The ENZ Manual

Contents

About this document

This manual accompanies the public release of the 'Emissions in New Zealand (ENZ)' model by He Pou a Rangi Climate Change Commission (the Commission). It provides a guide for using the model and a summary of some of the core functionality and architecture.

This document is the second version of the ENZ Manual and was published on 8 April 2024.

Software required

The ENZ model has been developed and tested to work on the latest version of Microsoft Office on a Windows 10 Enterprise device. Visual basic macros will have to be enabled in Excel in order for the model to run. Performance may be reduced, or the model may not function on legacy versions of Excel or under alternative operating systems.

Installation

The ENZ model is provided as a zipped file for download and the file contents will have to be extracted into a local directory. By default, Excel opens spreadsheets with macros disabled and the 'Enable Content' prompt will have to be accepted in order for the model to run. If asked to make the file a trusted document, select 'yes'.

Model structure

ENZ is an Excel based model with functionality distributed across multiple linked workbooks. The workbooks disaggregate the core emitting sectors of the economy into heat, industry and power (HIP.xlsx), transport (Tpt.xlsx), and land use and waste (LnW.xlsx). The structure of the workbooks and key interactions is depicted in Figure 1 below.

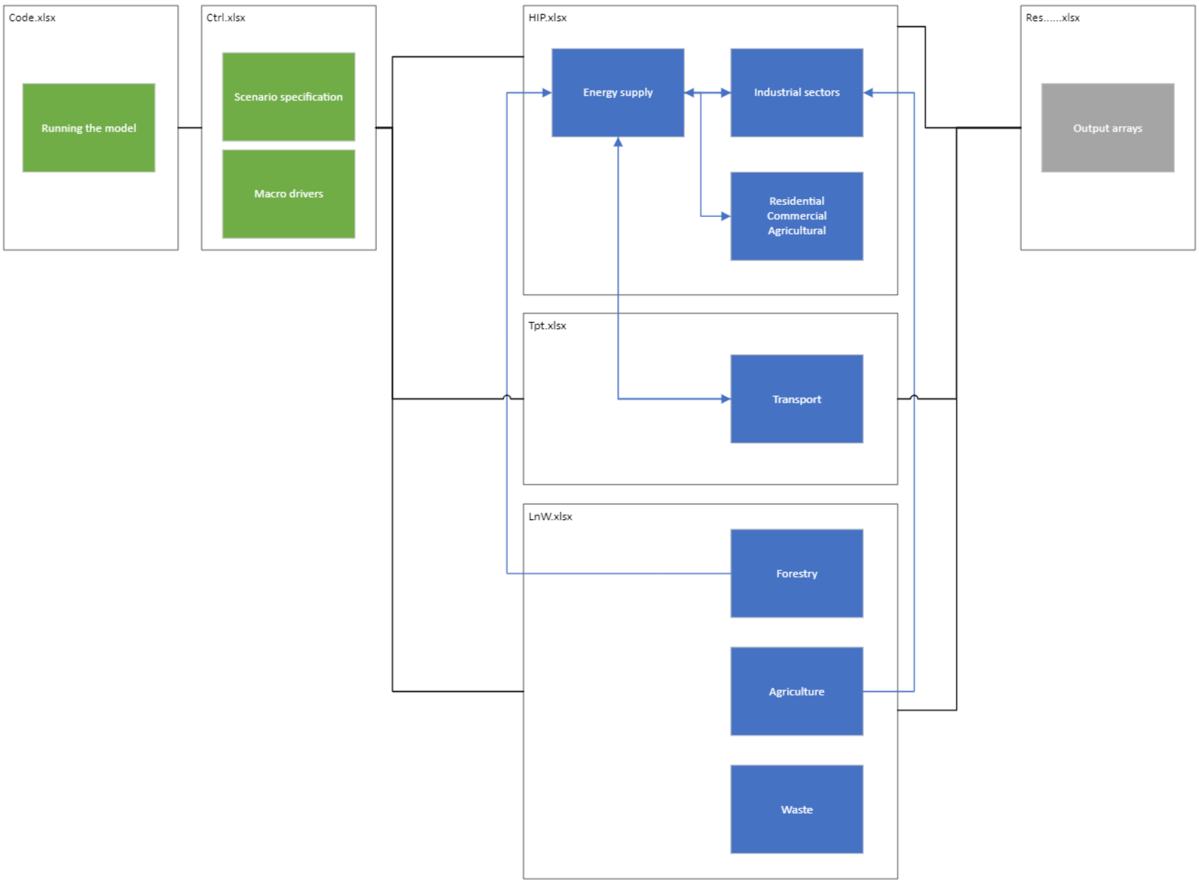

Figure 1 The structure and linkage between workbooks of the ENZ model

The **Code** workbook is used to initiate a model run. It has a number of underlying Visual Basic (VB) routines which pass settings to the other workbooks, drive some of the workbook interactions and copy back specified output arrays into a results file.

