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Opportunity for forestry ash utilisation in a New Zealand bio-circular economy

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Executive summary

The problem

The use of forest residues for bioenergy is an increasing opportunity for Aotearoa New Zealand. Policy targeting climate mitigation is guiding circular bioeconomy goals, and the resource base of natural gas is in decline. With the opportunities comes some key challenges, and the production and reuse of ash is an integral component of this opportunity.

Key results

With approximately 25,000 tonnes of wood ash produced annually, the long-term environmental risk of annual bulk storage far exceeds the current costs of disposal. With lime treatments to some forest areas likely to enhance site and crop productivity, the use of ash as a liming or fertiliser treatment is a practical long-term solution.

Internationally use of forestry-based furnace ash is already common practice and guides potential solutions for the New Zealand forest industry. However, there are still some critical questions to be answered, is it possible to achieve: 1) ≥ 70% diversion of some ashes from landfills. 2) A positive shift in soil pH at target sites within 24 months of application. 3) A 2–5% MAI increase on low cation sites 5 –10 years after application. 4) 15 –35% net GHG reduction vs landfill baseline, verified by LCA. 5) Lower delivered nutrient cost vs conventional lime or fertilisers on matched sites, and 6) regulatory acceptance of an NZ forestry-ash standard and monitoring and verification protocol.

Implications for the client

In New Zealand, the current legislation is restricting coal use, and the gas supply is also in significant rapid decline, the transition to wood fuels is expected to accelerate rapidly over the next 5 –10 years. With more wood used as fuel, the available ash volume will increase. The evolving energy landscape presents a critical opportunity to reframe wood ash not as a waste product, but as a valuable resource for nutrient recycling, soil amendment, and carbon-smart forestry practices. Unlocking this potential will require coordinated efforts across policy, industry, and research to develop cost-effective, scalable ash utilisation pathways.

Forestry biomass ash production clearly represents both a future concern and a circular economy opportunity but progress in New Zealand significantly lags international role models such as Nordic countries.

Further work

This project outlines some critical steps and these form a strong basis for further investigation if the appropriate funding became available from commercial and government coordinated efforts.

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Introduction

The utilisation of post-harvest forest residues for bioenergy and carbon capture and storage (BECCS) represents a strategic and increasingly realistic opportunity for forest managers across Aotearoa New Zealand. As global and national efforts intensify the transition toward low-carbon economies, the value proposition of forest residue use is gaining prominence—not only for its energy potential but also for its role in achieving circular bioeconomy goals and climate mitigation targets.

However, the viability of this opportunity hinges on a complex interplay of logistical, operational, and environmental factors. While the New Zealand forest industry continues to innovate in extraction efficiency, this review places a spotlight on environmental mitigation strategies, particularly nutrient sustainability—a critical factor in maintaining long-term forest productivity.

Increasing the volume of residues removed from forest stands in time has the potential to increase nutrient removals. Currently landing based residues are the core but with increasing demand the utilisation of different products such as thinning's, with live branches and needles will have greater nutrient concentrations. This shift in nutrient removals will necessitate robust mitigation strategies to prevent site degradation and ensure sustainable wood production at low carrying capacity sites.

Globally, countries like Sweden have made significant strides in addressing some of these challenges. Forest ash recycling—particularly from biomass boilers—is now a mainstream practice, with ash applied across 12% of the Swedish forest estate where whole-tree harvesting occurs (Brandtberg et al., 2023). This practice not only offsets nutrient losses but also reinforces circular resource use.

Three key types of ash are typically produced in grate bed or fluidised bed combustion boiler/furnaces:

1. **Bottom ash** from the primary combustion vessel,
2. **Multiclone / multicyclone fly ash** from the agitation of combustion materials.
3. **Electrostatic precipitated fly ash**, from the output chimney flue.

