

Subcritical Water Processing of Organic Waste and Wastewater Sludge

A Broad Hydrothermal Processing Platform for Waste Reduction, Resource Recovery and Contaminant Management

Technical Discussion Paper — September 2026

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Executive Summary

New Zealand does not have a shortage of waste.

It has a shortage of practical pathways for dealing with some of the material that remains after conventional recovery, recycling and wastewater-treatment processes have done what they can.

Municipal residual waste, wastewater sludge, contaminated organic material, medical waste, difficult plastics, treated timber and other carbon-containing residuals are normally considered separate waste problems.

Chemically, however, many have something fundamental in common. A substantial proportion of the material is **organic and carbon-based**.

Subcritical Water processing (SCW) uses water maintained at elevated temperature and pressure below its critical point to create a highly reactive hydrothermal environment. Under these conditions, many organic structures can be hydrolysed, decomposed and transformed without conventional combustion.

This means SCW should not necessarily be considered as a machine designed for one particular waste stream.

It is better understood as a **processing platform**.

An oven is not designed only to bake bread, roast meat or cook vegetables. Its underlying function provides a controlled thermal environment within which many different materials can be processed.

SCW is analogous in that respect.

The reactor does not fundamentally care whether an organic molecule arrived labelled as sewage sludge, food waste, medical waste, plastic, biomass or municipal residual waste. The composition of the feedstock determines the reactions, operating behaviour and products — but the fundamental hydrothermal processing principle remains the same.

This does **not** mean that SCW can process everything, that every feedstock behaves identically, or that every output is automatically useful.

Inorganic material does not simply disappear. Metals remain. Mineral matter remains. Some persistent organic compounds are more resistant than others. Different wastes produce different solid, aqueous and gaseous products.

But that is precisely why SCW is interesting. The objective does not need to be perfection. It can be much simpler: **Reduce the bulk problem. Characterise what remains. Recover what has value. Treat only what still requires treatment.**

More than thirty years of Japanese development and over twenty years of commercial experience provide practical precedent for SCW treatment of a broad range of wastes. Wastewater sludge is particularly interesting because it is already wet, contains substantial organic material, and therefore represents an inherently logical feedstock for hydrothermal processing.

Independent scientific research strongly supports that proposition. Primary sludge, waste-activated sludge and anaerobically digested sludge have all been processed hydrothermally, producing carbonaceous solids, aqueous products and gases. Research also demonstrates substantial transformation of organic contaminants, strong partitioning of many heavy metals toward the solid phase, and — importantly — significant degradation of several PFAS compounds under hydrothermal conditions.

Recent research is particularly relevant. A 2026 study of hydrothermal carbonisation of sewage sludge at 200–300°C reported greater than 94% removal of the tested C5–C10 PFAS, although the more resistant PFOS achieved lower removal of approximately 55–75%. The researchers used product-phase mass balances and found very little transfer of the measured PFAS to the gas phase.

This does not establish the performance of an Arinkai SCM reactor on a particular New Zealand sludge. It does however, establish something more fundamental: **there is sound scientific reason to investigate it.**

The next step therefore need not be a major infrastructure decision. It can begin with a conversation, inspection of operating technology in Japan, and independent processing and analysis of representative New Zealand material.

1. What Is Subcritical Water Processing?

Water is normally thought of as a washing, transport or heat-transfer medium. However, under elevated temperature and pressure, its behaviour changes significantly. SCW maintains water in the liquid phase at temperatures well above its normal atmospheric boiling point. In the modern Arinkai SCM system, typical operation is approximately:

- **230–265°C**
- **3–6 MPa**
- sealed, pressurised processing
- approximately **2–3 hours per batch**, depending upon feedstock and operating requirements.

Within this environment, water becomes much more chemically active. Hydrolysis and other hydrothermal reactions break down many complex organic structures. Large molecules can be converted into smaller molecules; polymers can be disrupted; biological material is

decomposed; and carbonaceous solids, soluble organic and inorganic compounds, water and relatively small gaseous fractions can result.

The process is fundamentally different from conventional combustion. SCW does not depend upon burning the incoming material in air. It uses **hot pressurised water as the reaction environment**. That distinction is particularly important when considering wet waste. Conventional thermal processes often regard water as a burden because energy must first be used to remove it. Hydrothermal processing can instead use water as part of the process.