The **Ctrl** workbook is the control panel for the model and is used to set the main model scenario parameters.

The **heat, industry, and power (HIP)** workbook contains the underlying data and projection functionality for energy use and emissions from industrial, residential, commercial, and agricultural sectors. The workbook includes detailed models of electricity supply and fossil gas production and has significant interactions with the **transport** workbook.

The **transport** workbook (Tpt.xlsx) contains the underlying data and projection functionality for transport activity and emissions. This workbook interacts heavily with the **HIP** workbook by setting the requirement for oil products, biofuels, and electricity demand from electrification of transport. Transport outcomes are driven by the price of electricity which is calculated endogenously and passed from the **HIP** workbook.

The **land and waste** workbook (LnW.xlsx) contains the underlying data and projection functionality for activity and emissions source or removals in the agricultural, forestry and waste sectors (note that emissions from energy use in the agricultural sector are included under the **HIP** workbook and the **land and waste** workbook includes emissions from livestock). Forestry and agricultural production projected in the **land and waste** workbook provides an input to the **HIP** workbook where it sets the requirement for food processing and the availability of biomass as an energy resource.

When a model run is completed the output arrays which have been selected are saved into a unique results file which is identified with a timestamp.

Model use

The model allows a scenario-based approach for projecting future emissions and other outcomes of interest. A scenario is a set of coherent assumptions about how the world might develop. A scenario-based approach allows the user to examine alternative ways that future emissions could evolve and the impact of some of the key uncertainties around assumptions.

The ENZ model is largely controlled from the **Scn** worksheet of the **Ctrl** workbook. This sheet is referred to as the control panel from here on in.

Once scenarios have been defined the model is run using the **Code** workbook.

Defining a scenario

Scenarios are defined by a set of scenario parameters which drive outcomes in one or multiple dependent workbooks. Parameters can either specify a key input – such as the oil price – or set an alternative modelling dynamic which is to operate. The scenario parameters are broken down under the categories of Carbon pricing parameters, Economic driver parameters, HIP parameters, Transport parameters, Land parameters and Waste parameters.

Scenarios are defined in the columns across the control panel, starting from column I. The entries in column I of the **Ctrl** workbook define *the reference scenario*. Scenarios can be defined in relation to another scenario. Where a parameter is left undefined, the scenario inherits the parameter of the parent scenario. In this way it is possible to specify only the parameters which are different.

When completing a model run, a scenario will be run if an ‘x’ is set in the run column (row 2).

The **Ctrl** workbook comes prepopulated with the scenario definitions which were used in our draft advice on the fourth emissions budget. New scenarios can be added as new columns.

Common scenario parameters

The emission pricing and economic driver projections are used in a number of the model workbooks. The projections of these are built up in the Assumptions worksheet of the **Ctrl** workbook. The functionality on this Assumptions worksheet is largely the selection of projections in predefined arrays based on the scenario parameter settings which are then linked to the model workbooks. There are options for defining new emission value paths and it is simple to adjust settings for the other arrays.

Running the model

The *run* button in the **Code** workbook is pressed to run the model. This launches a routine which steps through all the scenarios selected on the control panel, performs the model calculations, and saves the specified output arrays into a results file.

Specifying output to include in results file

In addition to the core set of outputs, the user can specify whether to include additional outputs aligned in format with the greenhouse gas inventory. This is set using the *Results to include* parameter in the control panel. A value of '1' outputs the core set, while a value of '2' will include the core set, inventory output and outputs needed for the C-PLAN model.

The results file

When the model runs it copies the outputs for the specified scenarios into a results file. The filename begins with 'Res_' and is appended with a datetime string e.g., the file 'Res_202107161620' is a record of a model run that was started on the 16th of July 2021 at 4.20pm. The results files are saved into the Results directory in the directory where the model runs.

The 'RunParams' worksheet of the results file is an exact copy of the control panel and so records the particular settings for each model run. The 'Runs' worksheet lists each of the model runs completed. Each run is listed alongside a long string of all the assumptions selected for that particular run. The "Res" tab contains one large table with all results from all model runs. This table has a number of columns which are used to identify each results sub-table.