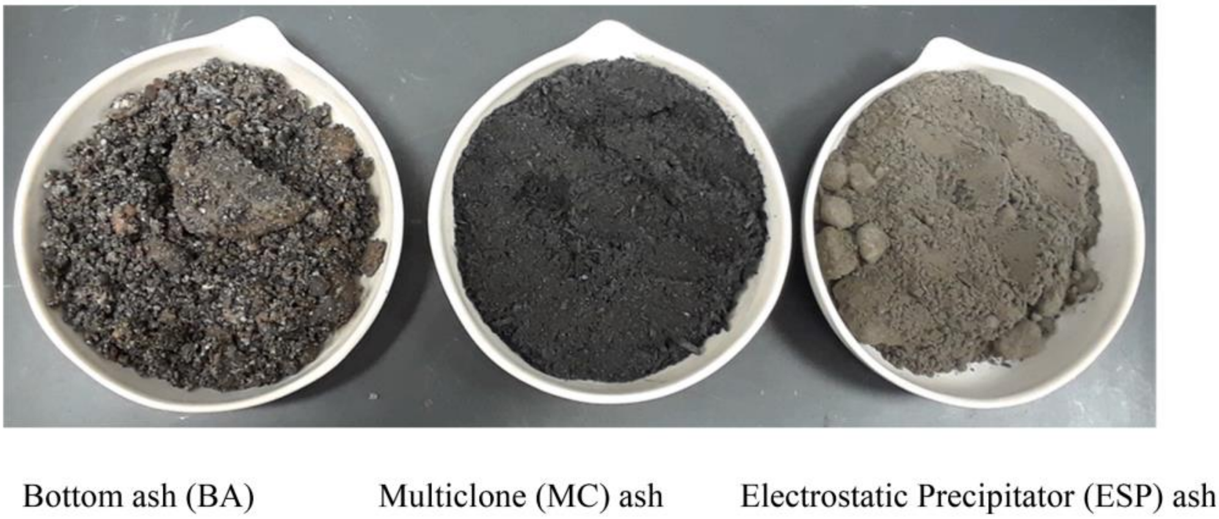

Figure 1 Example of the visual characteristics of the different biomass ash types. **Source:** Mahmood & Kamal 2022

Methods

Recent literature in Scopus and advanced searching techniques using 'Ai2 Asta' at https://asta.allen.ai/ were used to identify recent publications associated with biomass ash utilisation internationally.

This brief review highlights international progress in ash utilisation, outlines New Zealand-specific challenges, and proposes strategic pathways forward to unlock the full potential of forest residue use in a sustainable and circular bioeconomy.

Discussion

Fly ash is typically nutrient rich (Ohenoja et al., 2020). Obviously, there are wide ranging variations in ash type proportions across different furnace and operating systems. For example, Bottom ash may constitute between 30 – 60% of total ash, cyclone / mechanical separator (coarse fly ash) can be between 20 – 40% and ESP (fine fly ash) 5 – 30%.

In New Zealand, the use of boiler ash for nutrient maintenance or liming is currently negligible, largely due to the perceived low value of the nutrients, concerns over heavy metal concentrations in the ash and current disposal costs. However, this status quo is unlikely to persist. As bioenergy production scales up and the demand for non-fossil carbon sources grows, the need to recycle ash by-products will become both an economic and an environmental imperative.

Ash supplies – a growing resource with untapped potential

Wood fuels are a critical and increasing source of renewable energy in New Zealand, particularly within the wood processing sector. By-products such as sawdust, shavings, and bark are widely used for heat generation, and for electricity via combined heat and power (CHP) systems. This practice not only supports energy self-sufficiency but also aligns with national goals for decarbonisation and circular resource use.

According to the Energy in New Zealand report (MBIE, 2025), wood contributes 46.7 PJ to total energy supply, accounting for 5.6% of New Zealand's primary energy needs, and 25.9 PJ or 5% of consumer energy requirements. The gap between primary and consumer energy reflects conversion losses, particularly in transforming solid wood into heat and electricity—where up to 15% more fuel is required for a given heat output and up to 30% more if going to electricity.

Data from Scion's Heat Plant Database, EECA's Regional Heat Demand Database, and the Energy End-use Database provide a comprehensive view of wood fuel consumption across regions and industries. These insights are essential for understanding the scale and distribution of wood ash production, which is currently estimated at 25,000 dry tonnes per annum.

Regional distribution of wood ash production

Regions with the greatest wood ash production include Waikato, Bay of Plenty, Nelson, Southland, and Hawkes Bay (Table 1). The associated disposal costs are currently estimated at around $6 million annually and highlight a significant economic burden and an opportunity to redirect this material towards more beneficial reuse rather than stock piling in landfills and exposure to rainfall leaching.