2. A Processing Platform Rather Than a Single-Waste Technology

SCW is sometimes easiest to understand by considering what it is **not**.

It is not simply:

- a sewage-sludge machine;
- a municipal-waste machine;
- a medical-waste machine;
- a plastics machine;
- a biomass machine; or
- a treated-timber machine.

Its broader significance is its potential applicability across **most organic-based waste streams**. These materials may have completely different names within conventional waste-management systems, but their organic fractions share the same fundamental characteristic: *they contain carbon-based molecular structures that can be transformed hydrothermally*.

The reactor therefore does not need an entirely different fundamental technology simply because the label on the incoming waste changes.

What changes is primarily:

- feed preparation;
- water content;
- organic/inorganic composition;
- reaction behaviour;
- optimum operating conditions;
- mass reduction;
- solid yield;
- aqueous chemistry;
- contaminant partitioning; and
- potential end use of the resulting products.

This is an important distinction. **SCW is not a universal answer to every waste.**

But it potentially represents a **broad, or PAN, processing platform for most organic-based residual waste streams**.

That proposition is supported not merely by chemistry, but by the breadth of material already investigated and processed through hydrothermal systems internationally and through Arinkai's development work of over 40 reactors across Japan and in the wider Asian region.

3. What Happens to Waste in SCW?

The simplest conceptual mass balance is:

$$\begin{array}{c} \text{Feedstock} \downarrow \\ \text{Subcritical Water Processing} \downarrow \\ \text{Solid fraction} + \text{aqueous fraction} + \text{gas fraction} \end{array}$$

Apart from a significant typical reduction volume of 70%-80% depending on the feedstock, nothing needs to be assumed to disappear - That is important.

For any serious evaluation of SCW, the appropriate question is not:

“Did the waste disappear?” It is: **“What did the original material become?”**

A proper evaluation therefore follows the important components through the process.

For example:

Carbon → solid carbonaceous material, dissolved organic carbon and gaseous carbon compounds.

Nitrogen → solid nitrogen compounds, ammonium and other aqueous nitrogen species, with some potential gaseous products.

Phosphorus → frequently concentrated significantly within the solid fraction, although distribution depends upon chemistry and process conditions.

Chlorine → organic chlorine compounds can be transformed, with chloride and other inorganic forms becoming important in the resulting chemistry.

Heavy metals → cannot be destroyed and therefore must remain somewhere within the mass balance, frequently concentrating substantially in the solid carbon phase.

PFAS and other persistent organic contaminants → may undergo varying degrees of hydrothermal degradation depending upon molecular structure and operating conditions.

Mineral matter → remains principally as inorganic material within the resulting products.

The point is not that SCW makes matter vanish. The point is that it can **transform a large, heterogeneous waste problem into substantially smaller and more clearly defined material streams.**

4. Japanese SCW Experience

Arinkai's present SCM technology is the result of more than thirty years of hydrothermal development and over 20 years of commercialized use led by Mr Kaneo Ishimori and his team in Japan.

Approximately forty reactors have been supplied across Japan and Asia during that development history, encompassing a range of applications and feedstocks.

These include experience with mixed organic wastes, municipal-type residuals, medical waste and other difficult carbon-containing materials.

The significance of this experience is not that every waste produces the same result.

It clearly does not. The significance is that the same fundamental hydrothermal platform has demonstrated applicability to **material streams substantially more heterogeneous and physically difficult than wastewater sludge**.

For mixed waste, indicative mass reduction can be around 70%, depending upon composition.

Carbonaceous char produced from mixed municipal-type wastes has demonstrated useful energy content. Japanese samples examined to date have included typical values in approximately the **18–24 MJ/kg** range, while a particularly plastics-rich Japanese sample reached **37.1 MJ/kg**. These figures should not be assumed for sewage sludge.

They demonstrate something different: **SCW can convert appropriate organic residual material into a carbonaceous product containing recoverable chemical energy**.

The fuel characteristics of any particular output must then be measured.

5. Why Sludge Is Particularly Interesting

Wastewater sludge may be one of the more logical SCW feedstocks. That is because one of the principal difficulties associated with conventional thermal treatment — **water** — is already present.

