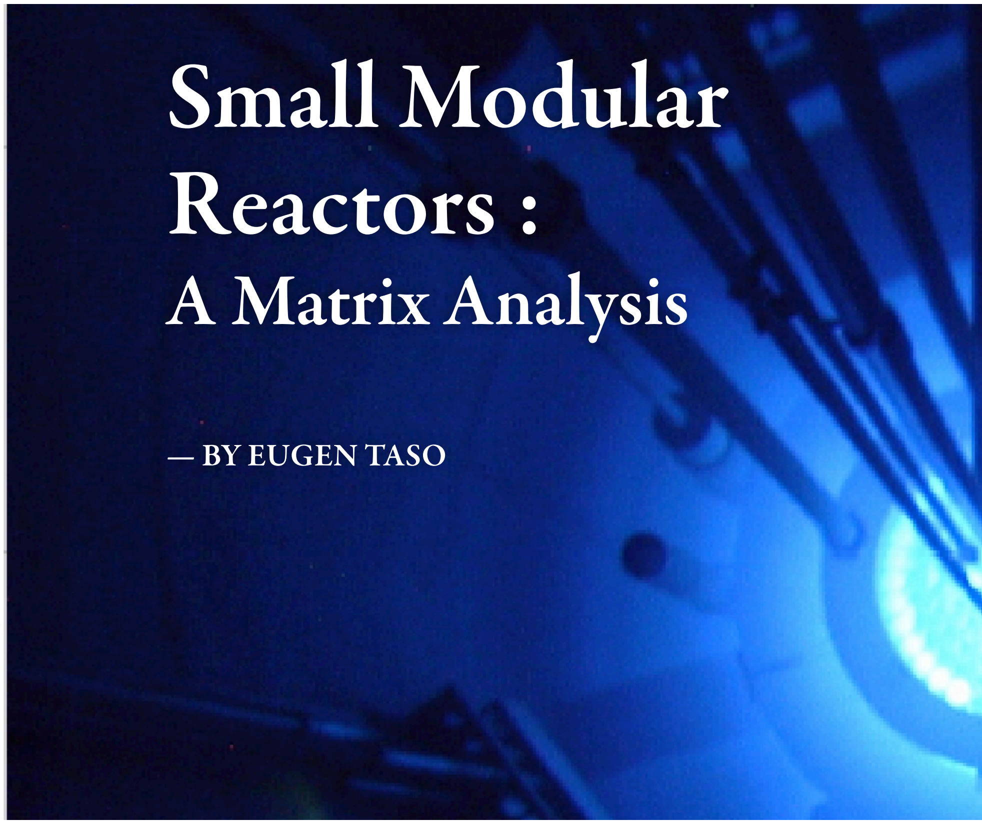


Small Modular Reactors : A Matrix Analysis

— BY EUGEN TASO

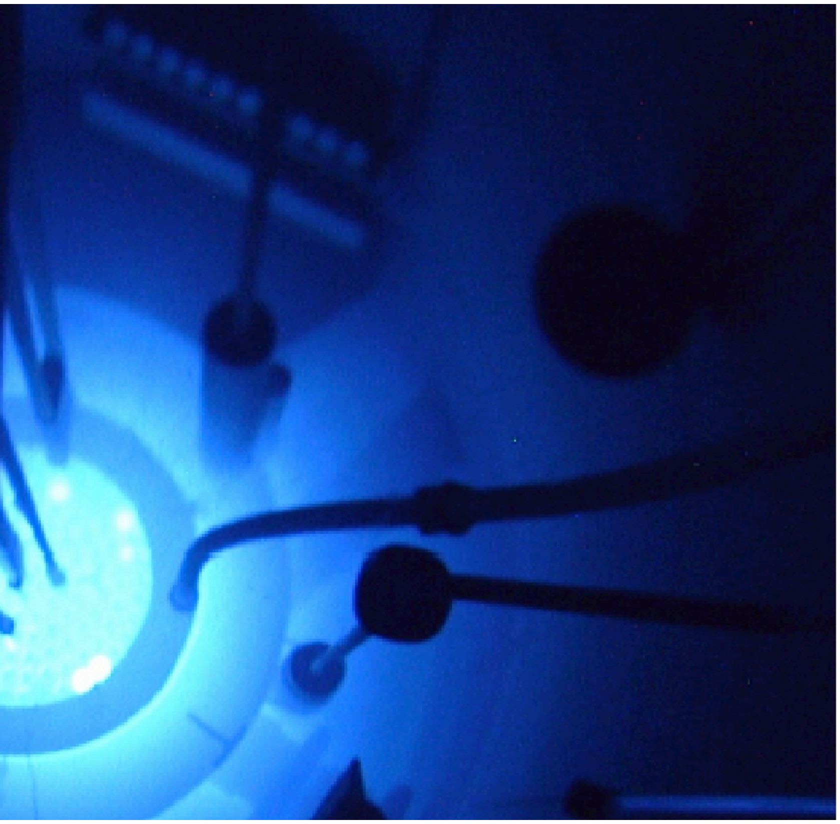
Civilian nuclear power has had a tumultuous history. Although it provides benefits, such as reduced carbon emissions, low operating costs, provision of reliable baseload electrical power, and a path to reducing energy dependence, it has experienced an uphill battle since the 1960s. There are multiple reasons for the opposition to nuclear power, and most of them are valid, albeit not always proven or supported by evidence. Many are concerned about issues like capital cost, safety, regulation, waste, subsidies, public perception, proliferation, and above all, economics. Furthermore, in the wake of the Fukushima nuclear accident following the devastating earthquake in Japan in March, 2011, policymakers, opponents and the public at large are intensifying their scrutiny of the already ailing industry. Despite its advantages of being a near zero-carbon energy source, operating on very high density fuel at typically over 90 percent capacity and having low operating costs, nuclear power is today not materializing its "renaissance," as was predicted at the beginning of the 21st century. However, a new technological approach is currently being promoted in the nuclear industry – small modular reactors (SMRs) – perceived as an innovation allowing the industry to rebound and expand beyond its current capacity, and to areas that were not possible before, a development that some argue could bring a "renaissance" of the industry.