Table 1 – Regional annual data on ash from wood fired boilers, listed in order of highest quantity and predicted costs of disposal.

Region	Tonnes of green wood equivalent per annum	Tonnes of ash at 1.2 %	Cost at $240/t to landfill
Waikato	1,206,295	6,213	$1,491,212
Bay of Plenty	1,183,305	5,415	$1,299,696
Nelson	713,281	2,931	$703,510
Southland	486,911	2,272	$545,284
Hawkes Bay	440,793	1,878	$450,614
Northland	305,156	1,459	$350,208
Otago	226,888	1,258	$301,888
Canterbury	274,765	1,236	$296,553
Wairarapa	178,913	846	$203,025
Auckland	170,749	807	$193,761
Marlborough	84,885	404	$96,857
West Coast	58,528	276	$66,227
Taranaki	42,102	199	$47,682
Manawatu-Whanganui	16,020	76	$18,171
King Country	14,849	70	$16,850
Wellington	14,142	67	$16,048
Total	**5,417,582**	**25,407**	**$6,097,588**

Industry breakdown – beyond wood processing

While wood processing and pulp & paper industries dominate ash production (Table 2), other sectors such as dairy, meat, horticulture, and food processing are increasingly adopting wood fuels—a trend driven by the phase-out of coal and declining gas supplies.

Table 2 – Wood fuel and ash quantities across the main industry categories

Industry	Green tonnes of wood per annum	Tonnes of ash per annum
Wood processing	2,538,381	11,575
Pulp and paper	1,487,677	6,784
Dairy processing	387,916	1,769
Meat processing	105,977	483
Horticulture	54,970	251
Other Food processing	28,394	129
Other Manufacturing	7,198	33
Laundry & Drycleaning	5,033	23
Total	**4,615,546**	**21,047**

Ash utilisation – nutrient composition and lime/fertiliser substitution

In decreasing order of abundance, the elements in biomass typically are C, O, H, N, Ca, K, Si, Mg, Al, S, Fe, P, Cl, Na, Mn, and Ti (Vassilev *et. al.* 2010). The biomass nutrient proportions are reflected in the composition of ash with the exception that most of the C, O, H and N are burnt off in the combustion, pyrolysis or gasification process used to convert the biomass to an energy product. During combustion, nutrients are concentrated and the resulting products can be collected at multistage output filtering locations. Bottom ash represents the coarse fraction and electrostatic fly ash the finest with greater nutrient concentrations (Fig.2).

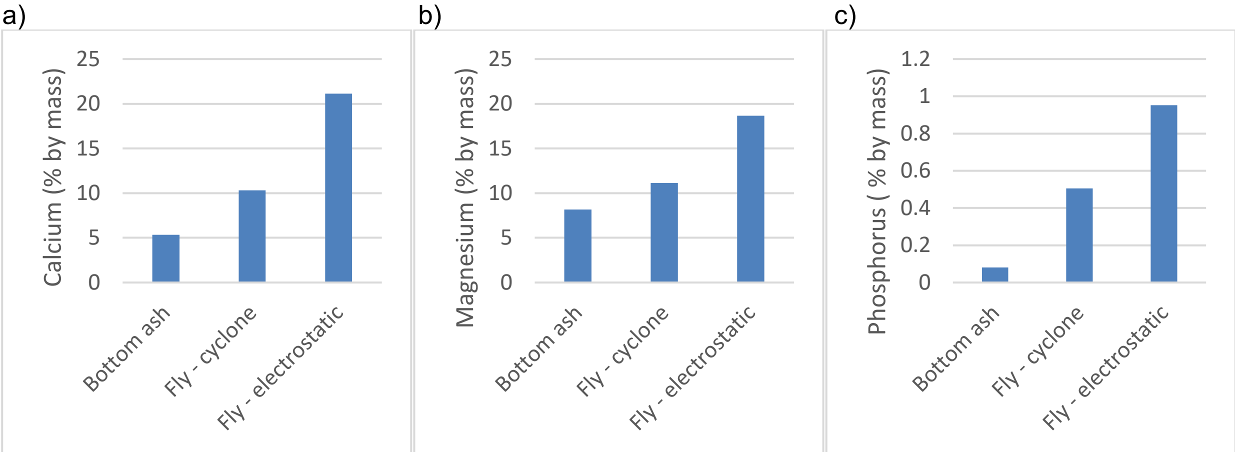

Figure 2, Average ash concentration – a) Calcium, b) Magnesium, and phosphorus concentrations across ash type. **Source** Kamal & Mahmood (2024)

