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The Future of Nuclear: Small Size, Big Impact

The Importance of Nuclear Microreactors in the Context of the Climate Transition

Techno-Sustainability Series – 3

Abstract:

As stakeholders all over the world explore new tools to fight climate change, a new and disruptive technology has begun to receive more and more interest from governments and the private sector alike: nuclear microreactors (NMRs). While all of us know about the history and uses of nuclear power as well as the controversies surrounding it, few have familiarised themselves with NMRs and their potential to help bring climate goals to fruition. This paper aims to describe possible applications of this carbon-free energy source in the context of the EU Green Deal, describing the potential of its characteristics, and how it can contribute to the transition to a sustainable future.

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Executive Summary

The EU's plan to move towards achieving net-zero levels of emissions in the next 30 years needs bold economic and industrial policies, which were put forward in the Commission's 'Fit for 55' package (FF55). The FF55 is ambitious and necessary, but it comes with costly trade-offs and many checkpoints down the road towards 'greening' our future. Whereas the 'green' agenda only offers a single path, trust in the role of technology and innovation is needed for Europe to be open to new and perhaps unforeseen ways forward for economic and human development. Instead of a narrow, unbending, and dogmatic approach, it is time for us to recognise the many roads to a net-zero future.

Seeking a sustainable future without a strategy for engaging cutting-edge technologies would be a risk, both to investments and Europe's strategic autonomy. Meanwhile, EU Member States' joint effort to bring together technologies, knowledge, and resources to achieve a techno-sustainable future will contribute to a better tomorrow. It will enable us to take advantage of the fourth industrial revolution with its technological advancements and translate them into a concrete sustainability project providing technological and market-based solutions to environmental problems.

The ELF's Techno-Sustainability Series is built on the assumption that technology is our ally in tackling climatic and environmental challenges. Existing applications of AI and quantum computing, new generations of networks, and IoT can already help in preventing energy poverty, enhancing energy efficiency in housing, and providing data and information to help achieve better living standards. Moreover, the techno-sustainability connubium will also contribute to creating new business opportunities that could boost the EU's economy. New and existing technologies are the pivotal point around which to construct the whole discussion about sustainability in Europe.

The inclusion of nuclear energy in the EU taxonomy has to do with the fact that nuclear fission-produced energy is de facto the only zero-carbon electricity available on a large scale across the EU. It represents a valuable resource for a new energy mix and complements intermittent renewable sources during the transition. While all of us know about the history and usage of nuclear power, as well as the controversies surrounding it, only a few have familiarised themselves with nuclear microreactors (NMRs) and their potential to help bring climate goals to fruition. The possible applications of this carbon-free energy source in the context of the EU Green Deal can contribute to the transition to a sustainable future.

NMRs can contribute to reducing carbon footprints and diversifying the energy mix for electricity and heat. Using NMRs would benefit the transition not only because they represent a carbon-free energy source to generate heat and electricity, but also because the energy produced can be used to create hydrogen and purify or desalinise water. Moreover, it is a way to compensate for the fluctuations in the production of renewable energy. Because of its small environmental impact and high efficiency, this technology could represent a solution within the EU sustainability agenda to help bridge the transition from fossil fuel-produced energy to clean energy.

Recommendations

- It will be essential in the next decade to foster R&D projects for the design, production, and certification of NMRs within the EU.
- European institutions should help overcome any regulatory hurdles and fuel availability concerns.
- NMRs must be promoted as a carbon-free energy source with different benefits, such as creating hydrogen, purifying or desalinating water, and helping compensate for the fluctuations and variability of energy supply from renewable sources.
- Promoting investments in NMRs could act as a catalyst for the long-term transition to a sustainable industry in Europe and beyond.

The EU has the opportunity to foster the development of a flourishing market based on a different paradigm: the one complementing environmental governance with advanced technological and market-based solutions. This will enable Europe to secure its place not only as a global frontrunner with regard to 'carbon targets' and 'emission crops' but also as a provider of best practices in terms of growth, circularity, and sustainability for our future. Climate goals should be eco-pragmatic and follow a realistic approach towards making our future more sustainable and more prosperous. Instead of a Green Utopia, our climate goals need to be based on a realistic vision for a techno-sustainable future. .