Sewage sludge contains:

- water;
- microbial biomass;
- proteins;
- lipids;
- carbohydrates;
- cellulosic material;
- organic residues;
- phosphorus and nitrogen;
- mineral matter;
- metals;
- pharmaceuticals and personal-care residues;
- microplastics and other polymer material; and potentially
- PFAS and other persistent contaminants.

Hydrothermal treatment is particularly suited to wet feedstocks because extensive drying before treatment is not inherently required. More importantly, this is no longer simply a theoretical proposition.

A 2025 study independently processed **primary sludge, thickened waste-activated sludge and anaerobically digested sludge** at hydrothermal temperatures between 180°C and 270°C. All three sludge types were successfully hydrothermally processed.

The researchers found that temperature was the most influential factor controlling product yield and composition, and that hydrochar produced from primary sludge demonstrated attractive bioenergy properties.

This is important for practical wastewater applications. Different wastewater-treatment plants will produce different sludges. Different stages within the same plant will also produce different sludges. That does not necessarily mean each requires a fundamentally different processing technology. For SCW, the differences may principally determine **what comes out and in what proportions**, rather than whether the material can be processed hydrothermally at all.

6. The Japanese Sludge Precedent — Rumoi

Mr Ishimori's work with sewage sludge extends back approximately 25 years. An early hydrothermal system was installed in connection with sewage sludge processing at Rumoi in Hokkaido.

It is important not to confuse that historical equipment with today's SCM technology. Mr Ishimori has clarified that the Rumoi equipment was an early-generation **hydrothermal reaction system**, operating at approximately: **maximum 180°C / 1.5–1.6 MPa**

At the time, people associated with the project largely regarded the equipment as a form of **sludge-cake dryer**.

Mr Ishimori has specifically stated that this equipment was substantially different from the modern SCM system. Rumoi therefore should not be presented as evidence of the performance of today's SCM reactor.

It is nevertheless important historical precedent.

It demonstrates that sewage sludge was being considered and processed hydrothermally by Mr Ishimori's team approximately a quarter of a century ago.

Modern SCM subsequently evolved to significantly higher operating conditions and a much broader waste-processing capability.

7. Current Japanese Sludge Proposal — Gushikawa, Okinawa

The present-day Gushikawa Wastewater Treatment Centre proposal provides a relevant example of how Arinkai envisages modern SCM being applied to sewage sludge. The wastewater-treatment process produces several sludge streams, including primary sludge, excess sludge and return sludge. According to information provided by Mr Ishimori, only approximately 3% of the material from the three sludge-related streams is presently utilised as compost.

Arinkai's current proposal focuses particularly on the excess-sludge and return-sludge treatment processes, which require equipment, time, maintenance and operating expenditure. Mr Ishimori states that treatment of the relevant quantities presently takes approximately 2–3 days, whereas SCM treatment would complete this processing in approximately one day. Most significantly, Arinkai states that the recovered material would amount to approximately 20% of the total sludge, with the recovered material becoming either organic fertiliser or SCW-derived fuel.

In simple terms, the proposed relationship is therefore: 100 tonnes sludge → SCM → approximately 20 tonnes recovered material, representing an overall reduction of approximately 80%.

Arinkai's proposed Gushikawa configuration comprises **12 m³ SCM reactors, 2 reactors in parallel × 4 sets, for a total of eight 12 m³ reactors.**

Based on proportional scaling from Arinkai's standard commercial SCM configuration of three 10 m³ reactors with nominal throughput of approximately 70 tonnes/day, the proposed eight-reactor Gushikawa system represents an indicative processing potential of **approximately 220 tonnes/day**. The actual design throughput for the Gushikawa application is currently being confirmed with Arinkai and the treatment centre.

At this indicative processing capacity, an 80% reduction would leave **approximately 44 tonnes/day** of recovered material.

In practical terms, SCW takes a large and continuing waste liability and reduces it, in this case, to approximately one-fifth of its original quantity, while converting the remaining material into a safe, storable, transportable and potentially saleable SCW-derived fuel.

Instead of continuing to manage approximately 220 tonnes/day of sludge as a problematic waste stream, the proposition is to recover approximately 44 tonnes/day as a manageable energy resource.