Wood ash can raise soil pH and therefore substitute for agricultural or forest lime. Comparisons between ash and lime are typically expressed using calcium carbonate ($CaCO_3$) equivalence or neutralising value, meaning that users should consider a “lime equivalent” rather than a direct tonne-for-tonne replacement (Adoety et al. 2018). In New Zealand forests, however, productivity is often constrained by magnesium availability, making dolomitic lime a more appropriate comparison than agricultural lime, as dolomite contains both calcium and magnesium. Based on limited unpublished New Zealand wood ash data, a preliminary estimate suggests that approximately 0.2 t of dolomite lime could be replaced per tonne of wood ash. At a current dolomite price of around \$425 t^{-1}, this equates to an indicative ash value of approximately \$85 t^{-1} for liming and magnesium supply alone.

In addition to liming value, wood ash contributes plant nutrients. On average, each tonne of wood ash supplies approximately 35 kg potassium (as K_2O), 13 kg magnesium and 2 kg phosphorus (as P_2O_5). Consequently, for both farm and forest applications, wood ash functions not only as a liming agent but also as a multi-nutrient soil amendment. When benchmarked against current fertiliser prices, the combined nutrient replacement value is approximately \$440 t^{-1} (Table 3). Some adjustment may be required in practice, as replacement products can supply multiple nutrients—for example, superphosphate contains calcium and dolomite provides magnesium.

Table 4, Compares the ash nutrient supplies with fertiliser products and substitution cost for those equivalent nutrients.

Nutrient	Ash nutrient supplied (tonnes)	Product replacement	~Cost/t	Fertiliser nutrient supplied (tonnes)	Nutrient value in ash ($/tonne)
Ca	0.046	Dolomite	425	0.24	81.5
K	0.035	Potash	1790	0.42	149.2
Mg	0.013	Kerisite	832	0.15	72.1
P	0.02	Super	549	0.08	137.3
Total					**440.0**

Combustion substantially increases nutrient concentrations on a mass basis. For example, calcium concentrations typically increase from <1 % in standing radiata pine biomass to >5 % in ash. While this concentration effect underpins the fertiliser value of ash, it can also elevate trace element concentrations, particularly heavy metals. Without adequate dilution or immobilisation within co-products, elevated concentrations may pose toxicity risks (Guo & Wu 2025). Trace elements requiring monitoring commonly include Cu, Zn, Mn, Pb, Cr and Ni.

Wood ash may also contain appreciable proportions of unburnt carbon, depending largely on combustion conditions, which can influence both agronomic performance and environmental behaviour.

Trace metals such as cadmium, mercury and lead are of relevance in a New Zealand context. Mercury is highly volatile and is largely emitted in flue gases during combustion, resulting in very low residual concentrations in ash. Lead, by contrast, is relatively non-volatile, although both elements typically occur at very low concentrations in forest biomass as non-essential nutrients. Cadmium is less well characterised and warrants closer consideration, particularly where hill-country soils have elevated cadmium levels due to historical superphosphate use. While stem-wood feedstocks are likely to contain low cadmium concentrations, further empirical evidence would strengthen confidence in ash reuse pathways.

Ash utilisation - environmental risks

The key risks that need mitigation are, nutrient leaching, dust nuisance and excessive heavy metal concentrations. Policy and heavy metal regulations are well established in Finland (Table 3). The costs of disposal are small in comparison to the full long-term environmental considerations under best practice scenarios.

Table 4, Regulated upper limits for micronutrients (mg/kg) in Finnish forestry ash fertiliser/mineral soil amendments. After Ohenoja et al 2020.