- Column A "Scenario" – contains the name of the model run the results relate to (e.g., "EB4 demonstration path").
- Column B "Class" – contains the highest-level grouping of results type (e.g., inventory, emissions, financial).
- Column C "Table" – contains the name of the sub-table (e.g., "Summary_All_Emissions")
- Column D "Unit" – the unit the results row is measured in (e.g., ktCO2e)
- Column E "Sector" – sector or group the results relate to (e.g., "Transport", also includes "Net" and "Gross")
- Columns F-K "ID1"-"ID6" – additional columns to identify the specific results each row relates to.
- Column L "LongName" – relates specifically to the results that align with the greenhouse gas inventory groupings. Contains the long name from the inventory.
- Columns M-CT "1990"-"2075" – contains the results for each year. Projected values generally start from 2022.

Live viewing a scenario

A scenario can be selected for live viewing by setting cell E1 of the Ctrl workbook to the desired scenario number (e.g., the EB4 demonstration path is scenario number 7). This sets the scenario parameters in all of the dependent workbooks (HIP_02.xslx, Tpt_02.xlslx, LnW_02.xlsx) to the values defined in the **Ctrl** workbook and so enables one to inspect in detail the model calculations.

The **waste** and **land** workbooks take inputs only from the **Ctrl** workbook and so they can be opened and inspected without complications. However, because of the interactions between the HIP, transport and other workbooks, and the use of VB code driven hardcoded values, the following steps should be taken to ensure they are correctly live viewed:

- The **transport** and **HIP** workbooks use live links and should be opened together to ensure up to date values are being linked between them.
- The *Iterate HIP* button in the **Code** workbook should also be run. Several electricity pricing arrays in the **HIP** workbook are calculated dynamically based on demand. The iterate HIP routine copies these arrays and pastes them as fixed values, which subsequent calculations then depend on. The routine repeats this copy → paste → recalculate until the model has sufficiently iterated to arrive at a solution.

The HIP workbook (HIP_02.xlsx)

Overview

The **HIP** workbook includes a breakdown of all non-transport energy consuming sectors and makes projections of future levels of activity, energy consumption and emissions. The model represents a diverse range of emitting activities and varied opportunities to mitigate. Some industries operate at a single site and there is considerable uncertainty around their future operation, whereas other sectors consist of many agents. A varied approach to modelling is applied.

The workbook also includes modules representing energy supply which interact with the consuming sectors through prices and also contribute system emissions. Electricity generation and fossil gas production are represented at a high level of detail within ENZ with endogenous supply modules representing generation/production and transmission/distribution to consumers. Biofuels, oil, and coal are also modelled in ENZ, but at a more basic level.

Figure 2 below illustrates the core functions and interactions within the **HIP** workbook and with the **transport** and **land and waste** workbooks in ENZ.

Description of the HIP worksheets

There are six key worksheets within the **HIP** workbook. The **Ctrl** worksheet contains a subset of the scenario settings from the control panel which are relevant to the **HIP** workbook. The **Param** worksheet summarises the key constants and assumptions that drive the model. The relevant macro driver assumptions which flow through from the control workbook are staged here, and the HIP relevant scenario parameters are applied to select assumption values applied in each scenario. Note that there are many other assumptions which are selected and applied in other parts of the workbook. The worksheet also summarises the key equipment costs which are used in the economic output.

The **For** worksheet contains most of the sector detail and the functionality depicted in Figure 2. The worksheet is structured with inputs from other workbooks and historical inputs at the top. Projections that drive future demand for energy, such as the building stock model, population and GDP projections, and energy efficiency improvements are grouped together.

The different industrial segments modelled individually are grouped together under the *Specific industrial segments* grouping. This is followed by projections of emissions specifically relating to coal, liquid fuels, and gas and LPG. The electricity modelling follows this. Electricity demand is modelled first, followed by networks and then generation.

The **For** worksheet also includes some economic reporting including consumer and household bill impacts. These costs are built up from the energy cost calculations and assumptions about capital and operating costs for equipment.

The *Final results table* grouping contains the results which are transferred into the results file.

The **GNB and ENB** worksheets contain calculations of the costs and associated required revenues of the gas and electricity network businesses respectively.

The **G2X** worksheet contains the detailed fuel switching calculations for fossil gas. These are only used when fossil gas phase out assumptions are not set exogenously.