This represents a fundamental change in the nature of the problem: approximately 176 tonnes/day of the original material burden is removed through processing, while the remaining approximately 44 tonnes/day becomes a potentially useful asset rather than simply another waste requiring disposal.

These figures represent Arinkai's current engineering proposal and an indicative capacity calculation rather than operating results from an already-installed Gushikawa SCM plant. The actual Gushikawa design throughput is currently being confirmed.

The precise characteristics, safety and suitability of SCW-derived material produced from New Zealand sludge would likewise be confirmed through independent New Zealand testing before any particular end use.

The Gushikawa proposal is therefore significant not because it provides final proof of how a New Zealand sludge will behave, but because it demonstrates that modern SCM is being actively engineered in Japan as a commercial-scale sludge-processing system, with substantial mass reduction and resource recovery forming central elements of the proposed treatment pathway.

8. Approximately 80% Reduction — What Does That Really Mean?

An 80% reduction should not be interpreted as 80% of the matter somehow ceasing to exist. SCW changes the distribution and chemical form of the original material. For a hypothetical **1,000 kg** sludge input on the same basis used by Arinkai's Gushikawa proposition:

Input: 1,000 kg sludge

After SCM processing; Approximately: 200 kg recovered solid/product

plus material transferred into:

- the aqueous phase;
- dissolved organic and inorganic compounds;
- gaseous reaction products; and
- water already associated with the feed.

The precise mass balance will depend heavily upon whether the incoming quantity is expressed on a wet, dewatered-cake or dry-solids basis. That distinction must therefore be defined clearly in any New Zealand trial.

But the fundamental proposition remains simple: **A large sludge stream can potentially be converted into a much smaller recoverable solid stream, while the remaining material is transferred into aqueous and gaseous fractions that can be characterised and managed.**

9. What Might the Solid Product Be?

Hydrothermal processing of sewage sludge commonly produces a carbonaceous solid often described in the scientific literature as **hydrochar**.

Within this paper, the more general term **char** is used. Its properties depend strongly upon the incoming sludge and processing conditions.

Potential characteristics include:

- increased carbon concentration relative to the incoming wet sludge;
- reduced mass and water burden;
- retained mineral matter;
- phosphorus retention;
- concentration of some metals;
- altered combustion characteristics; and
- potentially useful calorific value.

The 2025 comparative study of primary, waste-activated and digested sludge found particularly attractive bioenergy characteristics in char derived from primary sludge. That does **not** mean every sewage-sludge char will automatically be a suitable industrial fuel. Fuel suitability should instead be treated as a measurable engineering question.

The appropriate analysis would include:

- higher and lower heating value;
- moisture;
- ash;
- volatile matter;
- fixed carbon;
- sulfur;
- chlorine;
- phosphorus;
- major and trace elements;
- heavy metals;
- ash behaviour;
- combustion characteristics; and
- any additional parameters required by the intended industrial user.

The result then determines the end use. **End use follows chemistry.**

10. Heavy Metals — Concentrated, Not Destroyed

Heavy metals cannot be destroyed by SCW. That is not a weakness peculiar to SCW. It is a consequence of basic chemistry.

The relevant question is therefore: **Where do the metals go, in what chemical form, and how available are they for subsequent release?**

Hydrothermal sewage-sludge research provides useful evidence.

A 2026 study found that **more than 86% of measured heavy metals were enriched in the resulting solid** following hydrothermal carbonisation. Higher temperatures also shifted metals toward more stable chemical fractions and reduced their bioavailability under the investigated conditions.

Other research demonstrates that metal behaviour depends upon temperature, pH, sludge chemistry and additives, with precipitation, adsorption, complexation and co-precipitation all contributing to the resulting distribution. This suggests a potentially useful outcome.

Rather than heavy metals remaining distributed throughout hundreds of tonnes of wet sludge, a substantial proportion may become concentrated within a much smaller solid fraction.

That does not automatically make the solid safe. It makes the problem **smaller and measurable**.

The appropriate New Zealand evaluation would therefore include: **total metals + leachability + relevant speciation/bioavailability testing**.

If the resulting char meets a fuel-user specification, it may have energy value. If it does not, its much smaller volume may still provide a substantially more manageable disposal or further-treatment problem than the original sludge.

