, since much of total nuclear costs are due to financing. Worse, in 2020, the first full year of production, the units only had respectively 29% and 19% load factors, the portion they delivered in reality compared to their nominal capacity. In China, two 100 MW modules were scheduled to start up in 2017, one was connected to the grid late 2021. Thus, it took twice as long as planned with the obvious financial implications. In the western world, only one general design has been approved in one country, NuScale in the US. Since approval, the targeted module size has been increased by 25% from 60 MW to 75 MW, significant safety issues have appeared, and cost estimates sky-rocketed.

"SMRs don't exist. They are PowerPoint reactors. There is no credible scenario by any of the major developers to start up a prototype before the end of the decade. It would take at least another decade to fabricate a noteworthy series of reactors. It would take 20 NuScale modules to generate the equivalent power of one EPR unit. The main reason for reactors to have become bigger and bigger over time is the economy of scale, which is lost with the SMR. It is like starting nuclear history all over.

"The EPR was an evolutionary design developed on the basis of existing French and German designs. Most of the SMR designs involve new conceptual ideas. It took over three decades to go from the EPR design idea to an operating first unit (OL3 in Finland). It would take decades to get from the SMR theoretical designs to an operating system of module manufacturing.

"If we are talking climate change, time is of the essence. New nuclear plants—especially entirely new designs—are uncertain, expensive and slow. Investing in options other than the cheapest and fastest ones available now, makes the climate crisis worse."

Bill Gates ...

The second part of "Nuclear power plants under construction", a study published by Energiaklub in 2021, dedicated a full chapter to the TerraPower project, referred to as "Bill Gates' nuclear power plant" in the Hungarian press. The promise was that a sodium-cooled reactor unit would be developed and constructed by 2030 in an attempt to show the world the future trajectory of the nuclear industry. The topic was also discussed in the Hungarian press in 2021, when at the Nuclear Energy Institute (NEI) meeting in June Bill Gates reiterated that "that nuclear power must play a role in getting the world to net zero", and then the American and British press came to know that Gates and Warren Buffet joined forces in the field of business, and selected Wyoming as the site of the first demonstrative power plant construction. Since the sensationalist news there has been a lot of silence: Bill Gates did not do more than giving a wave in January, when the site of the nuclear power plant replacing the coal mine was designated in the vicinity of Kemmerer, a city with a population of 2700. The “world-changing” idea underlying TerraPower was that the heat generated by nuclear fission is not used directly to move a turbine, but is stored in a tank of molten salt. In fact, this idea is nothing new. And although US Energy Secretary Jennifer Granholm, in a comment made at the NEI forum, encouraged Gates saying that the future will be shaped by nuclear power plants which are constructed faster, in simpler schemes and at lower costs, there remains a problem: that small nuclear power plants are best characterised by the fact that since the 1960s they have not been able to meet the basic requirements cited by Granholm.

In 2019, Michael Barnard founder and chief strategist of TFIE (The Future is Electric), a think tank on low-carbon technologies and their implications in the field of politics, explained in Cleantechnika the reasons why Bill Gates and TerraPower, based on a “revolutionary new nuclear technology” will not be able to achieve their goals. “Even if Terrapower succeeds in building a form of generation that can successfully and reliably deliver low-carbon electricity to the grid, the odds that it will be cheaper than the projected $20 per MWh by 2030 of renewables are incredibly low”, says Barnadr, adding that while Gates claims his “invention” to be revolutionary, the approach that puts nuclear power in the centre of the energy mix and presumes that renewables may not be sufficient to replace nuclear power had become an outdated notion by the late 2010s. “Renewables are the core part of the toolkit. Nuclear isn’t up to the job. Bill Gates is listening to the wrong people”, he adds.

In fact, the sodium cooling technology was also thought to be promising by the military industry once: the US Navy performed live tests with the technology in the 1950s, having installed a mini nuclear power plant developed in GE's nuclear lab in nuclear submarine USS Seawolf (SSN-575). However, the system failed in tests, mainly as a result of problems with control and full load, and, therefore, the saline technology was replaced by a conventional water-cooled reactor unit. (It is also worth mentioning that in April 1959 the Navy dumped the reactor vessel and reactor plant components of the USS Seawolf into the Atlantic Ocean, not more than 150 kilometres off the Maryland coast. In 1980, the Navy made an unsuccessful attempt to recover and neutralise the package “buried away” at a depth of 3000 metres. This means that now we can only hope that the radioactive material in the container will decay before the container is corroded.)

In fact, due to its capacity (345 MW), Bill Gates’s TerraPower does not really fit in the SMR category. And it creates other problems as well. In May 2021, The Bulletin published a long article by Professor Frank N. von Hippel which is worth consideration: von Hippel has been studying issues of fissile material policy for more than 30 years. In his view, Bill Gates’ plan is not only expensive, but also involves a huge security risk, because the technology produces plutonium desired by the military industry. There is no doubt about von Hippel's credibility, given that he spent his whole life working with such plutonium-breeder reactors. In his opinion, it is no coincidence that, besides the United States, Germany, the United Kingdom, France and Japan also abandoned their breeder-reactor efforts after spending more than USD 10 billion on related research and development.