A technology rediscovered

Nuclear microreactors (NMRs) are simple and compact nuclear reactors that can produce up to 20 MW of clean, reliable energy, even to remote or isolated areas (Department of Energy, 2021). The energy output, even though significantly smaller than that of conventional reactors, is sufficient to power small communities of approximately 20,000 households.

They are 100 times smaller than conventional nuclear reactors, which generate around 1000 MW, and ten times smaller than small modular reactors (SMRs), which generate 50–300 MW (Zohuri, 2020). The small size is essentially their defining feature – that enables the reactors to be factory-built and deployed by train, railcar, or shipping vessel to various sites where large reactors cannot operate (Zohuri, 2020), and they can be active for up to ten years without refuelling.[1]

A big incentive for their use is that they do not emit carbon and so support a country's decarbonisation goals. Nuclear power, in general, is a low carbon contributor and in the context of the European Green Deal it can be defined as a clean energy source since it does not emit greenhouse gases or other pollutants. As such, the reliance on nuclear energy should increase as a means to achieve climate goals, especially after nuclear's inclusion in the EU green taxonomy after months of political negotiations. NMRs come into play to facilitate renewable penetration and provide a low-carbon alternative to markets transitioning from fossil fuels to energy sources with low carbon emissions.

> NMRs can produce energy continuously and can function in any circumstances, whereas wind and solar are intermittent sources, and hydro-power is affected by seasonal changes and draughts.

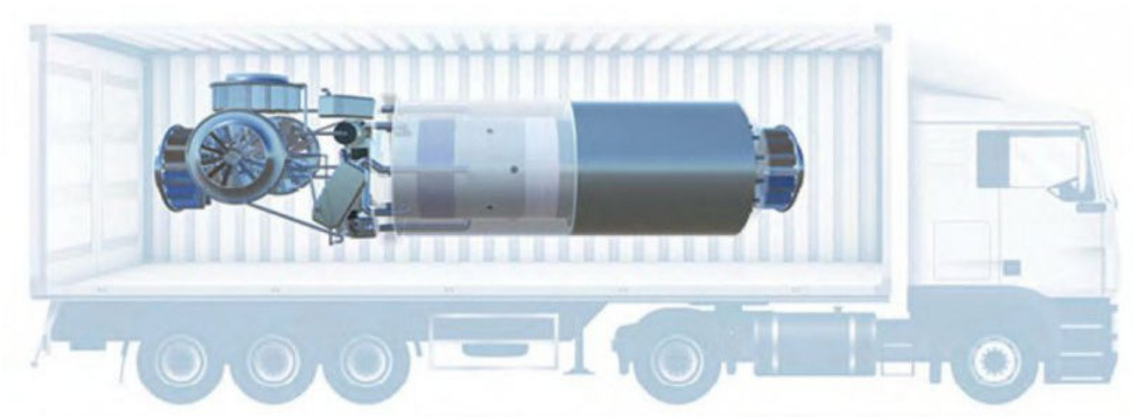
Nuclear is in the same bracket as other renewable energy sources – wind, solar, and hydroelectricity – in terms of carbon footprint (Shropshire et al., 2021). However, compared to renewables, the increased benefits of NMRs are clear: NMRs can produce energy continuously and can function in any circumstances, whereas wind and solar are intermittent sources, and hydropower is affected by seasonal changes and draughts.

Other important characteristics marking NMRs as a valuable replacement for traditional energy sources are transportability, self-

[1] This is because the NMRs use fuel enriched up to 20 per cent.

adjustment, 24/7 operability, and being factory fabricated. Being small, they can be easily transported via truck, shipping vessel, or train from site to site, and be rapidly deployed and readily available for use in areas hit by natural disasters or in locations that need urgent energy restoration (Department of Energy, 2021). Once deployed, the microreactors can be connected to the local electric grid and heat network.

