



# Zap Energy's Integrated Approach to Fission and Fusion

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## 1.0: The Zap Energy Case for Combining Fission and Fusion in Brief

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Demand for electricity is on the rise. The [AI revolution in particular is triggering a surge in demand that is reshaping energy markets](#). Data center power usage is on track to grow more than [160% by 2030 compared to 2023 levels and Goldman Sachs forecasts that 85–90 gigawatts of new nuclear capacity](#) would be needed to meet all the data center power demand growth expected by that year. Against this backdrop of renewed and urgent demand for advanced nuclear energy, Zap Energy is pursuing a single integrated platform strategy anchored in two fundamental reactions — deuterium-tritium (D-T) fusion and uranium-235 fission — each releasing millions of times more energy per reaction than any chemical process, enabling radically smaller fuel volumes and waste streams per unit of power produced. Rather than advancing these as independent efforts, Zap is deliberately designing a shared engineering, supply chain, and deployment architecture in which progress in one directly accelerates the other. Fission, already commercial and expanding into new microreactor form factors up to 50 MWe, offers a near-term market entry point leveraging Zap's demonstrated expertise in liquid metal cooling. Fusion, while not yet commercial, advances rapidly through Zap's sheared-flow-stabilized (SFS) Z-pinch approach at uniquely low cost. Alkali metals — specifically sodium and lithium — are central to both tracks. This alignment is intentional. Zap's approach is to build common technical foundations—materials, liquid metal systems, high power density design, and neutron environments—once and apply them across both fission and fusion. As a result, engineering learning, vendor qualification, and operational experience compound across the platform rather than being duplicated. Sodium's high boiling point, exceptional thermal conductivity, and passive safety characteristics make it an excellent fission coolant, while lithium is irreplaceable in fusion as both coolant and tritium breeding medium. Critically, both product lines are being developed at similar physical scales (up to 50 MWe, ~3–4 m core dimensions), maximizing engineering cross-pollination and allowing hard-won manufacturing and operational lessons to compound in value across the portfolio. Looking further ahead, the high energy neutrons produced by D-T fusion open a path to fusion-fission hybridization, using Zap's fusion core to transmute minor actinides and address the growing inventory of spent nuclear fuel. The SFS Z-pinch geometry is particularly amenable to hybridization. The liquid-lithium blanket that already surrounds the fusion core for tritium breeding and heat extraction provides a natural medium in which to embed fission or transmutation targets, without requiring fundamental changes to the reactor architecture. Hybridization addresses this problem in ways that thermal reactors, fast reactors, and even accelerator-driven systems cannot fully match, positioning Zap at the frontier of both near-term clean power delivery and long-term nuclear fuel cycle closure.

## 2.0: Energetic Nuclear Reactions for Power Production

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Two fundamental nuclear reactions underpin Zap Energy's dual-track strategy: [deuterium-tritium \(D-T\) fusion](#) and [uranium-235 fission](#). Both release millions of times more energy per reaction than chemical processes, are carbon-free, and enable radically smaller fuel and waste volumes per unit of energy. The key physical distinction between them shapes the engineering of each. In fission, a neutron strikes a U-235 nucleus, splitting it and releasing additional neutrons that can sustain a chain reaction in properly arranged fuel. The engineering challenge is controlling that chain reaction and removing heat, including the decay heat that persists after shutdown. In D-T fusion, deuterium and tritium nuclei collide at extreme temperatures to produce helium and a 14.1 MeV neutron. There is no chain reaction, and the plasma must be continuously heated and confined. The engineering challenge is creating and



sustaining this extreme state. Zap Energy's mission since its founding in 2017 has been to realize the promise of nuclear energy for commercial power production, beginning with fusion and now expanding to include fission.