In the master's thesis project which prompted setting up the attached SMR matrix and this article, large-reactor civilian nuclear power is analyzed in an effort to explore its costs and benefits.[2] The thesis presents the history of the technology and industry, the current situation worldwide, and the future outlook. It analyzes the benefits and complete costs of nuclear power in order to present the reader with a full picture of the issue and the dilemma policymakers have to face. Concerns like safety (significantly enhanced after the Fukushima accident), cost (including constructions, subsidies, and insurance, among others), waste disposal, public perception, proliferation are introduced and discussed. Benefits are also explored, such as low operating and fuel cost, baseload capacity, high capacity factor, zero emissions in operation, and others, in order to paint a full picture of this energy source. It is of course not a clear–cut situation. A cost-benefit analysis, performed with the help of an economic and financial model reveals that a utility considering fossil fuels, renewables or nuclear has a hard time deciding what to pick, given the uncertainties in the market.

deciding what to pick, given the uncertainties in the market. Concretely, despite its appeal, in the absence of subsidies and other influences in the market (like a carbon tax or higher fuel prices), nuclear is not an attractive option in its current form.

However, SMRs have the potential to be different. The paper introduces the concept, definition and promising models being discussed by industry and regulators currently. Their benefits, such as modularity, reduced initial capital cost, versatility for remote areas and applications, and simplified designs, and their costs, including overruns, safety and proliferation, as well as waste management are also discussed. The analysis is conducted based on an extensive literature review, the opinions of 22 experts in the nuclear industry, and economic modeling.

This leads to policy recommendations for large and small reactors. In the case of the large plants, the government should remain involved with the industry and provide assistance necessary to maintain the civilian nuclear power industry.



Cost information was specifically omitted. While some reactors do have cost estimates, most do not, and since none have yet been built, the information was deemed too speculative and therefore not included. In fact, cost is one of the major concerns that experts indicated when referring to SMRs. There is little indication on how much they will cost to build, deploy and maintain, and until there are a few operational models, this will remain a big unknown.

Existing plants should be maintained, while new projects should be carefully analyzed economically before being approved and subsidized by taxpayers. SMRs should receive little government assistance, and only when they are ready to be deployed, as a first-to-market incentive. R&D should remain in government hands, as well as researching a solution for waste and reprocessing.

The SMR matrix presents the most promising models that are currently being considered by private companies and that have expressed at least some interest with the NRC or other regulatory agencies. The matrix is a table summarizing primary and secondary research. It was compiled with information from manufacturer's websites, discussions with marketing officers, NRC representatives and industry affiliates. The table contains information on the company, its country of origin, reactor type and capacity, size, fuel type, refueling needs, lifetime and license application information. Notes are presented at the end, based on interviews and conversations with experts.

While SMRs are not likely game-changers, they can play a role in re-inventing the nuclear power industry without significant support from policymakers.

The conclusion of the project is that SMRs, although likely not game-changers per se, can play a complementary role in re-inventing the industry without significant support from policymakers. SMRs present a great opportunity for the industry to move forward into a new market. This matrix is meant as a tool for whoever is interested in SMRs and wishes to get a quick summary of the promising models that are being discussed, both at an industry and a policy-making level. Overall, nuclear power is a fiercely contended topic, but it is also an opportunity to bridge to the future until new, renewable ways of producing energy become viable. Therefore, if SMRs can be proven to make a positive contribution to the industry, it is likely that their adoption could be considered a priority and the most promising models, which have been developed privately and without major government subsidies, could compete in the market, changing the trend in the nuclear industry.