Figure 1: Microreactors are designed to fit inside a truck.



Source: https://www.energy.gov/ne/articles/big-potential-nuclear-microreactors.

In addition, microreactors are fabricated in factories; all components can be assembled in a plant, then the entire reactor can be shipped to the operating site. This contrasts with conventional nuclear plants, which require onsite installation and are much less integrated. Full assembly in a factory will allow the reactor to be engineered in a suitable environment with quality control procedures in place, considering a sustainable cycle for the materials used (Department of Energy, 2021).

Moreover, NMRs are 'self-adjusting'. It follows that a smaller staff would be needed to care for the reactor (it's estimated that it will require ten people to operate a reactor) and that passive safety systems will be used to avoid potential overheating or reactor meltdown (US GAO, 2020).

NMRs offer an increased array of benefits, that do not exist in other sources of energy (US GAO, 2020):

- Provide electricity and heat: NMRs can offer heat for industrial applications such as oil refining and chemical processes or for households; the electricity generated can also be used to desalinate water and generate hydrogen.
- High resilience and reliability: NMRs can operate 24/7 for up to ten years without refuelling and can withstand natural disasters as well as man-made physical or cybersecurity threats (Nuclear Energy Institute, 2018).
- Clean and environmentally friendly: NMRs have the lowest carbon footprint of all energy sources, roughly on the same level as hydroelectric and wind power.

- Flexible and on-demand operations: NMRs can produce power on-demand and vary their output to adjust to changes in demand.
- Simple and safe: NMRs are easier to operate thanks to their small size, and they possess increased safety and security features.
- The use of NMRs is especially suitable in contexts such as isolated communities, remote mining operations, military structures, regional utilities, or disaster relief.

Process and design

A nuclear fission reaction in a much smaller package

NMRs mostly function like conventional reactors: they rely on a nuclear reaction to create heat, which, in turn, generates steam. This mechanical energy is converted, through turbine generators, into electric energy.

Like all nuclear reactors, NMRs use nuclear fission, wherein atoms are split and energy is released. The reactor's coolant captures and controls the heat created during the fission and transfers it to electrical generators (Nuclear Energy Institute, 2018).

The nuclear fission process occurs as in a regular nuclear plant, but in a much smaller package. To do that safely and sustainably, certain innovations are needed, such as improved cooling and heat transfer processes as well different approaches to the management of the nuclear reaction (Nuclear Energy Institute, 2018).

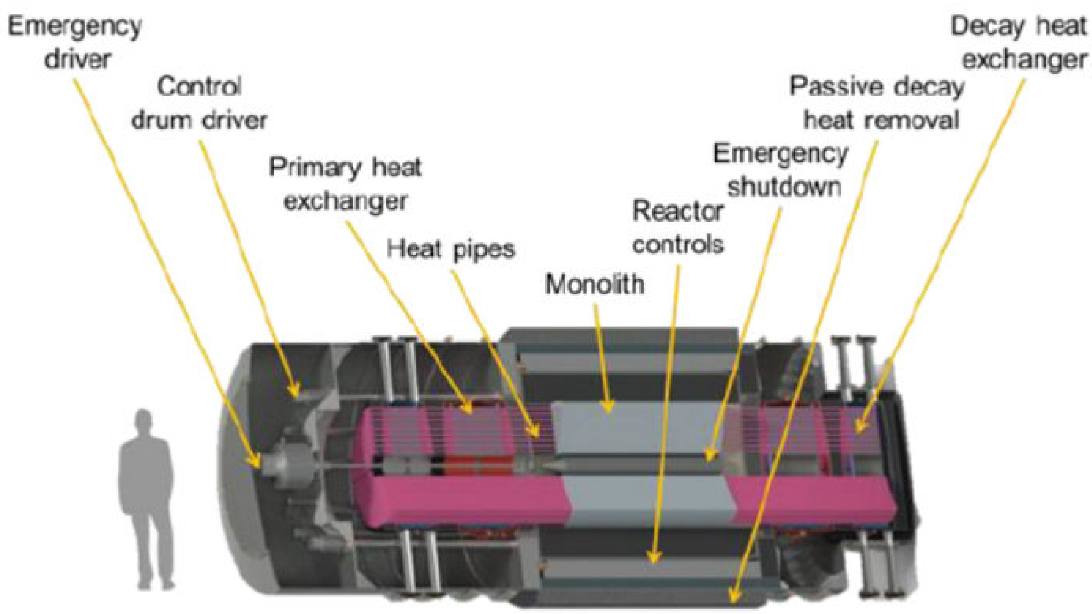
Dissimilar designs, same capabilities:

First of all, there is no 'one size fits all' design for NMRs. As each use case entails different needs and requirements, having a single design to cater to all markets will likely be challenging. The concepts currently in development feature a variety of reactor technologies that are technically different. It is outside the scope of this paper to reflect on each individual design that is being conceptualised. Hence, this paper will only outline the most general and prominent technological features of NMRs.

Overall, all NMR designs are part of the Generation III (GEN-III)[2] type of reactors. As of this writing, there is no design that has proven to be more effective or efficient, but some concepts are more mature than others. Even though most designs draw inspiration from light-water reactors (which means they use water as both a coolant and neutron moderator), most NMRs do not use water as coolant, instead relying on more innovative cooling approaches (NUVIA, 2016).

The microreactors that are further along the development pipeline make use of a heat-pipe-cooled reactor (heat pipes would conduct the heat from the core to a heat exchanger) whereas designs that are yet to reach maturity employ molten salts or a high temperature gas as coolants.17 The core of the reactor would consist of a compact block monolith, that is surrounded by reflectors that contains control drums to control the core's reactivity (NUVIA, 2016).

Figure 2: The eVinci model of micro reactor.



Source: https://www.westinghousenuclear.com/Portals/0/new%20plants/evincitm/GTO-0001%20eVinci%20flysheet.pdf.

Certain concepts are designed to be adjusted to match the performance needs of different markets. For instance, microreactors that will integrate with renewables would have to be able to swiftly adapt to the variable energy production of renewables, whereas designs that will support heat process applications, will require a greater thermal output (Abou-Jaoude et al., 2021).

[2] Gen III designs encompass most traditional nuclear plants and concepts currently deployed. Gen II refers to the class of reactors built before the end of 1990s, while Gen I are the early reactors from the 1950s and 1960s. Gen IV reactors are the new generation that are currently being researched.

Moreover, some NMRs designs attempt to contain the whole balance of the plant in one container, which would reduce the need for onsite preparation and civil work. Other designs could have 'mobile' configurations; that would enable the NMRs to be easily de-installed, removed, and redeployed from one operating area to another with few to no decommissioning requirements (Abou-Jaoude et al., 2021).

> Obviously, since the microreactors have an exponentially lower footprint than conventional reactors or SMRs, the emergency zone needed around the microreactor is considerably lower: as little as a 25-metre radius and unlikely to exceed 250 m.

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Special type of fuel

As with every type of nuclear reactor, uranium is needed as fuel for the nuclear reaction. NMRs generally make use of uranium-235 (U-235) enriched up to 20 per cent, also called high-assay, low-enriched uranium (HALEU) (Nuclear Energy Institute, 2018). This contains 5–20 per cent U-235, the fissile isotope in nuclear fuel that produces energy during a fission chain reaction. Notably, HALEU is produced using recycled uranium from used fuel.

Besides HALEU, some reactors (especially those that will rely on gas coolants) would utilise tri-structural isotropic particle fuel, which, in addition to HALEU, contains a carbon and oxygen fuel kernel (Abou-Jaoude et al., 2021).