11. PFAS — Potentially Part of the Solution, Not Simply a Problem for SCW

PFAS deserves particular attention. Wastewater-treatment systems can act as collection points for PFAS, with some compounds remaining in treated water while others partition into sludge. Conventional wastewater and sludge treatment does not necessarily destroy the carbon-fluorine structures responsible for PFAS persistence.

Hydrothermal treatment is therefore being actively investigated as a potential destruction pathway.

A 2024 scientific review of contaminants during hydrothermal sewage-sludge treatment identified PFAS, heavy metals, microplastics, pharmaceuticals and other contaminants as important areas of research and concluded that many contaminants undergo varying degrees of degradation or transformation under typical subcritical hydrothermal conditions.

More recent experimental results are particularly interesting.

A 2026 study subjected PFAS-containing sewage sludge to hydrothermal carbonisation at **200–300°C**. The researchers reported: **>94% removal of the tested C5–C10 PFAS** while the more resistant: **PFOS achieved approximately 55–75% removal**.

The study used mass-balance analysis across the product phases and found less than 0.001% of the measured PFAS transferred to the gas phase.

A separate 2025 study investigating sewage sludge at 270°C reported approximately **99% degradation of PFOA**, while PFOS was substantially more resistant.

Earlier 2024 work examining PFAS in sewage sludge and resulting hydrochar similarly reported near-complete removal of C8–C13 perfluorocarboxylic acids and approximately 70% removal for the investigated C4–C8 perfluorosulfonates.

The conclusion should therefore neither be: **“SCW destroys all PFAS.”** nor: **“PFAS prevents SCW from being useful.”**

The evidence supports something considerably more interesting: **Hydrothermal processing can substantially degrade a number of PFAS compounds in sewage sludge, while some compounds — particularly PFOS and other highly refractory species — are more resistant.**

This potentially fits naturally within a staged treatment philosophy:

SCW for bulk processing and contaminant transformation↓

Analyse the resulting solid and aqueous streams↓

Recover useful material↓

Concentrate any remaining refractory organic contaminants↓

Apply more severe treatment only to the much smaller fraction that requires it

Where appropriate, technologies such as **Supercritical Water Oxidation (SCWO)** could potentially provide a downstream destruction step for concentrated refractory organic material.

This is an important distinction. There may be little logic in subjecting hundreds of tonnes of wet material to the most severe possible treatment conditions if SCW can first perform the bulk conversion and leave only a much smaller refractory fraction requiring further destruction.

12. Microplastics and Other Organic Contaminants

Wastewater treatment does not necessarily destroy contaminants. In many cases, it removes them from the wastewater and concentrates them into the sludge. Microplastics are a particularly clear example.

A 2024 scientific review reported that more than 65% of microplastics entering wastewater-treatment systems can accumulate in sewage sludge. Consequently, the sludge becomes an important repository for contaminants that have been removed from the water but have not disappeared from the overall system. This is one of the areas where hydrothermal processing offers a fundamentally different treatment environment. Under subcritical-water conditions, high temperature, pressure and water-driven hydrolysis can break down and transform polymeric and other organic structures, rather than simply transferring them into another residual stream. The extent and pathways of degradation depend upon polymer type, temperature, residence time and process chemistry.

The broader scientific literature on hydrothermal treatment of sewage sludge similarly identifies microplastics, pharmaceuticals, personal-care products and other organic contaminants as materials that can undergo substantial transformation and degradation under hydrothermal conditions.

This does not mean that every compound disappears completely under every SCW operating condition. It does mean that SCW provides something conventional sludge management does not: *an opportunity to chemically transform many of the organic contaminants already concentrated within the sludge while simultaneously reducing the bulk quantity of sludge itself.*

That distinction is important. Conventional treatment may move the contaminant from the water into the sludge. SCW potentially provides the next treatment step — processing the sludge itself and transforming many of the organic contaminants contained within it.

13. The Aqueous Phase Matters

A carbonaceous solid is only one product of hydrothermal processing. The aqueous phase must also be understood.

It may contain:

- dissolved organic carbon;
- ammonium;
- nitrogen compounds;
- phosphorus;
- salts;
- chloride;
- organic acids;
- soluble metals;
- fluorinated transformation products; and
- other dissolved compounds.