	Zn	Cu	Cr	Ni	Pb	As	Cd
Finland	4500	700	300	150	150	40	25

A recent ash solution combines lime with biomass ash and molasses to create a new slow-release liming product while avoiding some of these risks of heavy metals (Obidziński *et. al.* 2025). This solution seems complex and scaling up may be a challenge, but it innovatively combines products and by-products to create a potentially beneficial product.

Ash utilisation - policy

Nordic countries have the longest history of ash use and therefore provide an example in developing knowledge and practices suited to their soils and climatic conditions. Finland and Denmark have established specific national legislation for ash recycling. Across the EU, ash generated from biomass is typically classified as solid waste and increasing landfill costs and penalties are used to encourage producers to divert ash away from landfill disposal (Silva et al., 2019). Early policy developments were largely driven by landfill regulations (EC 1999), followed by the introduction of fertiliser regulations (EPC 2003). These regulations, however, limited the introduction of innovative and environmentally friendly products, as many new ash-based materials fell outside their scope (Silva et al., 2019). Subsequent revisions to fertiliser regulations (EC 2016b), aligned with Circular Economy principles (EC 2015), broadened the categories of recognised products, including organic and waste-based fertilisers.

Several countries, including Austria, Denmark, Finland, Germany and Sweden have developed national guidelines for applying ash to soils, specifying minimum nutrient levels and maximum permissible concentrations of potentially toxic elements such as heavy metals (see Table 4). Targeted research appears to have informed these policy developments, particularly in Sweden, where key studies were undertaken between 2001 and 2003.

In the UK, the Forestry Commission has recommended the application of wood ash to restore nutrients in forest soils. Over time, perceptions of ash have shifted significantly—from being treated as a waste product to being valued as a usable resource.

Other uses and strategies

There is an extensive array of potential uses of biomass ash, some include adsorbents, catalysts, wastewater and soil stabilisers and road construction materials. One solution targets a lower carbon footprint from the combustion of wood biomass and different mixtures including bark or paper sludge to manage the right chemistry (Tosti *et. al.* 2021).

There is also keen interest in the partial replacement of cement in concrete with a successful example already reported from a 2023 implementation at Golden Bay Cement (https://www.genesisenergy.co.nz/about/news/golden-bay-and-genesis-create-sustainable-solution-for-ash).

Ash minimisation or De-ashing is another important innovation focus (Huang *et al* 2025). Pre-treatment of the biomass feedstock with a range of washing processes for extracting specific chemistry and increasing conversion efficiency. Emerging microbial de-ashing methods use microorganisms to help ash removal through various mechanisms (Huang *et al* 2025) such as i) enzymatic hydrolysis that helps break down the biomass for more efficient pyrolysis, ii) organic acid produced by microbes can solubilise ash components and iii) biosorption involves microbial cell surfaces interacting with ash components for improved removal.

In New Zealand critical questions and strategies remain to be determined for who pays for the ash product. Is it producer pays? or user pays? or what is the combination? Is it such a burden that the producers will need to pay? Or is it such a benefit to forest productivity that Forest Managers will pay? Given that the product comes from forest utilisation, the appropriate answers seem complex and are likely to shift over time.

Strategic outlook and research requirements

In New Zealand, the current legislation is restricting coal use, and the gas supply is also in significant rapid decline, the transition to wood fuels is expected to accelerate rapidly over the next 5 –10 years. This shift will likely include greater use of forest harvest residues, which tend to produce greater ash content than mill residues because of minor additional soil contamination during forest extraction. This evolving energy landscape presents a critical opportunity to reframe wood ash not as a waste product, but as a valuable resource for nutrient recycling, soil amendment, and carbon-smart forestry practices. Unlocking this potential will require coordinated efforts across policy, industry, and research to develop cost-effective, scalable ash utilisation pathways.

Conclusions and recommendations

Forestry biomass ash production clearly represents both a future concern and a circular economy opportunity. Progress in New Zealand is significantly behind international role models such as Nordic countries. Many of the key unknowns are listed as proposed research aims and requirements or would be highlighted by further research on ash utilisation in New Zealand.

We propose that the following tasks and research aims are practical ways to grow the understanding required to ensure the best outcomes in the future.