Applications

Given their unique characteristics and features, NMRs have the potential to solve energy problems in numerous markets that struggle with energy price premiums, high dependency on energy imports, limited domestic energy resources, acute climate sensitivity, or high risks of energy disruption (Shropshire et al., 2021). According to the Nuclear Energy Institute (2018), costs are estimated to be around US$0.14–0.41 per kWh of energy produced, with prices expected to go down to $0.09–0.33 per kWh following mass adoption of the reactors.

Moreover, as NMRs can operate for up to ten years without refuelling, they are suitable for providing clean and resilient energy to sites that are vulnerable to outages due to maintenance and failures, severe natural phenomena, or cyber and physical threats.

NMRs could be used for providing electricity and heat in a variety of cases, but so far, they are the most suitable target markets are the use cases shown in Table 1 (NUVIA, 2016: 17).

Table 1: Use cases for NMRs.

Remote and isolated communities	Remote and isolated communities, such as hubs in Alaska, Siberia, or the Arctic will benefit from the use of NMRs as most isolated communities are dependent on fuel deliveries that could be disturbed by adverse weather conditions. NMRs would provide energy security and reliability while also grounding the communities in the transition from fossil fuel to clean energy.
Military structures	For military and defence installations, energy security and resiliency is even more vital than for other use cases, as power black-outs could disrupt a country's national security activities and make it vulnerable to foreign incursions. NMRs can be deployed at critical defence sites, such as operational headquarters, naval dockyards, and major airbases. Receiving power from NMRs, defence installation would reduce reliability of vulnerable microgrids and enable defence structures to enhance their cyber and physical security, endurance, agility, and power availability. As a matter of fact, the first NMR (with 5Mwe output) is planned to be deployed at Eielson Air Base in Alaska.
Mining communities	NMRs are suitable for power mining communities, as the latter are energy intensive and often isolated from electric grids. Usually, mines are located in isolated areas where it is difficult and costly to provide conventional fuel and electricity, and where reliable electricity from the grid may be difficult to access.

Remote islands	Another use case for NMRs could be powering remote islands. They would empower communities on the islands through independent electricity grids that enhance their energy resilience and security. NMRs could be installed independently or be connected to the electricity grid. It's to be noted that a sole microreactor could only service an island with a population of less than 500,000 with an average demand of 500–750 MW, due to limited energy output capability.
Disaster relief	Due to their small size and transportability, NMRs would be available for quick deployment at sites affected by natural disasters such as hurricanes, typhoons, wildfires, earthquakes, and floods. They could be used to provide emergency power and help restore critical utilities in affected regions.
Desalination	As the demand for clean water increases, more and more desalination plants (that make sea water potable) are being deployed. NMRs can be used to power desalination plants.
Space and deep ocean exploration	Humanity is at the point of initiating a new wave of exploration into hostile territory, with more ventures into space and deep ocean regions emerging. NMRs can be used as a heat and electricity source for these missions, as they can easily secure energy reliability and continuous power. Their size allows them to be readily fitted inside a space shuttle or a submarine.
Data centres	Data centres are industrial installations that consume a lot of electricity and where uninterrupted power supply is critical. Providers require extreme reliability. NMRs, with their non-stop power generation, would guard against service failures that could negatively impact data providers' reputations or financial interests.

EU Green Deal and the EU taxonomy

The newfound interest in NMRs is based on a resurgence in the use of nuclear power. The Czech Republic and Poland are looking to nuclear power to tackle their energy issues and attain climate targets (Lynas, 2021), and France is one of the flagships states endorsing it.

The EU aims to lead the fight against climate change. It has introduced the EU Green Deal (what Commission President Ursula von der Leyen called Europe's 'man on the moon' moment)[3] – an ambitious package of policies aimed at achieving net zero greenhouse gases by 2050.[4]

For this, it needs to utilise all existing resources as well as new concepts or technologies. With this thought, and with the recent inclusion of nuclear in the EU taxonomy, a broad horizon of opportunities opens up for novel nuclear technologies.