Why pursue both fission and fusion? Both have advantages and disadvantages. Fission is commercial today and the market is expanding into new unit sizes and ever safer technologies. Zap is well positioned to enter segments of the expanding fission market with systems that leverage our demonstrated experience in liquid metal cooling. However, fission produces a waste stream of radioactive used fuel. Alternatively, fusion is not yet commercial. Zap Energy's [sheared-flow-stabilized \(SFS\) Z-pinch approach to fusion energy](#) is advancing rapidly and at radically lower cost than other approaches but requires further progress in terms of raw fusion gain. The current world record for controlled fusion gain is held by the [NIF with 8.6 MJ of fusion energy and a target gain of >4](#). It took [~330 MJ of electrical energy](#) to power the lasers that heated and compressed the NIF fusion target, much more than the fusion energy produced. To put those numbers in perspective, [burning a gallon of gasoline generates ~127 MJ](#). While no fusion system is ready to generate electricity, the promise of nuclear energy without long-lived nuclear waste using abundant fuel at near negligible cost continues to make fusion highly attractive. Fusion is also fundamentally safer than the already extremely safe modern fission technologies. Zap Energy's strategy is not to pursue fission and fusion as parallel efforts, but to sequence their deployment within a shared platform. Fission provides a near-term, commercially deployable foundation—establishing supply chain, operational experience, and customer adoption—while fusion builds on that same technical and industrial base over time.

### 3.0: Alkali Metal Cooling Enabling Fission and Fusion

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When considering power systems based on harnessing nuclear energy, the choice of the reaction and the coolant dominate the rest of the design. Lithium and sodium are the first two alkali metals, on the left side of the periodic table under hydrogen and have special significance in the context of fusion and fission. Lithium has an irreplaceable role in D-T fusion as a breeder of tritium. While deuterium is stable and abundant, tritium has a ~12-year half-life and must be manufactured via the transmutation of lithium. The neutrons generated by the D-T fusion reaction itself are suitable for transmuting lithium into tritium, and fusion power plants are generally designed to be tritium self-sufficient given external supplies of deuterium and lithium. [Zap Energy's fusion power plant design](#) also uses lithium as the coolant for the system, either in pure form or alloyed with lead. Lithium has many excellent properties as a heat transfer fluid and is also considered for [fission reactor design for use in space exploration](#). For five years, Zap Energy's fusion systems engineering program has built liquid metal loops using bismuth as a surrogate for lead-lithium alloy. These efforts culminated in our forced convection bismuth loop third-of-a-kind (FCLBi-03) which routinely operates as the cooling systems for the [Century fusion plant technology demonstration platform](#). [FCLBi-03](#) circulates 1,100 kg (112 L) of liquid bismuth through a plasma Z-pinch vacuum chamber and into a 200 kW duty bismuth-to-air heat exchanger where it can reject heat from Z-pinch plasmas firing every five seconds. The entire system was designed by Zap, built with Zap know-how, and is routinely operated by our staff. Zap's first pure lithium loop is near completion with a first circulation date late this spring and the first sodium loop is in preliminary design.

Sodium has a long pedigree as a fission reactor coolant which includes [EBR-II](#), several other historical reactors, and a number of [reactors that operate around the world today](#). Sodium melts at 98 °C but does not boil until 883 °C and therefore can be used at roughly atmospheric pressure. This contrasts with water which boils at 100 °C and must be pressurized to remain an effective liquid coolant, typically at ~150 atmospheres in the existing fleet of predominantly [pressurized water reactor \(PWR\)](#) power plants. In addition, sodium has a hundred times the thermal conductivity of water which reduces hot spots even under poor flow. These physical properties of sodium allow for reactor designs that shut themselves down if they start to overheat and can safely remove their own post shutdown decay heat through natural circulation. [Both of these capabilities were demonstrated in live tests on EBR-II](#). That is in contrast to water cooled reactors where [loss of active decay heat removal](#) and [boiling of the coolant water](#) were key factors in the few accidents that have ever occurred. Sodium coolant has other accident mitigation properties including its tendency to [absorb radioactive iodine rather than release it into the air](#). The substantial drawback of liquid sodium, which it shares with liquid lithium, is that it will start burning on contact with air and reacts quickly



with water to produce hydrogen, which can explode in the presence of oxygen. This issue is manageable with thoughtful design, quality craftsmanship, and the use of inert cover gases like argon or helium. The dominance of the Navy's requirements in early days of controlled nuclear power and sodium's reactivity with water are a major reason water-cooled reactors achieved such a large initial share of the commercial market.