Research confirms that nutrients can redistribute significantly between the char and process water during hydrothermal sludge treatment. The aqueous phase therefore cannot simply be ignored. But once again, this is a **characterisation and treatment problem**, not necessarily a reason to reject the underlying process.

Depending upon chemistry, treatment could potentially include:

- solids separation;
- pH adjustment;
- precipitation;
- filtration;
- reverse osmosis;
- biological treatment;
- water recycle;
- concentration; or
- more severe oxidation of a small refractory fraction.

The appropriate treatment train follows the measured chemistry.

14. SCW as Problem Reduction

This leads to perhaps the simplest way of describing the technology. SCW does not need to promise that every environmental problem disappears inside one pressure vessel.

Its potential value lies in something more practical: **Shrink the problem. Measure what remains. Deal with that.**

Consider a large organic waste stream containing:

- water;
- degradable organic matter;
- carbon;
- mineral material;
- metals;
- plastics;
- salts;
- persistent contaminants; and
- recoverable energy.

Conventional management may involve transporting and managing the entire mass. SCW potentially changes the problem. The organic fraction is hydrothermally transformed. The original bulk is substantially reduced. Carbonaceous material can potentially be recovered. Metals can become concentrated into a smaller solid stream. Many organic contaminants can be transformed. Some PFAS can be substantially degraded. A smaller number of clearly defined output streams remain. Those streams can then be analysed individually. That is fundamentally different from continuing to manage the original bulk material indefinitely.

15. A Potential PAN Platform for Organic-Based Residuals

The broader opportunity therefore extends well beyond sewage sludge. A region may separately identify:

wastewater sludge

medical waste

food and biological waste

mixed municipal residuals

difficult plastics

treated timber

contaminated organic material and other residual streams.

Conventionally, these can appear to be entirely separate problems requiring entirely separate technologies. SCW invites a different question: How many of these apparently different waste streams are fundamentally organic-material processing problems?

Importantly, these waste streams do not necessarily have to be processed separately. Where feed preparation, reactor loading and output requirements permit, different compatible organic-based waste streams can be combined and processed together through the same SCW system.

This is one of the potentially important advantages of SCW as a broad processing platform. A wastewater sludge, food waste, difficult plastic, treated timber fraction or other carbon-based residual may have a very different origin and regulatory classification, but from the

perspective of the SCW reactor they are all fundamentally materials containing organic or carbon-based components capable of hydrothermal transformation.

The question therefore becomes less about building a different processing technology for every waste label, and more about determining which materials can be processed through the same hydrothermal platform, either individually or in compatible mixtures, and what useful products and residuals result.

One processing platform can therefore potentially address multiple waste streams — separately when required, and together when advantageous.

16. Why Sludge May Be One of the Easier Applications

This perspective changes the way wastewater sludge can be viewed. SCW has been developed to process heterogeneous solid wastes containing physically difficult materials and widely varying organic components.

Sludge, by comparison, offers several potentially favourable characteristics:

- it is already wet;
- its solids are generally finely divided;
- it is pumpable or can potentially be made pumpable;
- it contains substantial organic material;
- it does not require the same degree of mechanical breakdown as large solid wastes;
- its production is relatively continuous and predictable; and
- wastewater facilities already centralise the feedstock.

That does not mean sludge chemistry is simple. It means its **physical form is inherently compatible with hydrothermal processing**. The major questions therefore become less about whether sewage sludge can undergo hydrothermal processing — the scientific literature already establishes that it can — and more about:

How much mass reduction does a particular sludge achieve?

What is the energy requirement?

What is the resulting char yield and calorific value?

Where do the metals go?

What happens to PFAS and other contaminants?

What is in the process water?

What can the resulting products be used for?

And what does the complete pathway cost?

Those are measurable questions.

17. A New Zealand Evaluation Does Not Need to Be Complicated

Before discussing major infrastructure, New Zealand can answer many of these questions experimentally. A useful programme could begin with representative sludge from a New Zealand wastewater-treatment plant.

Step 1 — Baseline Characterisation

Analyse the untreated sludge for:

- moisture and dry solids;
- proximate and ultimate analysis;
- carbon;
- nitrogen;
- phosphorus;
- sulfur;
- chlorine;
- major elements;
- heavy metals;
- plastics;
- PFAS;
- relevant organic contaminants;
- microplastics where practical; and
- calorific value where meaningful.