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Small Modular Reactor

Manufacturer	Country of Origin	Reactor Name	Reactor Type	Reactor Capacity (MWe)	Reactor Size (m, Diam, Height)	Coolant
NuScale Power, Inc.	USA	NuScale	MASLWR (iPWR)	45	4.3 x 18	Water (gravity)
Babcock & Wilcox Cmpany.	USA	B&W mPower	ALWR (iPWR)	125	4.5 x 23	Water
PBMR, Ltd/ESKOM	South Africa, China, Germany, Netherlands	Pebble Bed Modular Reactor	Fast Reactor (High Temperature, Gas-Cooled)	165	Graphite pebbles 60 mm diam	Pyrolytic graphite moderator, inert or semi-inert gas (helium, nitrogen or carbon dioxide)
Toshiba CRIEPI	Japan	Toshiba 4S	Fast Neutron	10 / 50	30m undergound, building 22×16×11	Sodium
GE Hitachi	USA/Japan	GE Hitachi PRISM	Fast Reactor	311	Underground Containment	Sodium
Hyperion Power Generation, Inc.	USA	Hyperion Power Module Reactor	Fast Reactor	25	1.5 x 2m	Lead-bismuth eutectic (LBE)
Atomenergoprom/OKBM	Russia	KTL-40s	PWR	70	21,500 tonnes Length: 144.4 meters, Beam: 30 meters, Height: 10 meters Draught: 5.6 meters	Water
General Atomics	USA	General Atomics EM2	Sodium-Cooled	285	Unavailable	Helium
Westinghouse	USA	Westinghouse SMR	iPWR	200	Unavailable	Water
Areva	France	ANTARES	Fast Reactor	285	Unavailable	Nitrogen/Helium mixture
INET & Huaneng	China	HTR-PM	High Temperature, Gas-cooled PBMR	100	Unavailable	Graphite
Bhaba Atomic Research Center	India	Unknown	AHWR	300	Unavailable	Boiling water coolant heavy water moderator
Invap/CNEA	Argentina	CAREM	iPWR	27	Unavailable	Water
KAERI	South Korea	SMART	Co-generation plant	100	Unavailable	Unavailable

Notes:

* Information obtained from manufaturer's website and other sources (WINS, etc). Information should be treated as preliminary until models are built

r Matrix (Promising Models)*

	Fuel Type	Refueling (#, Months)	Spent Fuel Storage	Service Life (Years)	NRC Application (Expected)	Notes
	4.95% Enriched Uranium	24	On-Site	40+	1st Quarter, 2012	NuScale has recently run into financing trouble, but its reactor is deemed by experts and the NRC to be a promising design that could be among the first to be certified
	5% Enriched Uranium	60	On-Site	60	4th Quarter, 2012	B&W are in advanced talks (non-binding agreement with TVA to build a reactor, and are in advanced licensing talks with the NRC
r r	UO_2 particles 1mm in diam	36	In pebbles	36	2013	PBMRs have had a long history and their history is uncertain. There have been instances when the fuel caught on fire. South Africa is not puruing it currently, but China is
	20% enriched Uranium or 11.5 – 24% MOX	Never	Not Applicable	30	2nd Quarter 2012	Partnership with city of Galena, AK for a reactor, and good candidate for the 2012 budget funding for SMRs if design is licensed
	Recycled fuel from Advanced Recycling Center (Pu or DU)	12 to 24	ARC on site - reuse spent fuel	40+	2012 or 2013	NRC staff conducted pre-application review in the early 1990s, resulting in NUREG-1368, "Pre-application Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISM) Liquid-Metal Reactor (January 1994)."
	20% enriched Uranium	Never	N/A	7 to 10	Unknown	Hyperion entered an agreement with Savannah River National Laboratory (SRNL) in fall 2010 to deployment the 25MWe modular reactor at the US Department of Energy's (DOE) Savannah River Site (SRS); details on timeline are unclear
	90% enriched Uranium-235	36	On Barge	12	Not Applicable	Based on the commercial KLT -40 marine propulsion plant, an advanced variant of RPs that power nuclear icebreakers. The first reactor was delivered in May and the second one in August 2009. Akademik Lomonosov was launched on 30 June 2010
	12% Uranium 253	Never	Not Applicable	30	Unknown	Unclear timeline, as design in in incipient phases
	4.95% Enriched Uranium	Unavailable	Unavailable	Unavailable	Unknown	Released on February 17, 2011, many details yet unavailable
	graphite speres, 10 - 19.9% enriched Uranium	Unavailable	Unavailable	Unavailable	Unknown	
	UO_2 particles	Unavailable	Unavailable	Unavailable	Not Applicable	Full-size demonstration module expectved in 2013. License application filed and under review
t,	233U-Pu-Th	Unavailable	On-Site	Unavailable	Not Applicable	Pre-licensing negotiations with the Atomic Energy Regulatory body of India. Construction expected in the next decade
	3.5% enriched PWR fuel	Unavailable	On-Site	Unavailable	Not Applicable	CAREM reactor is a test reactor for larger, 150-300MWe units to be built mainly for domestic market
	Unavailable	Unavailable	Unavailable	Unavailable	Not Applicable	Currently in pre-licensing process