## 4.0: Fission and Fusion Energy at Common Systems Sizes

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Zap Energy began as a company devoted to the development of small modular fusion power. The [SFS Z-pinch concept](#) is uniquely suited to fusion power plant units on the scale of 50 MWe. [Zap's conceptual fusion core design](#) uses a vertically oriented plasma operated in pulsed mode surrounded by a tank of liquid lithium roughly 4 m in diameter and 3 m high. The liquid lithium serves the dual functions of heat transfer fluid and tritium breeding medium. The liquid is pumped from the sides of the tank to form a spinning central cavity in the flowing liquid metal. The SFS Z-pinch formation system sits on top of the tank and repeatedly fires pulses of plasma that assemble and generate fusion reactions within the liquid lithium cavity. Each plasma pulse will produce a nominal yield of ~20 MJ of fusion energy at ~10 Hz for a thermal power of ~200 MW. Fusion is a driven reaction and a substantial fraction of the electricity generated from fusion power must be fed back into the plant to maintain its operation. After subtracting for conversion losses and this recirculating power, each Zap fusion core is expected to provide 50 MWe for use.

The Zap vision for fusion is a readymade fit with the burgeoning category of [fission microreactors](#). Microreactors are defined by an emphasis on factory fabrication, transportability, and self-regulation with powers up to 50 MWe. While not configured as a microreactor, EBR-II fit the classification in terms of power production at 20 MWe and the [reactor core with shield was about ~3.5 m in diameter and ~4 m high](#). EBR-II had a sodium intermediate loop, and steam system external to the core. The legacy of EBR-II was taken up by Toshiba when they designed the [4S \(Super-Safe, Small and Simple\) reactor](#). The 4S is a sodium cooled microreactor design that implements the safety features demonstrated on EBR-II and provides 10 MWe for 30 years without refueling. Zap is starting with the 4S concept and revitalizing it with modern design tools as a base for our first fission product design. This process includes evaluating how new manufacturing technologies, AI-enhanced methods, and the knowledge gained in recent years can enhance the design and reduce costs.

Lithium systems in a fusion power plant will have a similar arrangement to a sodium-cooled fission microreactor and also include pumps, heat exchangers, steam generators, flow meters, etc. Zap believes that engineering alkali metal cooled fission and fusion power systems at similar physical sizes and power production levels is foundational to a platform model, enabling shared supply chains, common component designs, and transfer of operational learning across both systems given the chemical similarity of lithium and sodium. To [paraphrase Admiral Rickover](#), any reactor will require a large amount of development work on apparently trivial engineering details and those details can change with system scale. While leveraging successful past designs like EBR-II and 4S reduces the number of engineering details that need solving, many remain on the path to reliable commercial products. Zap has always been a company committed to climbing the practical engineering curve by building and operating hardware like the liquid-metal-cooled [Century platform](#). Fabrication, welding, testing, ownership, and repair are core to Zap's operational philosophy. Pursuing primary testing goals frequently surfaces secondary lessons — what *not* to do — and understanding these small, real-world problems is critical before advancing to large-scale machinery. By maintaining similar sizes across products, as well as similar alkali metal coolant chemistry, Zap will maximize the value of every "trivial" engineering problem that we solve on the way to our fission and fusion based products. This approach ensures that each engineering solution, supplier qualification, and operational lesson directly strengthens the broader platform rather than remaining specific to a single product line.