The EU taxonomy is a classification system that lists the types of investments into energy that are sustainable and thus eligible for EU funding. Amid heated political debate, nuclear energy was included in the EU green taxonomy and that's a great news for NMR developers. The inclusion will allow more capital to be poured into R&D into new nuclear projects, such as investments in NMR and SMR concepts.

Including nuclear power in the EU green taxonomy means that energy produced in nuclear reactors can be used – from an investment perspective – as a non-carbon emitting technology to achieve climate neutrality, making them suitable for capital investment. This dynamic will increase reliance on nuclear energy in general, and will enable more R&D into microreactors, which in turn could lead to more production and more models being deployed throughout the EU.

Partnerships and projects to make microreactors a commercial reality

It is important to note that NMR technology is not new; it is only underutilised. The first NMRs came into use roughly 60–70 years ago, at the peak of the Cold War, when nuclear power first came into use. The USS Nautilus (Christley, 2012), the world's first nuclear-powered submarine, relied on a pressurised-water nuclear reactor, which has many commonalities with NMRs, while the Soviets developed microreactors for space missions (Scott Kemp, 2020: 1859).

The only currently operating microreactors are the four reactors at the Bilibino co-generation plant in Siberia. They have an output of 62 MWt, and produce heat and 11 Mwe net electricity each, but are not connected to a grid (World Nuclear Association, n.d.).

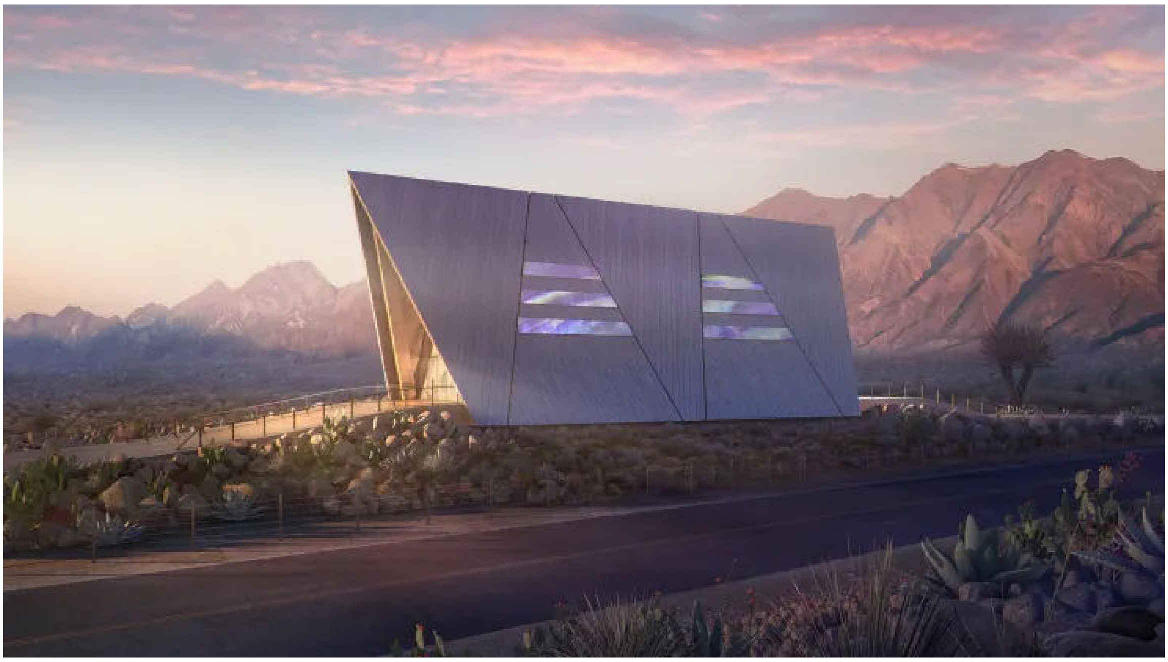
3 European Commission, 'Press Remarks by President von der Leyen on the Occasion of the Adoption of the European Green Deal Communication', https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_19_6749.