1) Ash Resource, Quality & Variability

R1. National ash atlas & forecasting

- Questions: Where, how much, and what type of ash will be produced over the next 10 –15 years under different fuel-switch scenarios (BAU, coal to biomass switching, gas decline and gas to biomass switching)
- Methods: Integrate and update Bioeconomy Science Institute Heat Plant database + EECA Regional Heat Demand + Energy End-use database; scenario modelling (biomass to heat and CHP uptake, residue vs mill fuel splits); spatial allocation (plant locations, transport networks).
- Outputs: GIS layers & dashboards (volume/ash type by region/site/month), uncertainty bounds; prioritisation map for pilot deployments in relation to forest area, age class and harvesting plans.

R2. Ash characterisation by source and process

- Questions: How do bottom ash, multicyclone fly ash, and ESP fly ash differ in nutrient content, alkalinity, solubility, bioavailability, and contaminants (e.g., As, Cd, Pb) across NZ fuels (radiata residues vs mill residues) and furnace types (grate vs fluid beds).
- Methods: Standardised sampling campaign (≥ 20 plants); proximate/ultimate; major/minor elements; pH, ANC, leaching tests based on standards such as EN 12457/SPLP; particle size; hygroscopicity; speciation for P, K, Ca, trace metals.
- Outputs: NZ reference database; Quality assessment/control protocols; batch-blending rules to meet end-use specs.

R3. Stability & shelf-life under NZ storage conditions

- Questions: How do moisture, CO_2 carbonation, presence and proportion of unburnt carbon and pile management affect ash reactivity, dust, and leachate chemistry?
- Methods: Controlled storage trials (covered vs uncovered, pelletised vs loose); seasonal trials in high-rainfall regions.
- Outputs: Best-practice storage and handling SOPs; emissions/leachate factors for consenting.

2) Soil, Forest Productivity & Environmental Safeguards

R4. Targeting: where ash gives the biggest productivity and pH gains. (Glasshouse trials?)

- Questions: Which sites, (low base ion status, high rainfall, intensive residue removal) benefit most?
- Outputs: Site selection tool for managers; indicative ash application rates by soil order. Transport distance.
- How much of the current fertiliser can be replaced at what cost advantage.

R5. Field trials: liming & nutrient-replacement efficacy

- Questions: What application rates and forms (loose, granulated, ash+lime, ash+biochar, ash+molasses binder) optimise pH, base saturation, and tree growth response without toxicity.

- Methods: Multi-site randomised trials; rates of application, soil/foliar/biomass responses (0–5–10 years).
- Outputs: Dose–response curves; calibrated guidance for operational use; cost–benefit by site class.
- Adding wood ash to existing fertilisers (super phosphate, DAP, urea etc) to get it applied in one operation for operational efficiency.

R6. Leaching, toxicity & biota impacts

- Questions: Under NZ forestry soils and rainfall regimes, what are the leaching risks (Cl, K, Na, B, heavy metals), stream health effects, and mycorrhizal responses?
- Methods: Lysimeters and paired-catchment studies; ANZECC comparisons; microbial DNA profiling; earthworm / macroinvertebrate bioassays.
- Outputs: Environmental thresholds, buffer zones, and application controls for consents.

3) Products, Specifications & Engineering

R7. Granulation and slow-release formulations

- Questions: What binders and process conditions create durable, flowable, low-dust granules (e.g., ash+lime, ash+molasses as per Polish work), with controlled dissolution?
- Methods: Pilot granulation (disc/pan); attrition & moisture cycling; dissolution kinetics in soil columns; agronomic performance.
- Outputs: Product specs (size, hardness, Acid Neutralising Capacity [ANC], solubility), manufacturing SOP, preliminary safety datasheets.

R8. Standards & certification pathway for NZ

- Questions: What specification envelope (nutrients, ANC, contaminants, leachability) ensures safety and performance, referencing Nordic/EU precedents (e.g., Finland limits)
- Methods: Gap analysis vs NZ biosolids/soil amendment regs; propose a forestry-ash technical standard; ring-fence limits by application type (forest vs pasture vs rehab).
- Outputs: Draft standard + test methods; template for EPA/RC consenting and industry CoP.