System size and alkali metal cooling are two of the keystone areas of overlap Zap envisions for our combined fission and fusion effort, but there are several additional synergies. Neutronics, radiation transport, and shielding design are core competencies for both approaches. Materials science challenges likewise overlap. Radiation damage, neutron activation, and compatibility of structural materials with flowing liquid metals at high temperature are



development efforts that serve both programs simultaneously. Maintaining similar physical and power sizing across the product offering will help build a robust and consistent supply chain for similar major components, e.g., large vessels. Finally, non-light-water reactor licensing pathways at the NRC overlap significantly between sodium-cooled fission and liquid-metal-cooled fusion systems, so lessons from one regulatory engagement accelerate the other. Quality assurance infrastructure will also support both fission and fusion. These shared competencies mean that Zap is building a vertically integrated nuclear engineering organization whose capabilities compound across product lines, forming the basis of a single integrated platform rather than parallel development programs.

## 5.0: Safety Regardless of the Reaction

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The very potency of nuclear reactions means that safety is a vital concern for all nuclear power systems. For fission, safety revolves around controlling and shutting down the chain reaction on command, as well as removing the decay heat that is still produced after the chain reaction ceases. It is not always appreciated that [radioactive decay of fission products will continue to generate ~6% of the core power](#) immediately after the chain reaction is stopped and takes hours to drop below 1%. Given the amounts of power involved, decay heat can generate megawatts of heat even in a microreactor. As noted above, the thermal conductivity and high boiling point of sodium coolant allows reactor designs engineered to be passively safe in all design-basis and beyond-design-basis events without active safety system actuation, operator intervention, or external power. Sodium's ability to operate near atmospheric pressure also eliminates many safety issues associated with high pressure coolants and ensures any loss of sodium through leaks will occur relatively slowly.

Fusion takes passive safety to an even higher level. Physics of the fusion process means that it must be externally driven by input energy to heat and compress the fusion fuel. The fusion reaction ceases immediately if the drive power is cut for any reason. There is no fusion chain reaction that can keep going on its own. While fusion neutrons will activate some of the materials in the fusion core, e.g., the SFS Z-pinch cathode in the Zap design, the decay heat generated post fusion shutdown is minor and does not require active cooling. Fusion plasmas also operate in a vacuum, so the system is at negative pressure with respect to the atmosphere which helps prevent any material from escaping.

Meeting fission's rigorous safety requirements will also build institutional muscle that directly strengthens Zap's position in the ongoing development of fusion safety standards. Safety aspects of using lithium and sodium for coolant will also overlap significantly including high reliability liquid metal systems design, leak detection, leak recovery, cover gas systems, AI-enabled efficiency improvements to remote handling and repair, etc. Finally, Zap investment in community relationships, social capital building, and communicating the extremely high safety standards of our systems will ultimately benefit deployment and siting of both our fission and fusion products.

## 6.0: Opportunities in Hybridization

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The high energy neutron provided by fusion opens new possibilities in extracting more energy from spent nuclear fuel and reducing its inventory of radioactive transuranic elements. Such a process could reduce both the volume and radiotoxicity of used nuclear fuel. Spent fuel from the existing fleet of predominantly pressurized water reactor (PWR) power plants is generally not recycled. In an example of typical current usage, fresh fuel is composed of 4.5% U-235 with U-238 making up the balance and it is mainly the U-235 that undergoes fission to produce power. The used fuel removed from the reactor typically has ~1% U-235, ~1% plutonium, ~95% U-238, and [~3% other fission products and minor actinides](#). The great majority of used fuel is simply stored at reactor sites in fuel pools and dry casks. While this approach is safe and effective, alternatives will be necessary in the long term. Simple disposal of spent fuel, e.g., in a geological repository, faces ongoing difficulties with public acceptance and ignores the substantial power generation potential it contains. Options for utilizing current spent nuclear fuel require either reprocessing the fuel, another type or reactor, or both. The most established reprocessing route is [PUREX](#), the only reprocessing technology used commercially today, which separates uranium and plutonium from fission products for recombination into MOX fuel. France has operated PUREX at industrial scale for decades, though it carries nuclear



weapon proliferation concerns and generates a residual minor actinide waste stream that still requires geological disposal. The [DUPIC cycle](#) offers a proliferation-resistant alternative by feeding PWR spent fuel directly into heavy-water CANDU reactors without chemical separation, exploiting their superior thermal neutron economy — but it was never commercialized despite two decades of Korean-Canadian development. While both of these used-fuel recycling techniques are workable, they struggle economically in competition against the new fuel supply chain.