4 European Commission, 'A European Green Deal', https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

The resurgence of NMRs comes is a response to the market demand for smaller, simpler, and less costly nuclear production. The trend has already been started by SMRs – the 'big brother' of NMR (IAEA, 2020). There are more ongoing projects concerning the development of SMRs than of NMRs, and SMR concepts are more advanced. For instance, Rolls Royce is currently undertaking an ambitious project to build a 220–440 MW SMR plant in the UK.[5]

Leading the innovation race in NMRs are the United States, Canada, Japan, and Russia. While there are several projects in Europe as well, concepts developed in the UK, Czech Republic (Energy Well) (Ruscak et al., 2021), and Sweden (Lead Cold) (World Nuclear Association, n.d.) are not nearly as mature as non-European projects. The first US deployment of an NMR is expected to be in Alaska, at the Eielson air base, in around 2027 (Nuclear Energy Institute, 2019). This development is part of Project Pele, a US Department of Defense undertaking that would see a series of microreactors powering military bases throughout the country (World Nuclear News, 2021). The Canadian Nuclear Safety Commission has been collaborating with developers to pre-licence designs for ten reactors (World Nuclear Association, n.d.). The British Department for Business, Energy and Industrial Strategy has awarded grants to develop NMRs to Westinghouse, U-Battery, and Tokamak (World Nuclear Association, n.d.). In the United States, Oklo, General Atomics, and NuScale have already begun interacting with the Nuclear Regulatory Commission in order to license and receive approval for their designs. It's worth mentioning that Oklo will even use HALEU fuel supplied by the US Department of Energy (Shropshire et al., 2021).

Figure 3: The eVinci model of micro reactor.



Source: https://www.westinghousenuclear.com/Portals/0/new%20plants/evincitm/GTO-0001%20eVinci%20flysheet.pdf.

[5] https://www.rolls-royce.com/innovation/small-modular-reactors.aspx#.

Even though government bodies are closely cooperating with the companies developing the microreactors, there is a noticeable shift from government-led and -funded projects to those led by the private sector, through start-ups and people with strong entrepreneurial ambitions, that also link the creation and deployment of NMRs with powerful social purposes – reaching a country's decarbonisation goals and developing environment-friendly technology.

> We hope that after the successful deployment of the first microreactors prototypes, more countries will embrace this technology and drive up investment in NMR, which would facilitate the large-scale employment of microreactors by the 2030s.

Conclusion

All in all, NMRs have tremendous potential to reduce the EU's carbon footprint and to diversify its energy mix. It is important to note, however, that few changes will occur by 2030. The full potential of NMRs will be tapped into in the next decade, and before their successful deployment, billions of euros will have to be spent for design, production, and certification, and to clear regulatory hurdles and address fuel availability concerns. That should not disincentivise or discourage anyone to make use of them.

Using NMRs would benefit the energy transition not only because they provide carbon-free heat and electricity, but also because of additional uses such as creating hydrogen, purifying or desalinating water, and compensating for the fluctuation and variability of energy supply from renewable sources.

Because of its low environmental impact and high efficiency, this technology could represent a solution within the EU agenda for sustainability to help bridge the transition from fossil-fuel energy to clean energy. NMRs are highly practical, have great utility, and are environmentally friendly. Ultimately, it is up to governments to take the leap of faith and devote resources to this exciting technology that – even with all its shortfalls, could act as a catalyst for the long-term transition to a sustainable industry in Europe and beyond. ■

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About ELF

The European Liberal Forum (ELF) is the official political foundation of the European Liberal Party, the ALDE Party. Together with 47 member organisations, we work all over Europe to bring new ideas into the political debate, to provide a platform for discussion, and to empower citizens to make their voices heard. Our work is guided by liberal ideals and a belief in the principle of freedom. We stand for a future-oriented Europe that offers opportunities for every citizen. ELF is engaged on all political levels, from the local to the European. We bring together a diverse network of national foundations, think tanks and other experts. In this role, our forum serves as a space for an open and informed exchange of views between a wide range of different EU stakeholders.

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