Step 2 — Hydrothermal Processing

Process representative material under conditions relevant to modern SCM operation. Where appropriate, independent New Zealand high-pressure laboratory facilities could initially reproduce relevant temperature, pressure and residence-time conditions.

Step 3 — Complete Mass Balance

Measure: **feed** → **solid** + **liquid** + **gas** rather than assessing only the solid product.

Step 4 — Solid Analysis

Determine:

- yield;
- moisture;
- ash;
- HHV/LHV;
- fixed carbon;
- volatile matter;
- elemental composition;
- metals;
- leachability;
- PFAS;
- chlorine;
- sulfur;
- phosphorus;
- ash behaviour; and
- other fuel-user requirements.

Step 5 — Aqueous Analysis

Determine:

- COD/TOC;
- nitrogen species;
- phosphorus;
- salts;
- chloride;
- fluoride;
- metals;
- PFAS and transformation products where analytically possible; and
- appropriate downstream treatment requirements.

Step 6 — Determine End Use

The analytical results then determine whether the char is:

a fuel,

a material requiring blending,

a potential nutrient product,

a feedstock for further processing,

or simply: **a much smaller residual requiring controlled disposal.**

Any of those outcomes provides useful information.

18. From Laboratory Evidence to Commercial Reality

Laboratory analysis alone is not sufficient to understand a commercial waste-processing system. SCW involves:

- pressure vessels;
- pumps;
- valves;
- seals;
- heating systems;
- control systems;
- feed preparation;
- material handling;
- corrosion management;
- water management;
- maintenance; and
- operator experience.

These are difficult to understand fully from a presentation or technical paper. For organisations seriously considering the technology, a logical next step is therefore straightforward: **Visit Japan**. See the equipment. Inspect the reactor. Observe the feed system. Examine the outputs. Talk to operators and engineers.

Ask about:

- maintenance;

- pressure-vessel life;
- corrosion;
- seals;
- pumps;
- electricity consumption;
- water use;
- throughput;
- downtime;
- feed preparation;
- operating problems;
- product handling; and
- lessons learned over more than two decades of development.

A technical paper should not attempt to answer questions that can be answered better by inspecting the equipment and speaking directly with the people who developed and operate it.

19. What Would Constitute Success?

SCW does not need to demonstrate perfection to justify further evaluation. A successful New Zealand sludge trial would establish whether the technology can:

1. reliably process representative wastewater sludge;
2. substantially reduce the original material burden;
3. produce a smaller, stable and characterisable solid fraction;
4. retain useful energy within that solid where possible;
5. substantially transform degradable organic contaminants;
6. demonstrate meaningful degradation of relevant PFAS compounds where present;
7. concentrate and stabilise metals sufficiently for manageable downstream treatment or use;
8. produce an aqueous phase that can be practically treated or recycled;
9. reduce transport, disposal or long-term residual-management requirements; and
10. do so at an economically credible whole-of-system cost.

If it cannot, that is useful information. If it can, the next step becomes a representative pilot or commercial-scale demonstration.

20. The Question Worth Asking

New Zealand does not need to decide today whether SCW is the answer to wastewater sludge. Nor does it need to decide whether SCW should replace existing waste-management technologies.

The first question is much smaller: **Is there sufficient technical precedent, scientific evidence and commercial experience to justify serious evaluation of SCW for New Zealand organic residual wastes?**

The Japanese experience says the technology deserves consideration. The broader hydrothermal science says the underlying chemistry is sound.

The sewage-sludge literature demonstrates that primary, activated and digested sludges can all be hydrothermally processed.

Recent contaminant research demonstrates that hydrothermal processing can substantially alter the fate of heavy metals, microplastics and persistent organic contaminants.

Recent PFAS research demonstrates substantial degradation of several PFAS compounds in sewage sludge under hydrothermal conditions while also identifying more resistant compounds such as PFOS.

This proposal should also be viewed in the context of Arinkai's wider commercial operating experience. Other SCW systems have processed more solid and heterogeneous feedstocks, including municipal waste, medical waste and other organic-based wastes, with some applications having operated commercially for decades. These substantially more solid and physically difficult feedstocks have typically demonstrated volume reductions of approximately 70%.