4) Climate, LCA & BECCS Integration

R9. Full life-cycle assessment

- Questions: Net GHG impacts of ash recycling (transport, processing, soil liming effect, cement substitution, avoided landfill emissions)?
- Methods: ISO 14040/44 LCA; NZ emissions factors; spatialised transport models; uncertainty analysis.
- Outputs: Verified carbon accounting framework for reporting and incentives.

5) Demonstrations & Scaling

R10. Regional pilots (2–3 years)

- Design:
- Regions: Waikato, Bay of Plenty, Nelson (highest ash supply) + a South Island site (Southland/HB/Canterbury).
- Treatments: Ash (loose vs granule), ash+lime, ash+biochar, controls; variable rates.
- Metrics: Soil pH/base saturation, P/K/Ca/Mg, foliar status, growth increment, leachate chemistry, biodiversity indices, operational costs, dust/H\&S.
- Outputs: Operational playbooks; ROI and emissions outcomes; stakeholder case studies.

R11. Monitoring & verification (M&V)

- Questions: How to verify nutrient replacement and environmental compliance efficiently?
- Methods: Remote sensing (hyperspectral for canopy nutrition), UAV foliar proxies; in-field pH/nutrient sensors; eDNA for biota.
- Outputs: M&V protocol accepted by regulators; reduced monitoring cost per hectare.

Indicative timeline & dependencies

- Phase 1 (0–12 months): R1–R3, scoping, regulatory roadmap (R8), pilot design (R10).
- Phase 2 (12–36 months): Field trials (R4–R6), granulation/product, logistics & ops (R10), LCA (R9).
- Phase 3 (36–60 months): BECCS integration (R9), national guidance & standards, scale-up via regional hubs (R11).

	Year 1			Year 2			Year 3	Year 4		Year 5
	Scoping	Regulatory roadmap	Pilot design	Field trials	Product granulation	Logistics and Ops	LCA	BEECS integration	National standards	Scale up regional hubs
Phase 1										
Phase 2										
Phase 3										

Success metrics (preliminary examples, needs further discussion)

- ≥ 70% diversion of *qualifying ash* from landfill in pilot regions by Year 3.
- +0.3–0.7 pH units increase at targeted sites within 12–24 months post-application.
- 2–5% MAI uplift on low base-status sites 5–10 years.
- 15–35% net GHG reduction vs landfill baseline, verified by LCA.
- ≥ 20% lower delivered nutrient cost vs conventional lime/fertiliser on matched sites.
- Regulatory acceptance of an NZ forestry-ash standard and M&V protocol.

Potential funding & partners (NZ)

- Funding: MBIE Endeavour, FGR, EECA, MfE Waste Minimisation Fund, MPI, regional councils, industry co-funding (pulp & paper, timber processors, energy users).
- Delivery partners: Bioeconomy Science Institute (lead), Forest owners, universities (Canterbury, Waikato), iwi partners, processors (Oji, Pan Pac, Laminex…), spreading contractors, councils.

Immediate next steps

1. NDA outreach to boiler operators for sampling commitments.
2. Pilot sites shortlist using Table 1 regions + soil risk layers.
3. Methods harmonisation (sampling, analytics, field design) across partners.
4. Regulatory pre-consultation with two regional councils to align on evidence needs.
5. Draft product specs (granule / slow release) to anchor R7 supplier discussions.

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Appendix

Abbreviations

MWh	Megawatt hour
GWh	Gigawatt hour (1000 MWh)
GJ	Gigajoule (1 GWh = 3600 GJ): 1 GJ = $1*10^9$ J
TJ	Terajoule (1000 GJ or $1*10^{12}$ J)
PJ	Petajoule (1000 TJ, 1,000,000 GJ or $1*10^{15}$ J)

Assumptions

Boiler efficiency on wood fuel = 80%. Modern wood boilers should be 85 to 87% efficient – but we assume the existing units in many cases are quite old.

Boiler loading = 70%. An estimate of the number of hours in a year that a boiler is running at capacity.

3.6 GJ per MWh

6.9 GJ per green tonne

Basic density of wood 380 kg per m^3

Ash content = 1.2% of oven dry weight, based on an average across wood processing residues such as sawdust, shavings, chip and hogged offcuts at the landing.