Alternative reactor types with higher energy neutron spectra open the door to burning radioactive transuranic elements in used fuel. Thermal reactors like PWRs have average neutron energies around  $\sim 0.025$  eV. Sodium-cooled fast reactors have a much more energetic neutron spectrum up to  $\sim 200$  keV that enables fission of minor actinides that thermal reactors cannot burn. This capability was demonstrated by France's Phénix and Superphénix and currently operated in Russia's BN-600 and [BN-800](#). More neutron energy provides more reaction options and the next step up in energy is provided by accelerator-driven systems (ADS). [MYRRHA](#), for example, will be the world's first large-scale ADS, which consists of a subcritical reactor driven by a high-power linear accelerator. MYRRHA's spallation neutrons have an average energy of  $\sim 0.5$  MeV. Fusion-fission hybridization takes the trend of increasing neutron energy to its logical conclusion by using the 14.1 MeV neutrons generated by the D-T fusion reaction. The spectral hardness of fusion neutrons opens reaction channels, particularly Am-241 fission and (n,2n) and (n,3n) reactions, that are largely inaccessible in other systems and have utility in addressing the full inventory of nuclear fission products in used fuel. As discussed above, Zap Energy's fusion core design with its liquid lithium wall and blanket is uniquely suited to handling the 14.1 MeV D-T fusion neutron flux. We believe these qualities also make Zap fusion core design an excellent candidate for fusion-fission hybridization. In the future, hybrids based on the Zap fusion architecture may provide an elegant way to address the issue of accumulating used nuclear fission fuel and associated costs. A Zap hybrid reactor could be an economical waste-to-energy play that receives revenue both from taking in used nuclear fuel and from selling power produced during the waste transmutation process.

## 7.0: Summary of Zap Energy's Strategic Direction

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Surging demand for firm electricity, particularly from the rapid expansion of AI infrastructure, requires new nuclear capacity. Zap's response is a sequenced platform strategy in which fission provides near-term market entry and fusion builds on that foundation for long-term differentiation, with both built on a substantial common technical base. In this model, fission is not a parallel product line but the enabling layer for fusion commercialization, providing infrastructure, supply chain maturity, regulatory engagement, and real-world operating data that accelerate fusion deployment. Alkali metal coolant engineering, neutronics and shielding analysis, materials qualification under irradiation, thermal-hydraulic design, and regulatory pathway development are all competencies built once and applied across both. Many hard-won engineering lessons, vendor qualifications, and regulatory relationships will compound in value across the full product portfolio. Both Zap's fission microreactors and fusion systems target the 10–50 MWe output range with core dimensions on the order of 3–4 meters, enabling a common factory fabrication model, shared supply chain infrastructure, and the logistics economics that come with high-volume production of standardized units with many similar parts. Safety is foremost across Zap's fission and fusion programs. The fission microreactor maximizes the passive safety advantages of alkali metal cooling — low operating pressure, high thermal mass, and natural circulation and decay heat removal — while fusion adds a categorical safety distinction in the complete absence of a self-sustaining chain reaction. Zap's SFS Z-pinch geometry and its dense 14.1 MeV neutron source create an architecture uniquely well suited for fusion-fission hybridization, enabling spent fuel burnup and actinide transmutation in ways that no other fusion or fission system can replicate alone. Taken together, Zap is positioned as a platform company for nuclear energy deployment: delivering clean, firm power to a grid that needs it now, while building the technical and commercial foundation for fusion deployment and closing the fission nuclear fuel cycle in the decades ahead.