Against that operating background, Arinkai's current Gushikawa proposal provides a modern commercial engineering proposition of approximately 80% sludge reduction, with the resulting material proposed for beneficial use as organic fertiliser or SCW-derived fuel. And the broader Japanese experience indicates that sludge is only one application of a technology capable of processing a considerably wider range of organic-based residual wastes.

That is sufficient to justify the next step. Not procurement. Not a major infrastructure commitment. Not an assumption that SCW will solve every problem.

A conversation.

Followed, where appropriate, by: **seeing the technology; testing representative New Zealand material; independently analysing what comes out; and allowing the results to determine what happens next.**

Conclusion

Waste management is often divided according to the name given to the material.

Sludge. Municipal waste. Medical waste. Plastic waste. Biological waste. Contaminated timber. Industrial organic residuals.

SCW suggests another way of looking at the problem. Much of this material consists substantially of **organic carbon compounds plus water and inorganic constituents.**

Subcritical Water processing provides a common hydrothermal environment capable of transforming many of those organic components.

Different materials will behave differently. Different outputs will result. Some feedstocks will be more suitable than others. And some residual contaminants will require further treatment.

But the underlying proposition is remarkably simple: **Use one broad processing platform to transform a large organic waste problem into smaller, measurable streams.**

Then:

Recover what has value. Measure what remains. Treat what still requires treatment.

Sewage sludge may be one of the clearest opportunities to test that proposition because it is already wet, centralised and inherently suited to hydrothermal processing.

Japanese experience provides precedent. Modern Arinkai SCM provides the commercial technology. Independent hydrothermal research provides the scientific foundation. Recent PFAS research adds an important potential contaminant-management dimension. The remaining questions are not reasons to stop the conversation. They are the questions that the next stage of evaluation should answer.

The technology does not need to be believed. It needs to be tested.

And before that happens, perhaps the simplest first step is: **Let's talk.**

Evidence Status

This paper deliberately distinguishes between three forms of evidence.

Published scientific evidence refers to independent hydrothermal research and does not establish the performance of the proprietary Arinkai SCM system.

Japanese/Arinkai experience and performance information is based on information supplied by Mr Kaneo Ishimori and the Arinkai organisation and should be understood in that context.

New Zealand performance has not yet been established for representative New Zealand wastewater sludge and should be independently demonstrated through appropriate testing. The purpose of this paper is therefore not to claim that SCW has already been proven for every New Zealand application.

It is to demonstrate that sufficient scientific, technical and practical precedent exists to justify finding out.

Selected Independent Scientific References

- Nahar, K. et al. (2025). *Hydrothermal processing of primary, waste-activated, and digested sewage sludge: Products characterisation, fate of heavy metals and nutrients, and process integration*. Journal of Industrial and Engineering Chemistry, 145, 519–533. DOI: 10.1016/j.jiec.2024.10.047.
- Nahar, K. et al. (2024). *Current understanding on the fate of contaminants during hydrothermal treatment of sewage sludge*. Current Opinion in Green and Sustainable Chemistry, 49, 100960. DOI: 10.1016/j.cogsc.2024.100960.
- Nahar, K. et al. (2025). *Catalytic and co-hydrothermal treatment of sewage sludge: Hydrochar properties and fate of heavy metals and per- and polyfluoroalkyl substances (PFAS)*. Journal of Water Process Engineering, 72, 107605. DOI: 10.1016/j.jwpe.2025.107605.
- Study on the removal of PFAS during hydrothermal carbonization of sewage sludge*. (2026). Environmental Technology & Innovation, 41, 104727. DOI: 10.1016/j.eti.2025.104727.
- Hou, S. et al. (2026). *Hydrothermal carbonization of sewage sludge: Effects of hydrothermal temperature and time on biochar properties and migration and transformation of heavy metals*. International Biodeterioration & Biodegradation, 206, 106216. DOI: 10.1016/j.ibiod.2025.106216.
- Analysis of perfluorinated compounds in sewage sludge and hydrochar by UHPLC LTQ/Orbitrap MS and removal assessment during hydrothermal carbonization treatment*. (2024). Science of the Total Environment, 929, 172650.