As for the projects revived in the US during the Trump presidency, goes on von Hippel, it is not only the Gates-promoted TerraPower that poses problems, but the Versatile Test Reactor (VTR) as well, planned to be constructed in Idaho and expected to generate 300 MW of electricity. Currently, the expected expenses of the latter is USD 5.6 billion, which will most certainly increase if the reactor is not finished in 2026. More worryingly, von Hippel adds, alongside GE-Hitachi Nuclear Energy, in January 2020 Bill Gates’ Terrapower joined VTR, which would be able to produce than 300 kilograms of plutonium a year. The primary purpose of the Russian and Chinese sodium-cooled breeder reactors (or also called fast neutron reactors) already in operation is not power generation, and this is why the proliferation of such projects poses immense dangers.

...and scientists

Long before the media started to pay attention to SMRs, Science & Development (SciDev.net, which typically looks at the world from the perspectives of Latin America, Africa and Asia beyond China, rather than from the perspective of Europe, China or the Unites States) published an article on the potential impact of small modular reactors on climate change. In August 2021, the Indian author opined that, due to climate protection considerations and the general obligation to reduce carbon emissions, there are far fewer obstacles to the evolution of SMRs into a technology suitable for mass production than before, but confidence in nuclear power was shaken by the Fukushima disaster, by the fear of nuclear weapons and by problems with nuclear waste management. Nanda Kumar Janardhanan, professor of energy studies at Jawaharlal Nehru University in New Delhi, adds that just as hydrogen could be the fuel for the next era of transport and industry, so could SMRs offer a solution for countries that intend to switch to clean energy and to generate heat and power in a concentrated manner. He also believes that there will be a crossover between the two areas: if the demand for hydrogen increases, SMR technology can supply energy for hydrogen production.

At this point, so as to avoid any misunderstanding, it must be noted that India is a world power in the field of nuclear power plants. Currently, it has 22 operating nuclear units, most of them of the CANDU type (which number would almost double by 2030 as per official information). Six of the 21 new units are already under construction. The latter category includes, among others, the Prototype Fast Breeder Reactor (PFBR) at Kalpakkam, of a 500-MW capacity, which, albeit significantly behind the original schedule, is expected to be commissioned in October 2022. In the event of success, the responsible ministry (DAE) can commission the construction of up to 10 more PFBRs India by the end of the decade. Continent-sized India sees thorium, which can be made available in large quantities, as a key to the future development of the nuclear industry. One of the webinars offered on the 2021 India Energy Forum was dedicated specifically to SMRs. At the webinar, Sunil Ganju, member of the government's Nuclear Control and Planning Wing, pointed out that PFBRs can be classified as small reactors.

As per other schemes of categorisation, the project (similarly to Russia's Bilibino Nuclear Power Plant and China's Shidao Bay, equipped with a similar technology) has a primary aim that is military in nature rather than energy-related, and is intended more for plutonium production. However, this is not the only reason why the optimistic vision of PFBRs (also called "Indian SMRs") is not shared unanimously. For instance, MV Ramana, physicist at Princeton University's Nuclear Futures Laboratory, highlights that "humanity does not have the time to invest in small modular reactors" because the climate problems are too urgent to allow for waiting another 10-15 years for a solution. Ramana, an expert at nuclear power focusing on the context of climate change and nuclear disarmament, believes that "there is no realistic prospect that small modular reactors can make a significant dent in the need to transition rapidly to a carbon-free electricity system". In the summer of 2021, in the *Bulletin of the Atomic Scientist* he argues that while the nuclear industry promises that the development of SMR technology and the production of units in ever larger batches will reduce the cost per unit, this rule has never applied to the nuclear industry, and, in fact, the opposite effect is observed: the later a nuclear power plant was built, the more expensive it was. Ramana believes that since SMR is a new promise based on a very complex technology, new information will keep emerging and will typically result in extra costs.

With regard to cheaper operation, it is to be mentioned that in spite of the promising-looking concepts presented by the Russians in 2016, such ideas have failed to materialise so far, and Russia's war against Ukraine means that Russian industry and technology will probably be neglected and sanctioned globally for a long time. This will be especially true, he adds, given that small and medium reactor projects are designed to include clusters of several small reactor modules, which, on the one hand, is an obstacle to the universal spread of the technology, and, on the other hand, the more plutonium and/or enriched uranium sources are concentrated in a given area, the more they may contribute to the production of nuclear weapons. As Ramana says, whoever has access to these materials is much closer to creating a nuclear weapon. Yet another problem is that even small nuclear power plants produce nuclear waste, the disposal and safe management of which remains a challenge for mankind.

In conclusion, as Charles Mandel, a climate change reporter for the Canadian Observer for more than 25 years puts it, "for the time being, any vision of SMRs is largely aspirational".