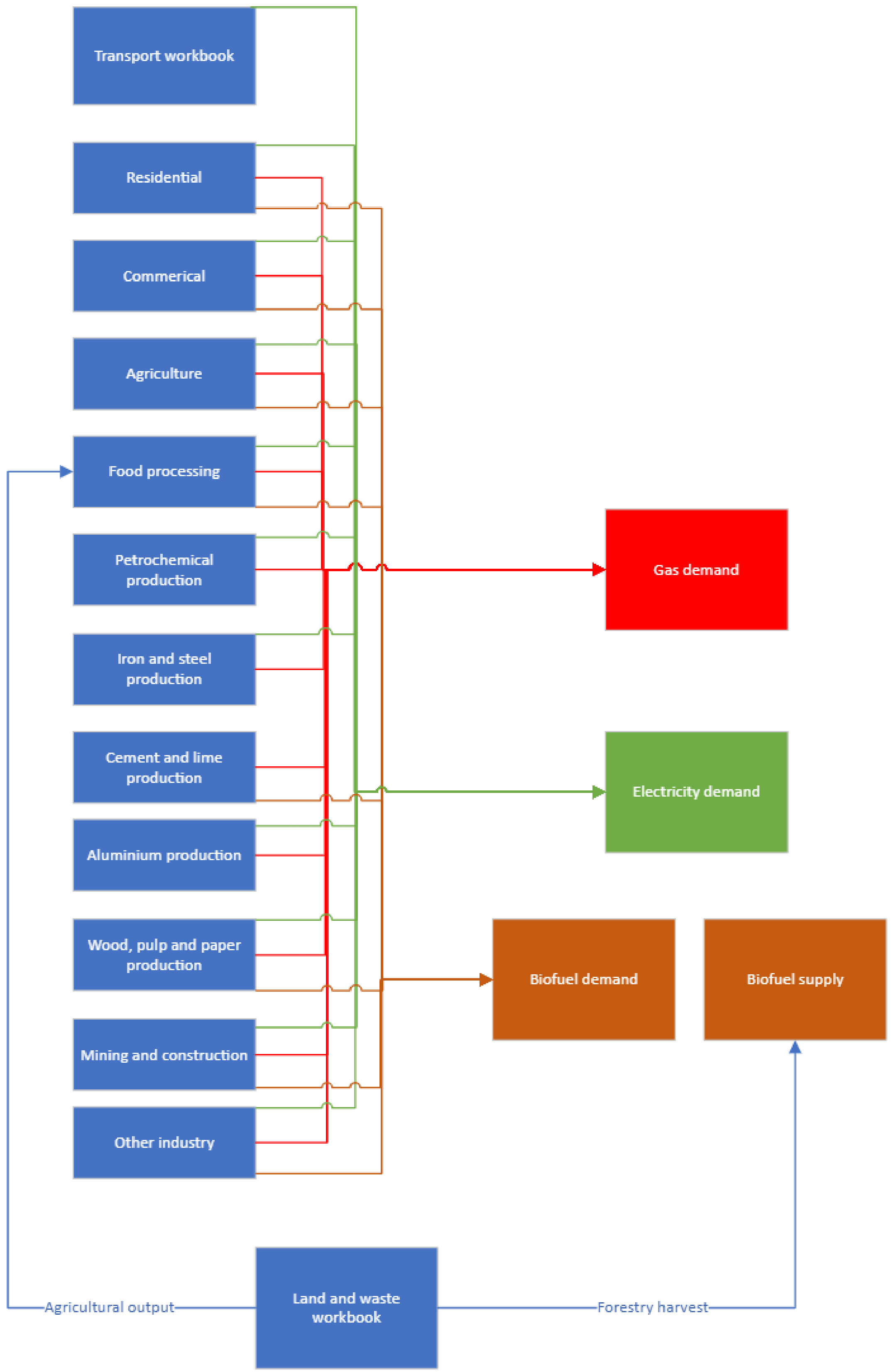

Figure 2 The HIP workbook and linkages with land and waste and transport, showing energy consuming and emitting sectors and their interaction with dynamic supply and demand modules. Note that this is a simplification of the model and not all linkages are shown.

Input data

The 2023 Greenhouse Gas Inventory ('the Inventory') provides a record of annual emissions in Aotearoa from 1990 to 2021. This data source follows a recognised system of emissions classification based on an established reporting framework. The Inventory is the highest tier data source for ENZ and provides the reference from which emissions are projected.

The Inventory includes a detailed disaggregation of emissions into sectors, activities, and types. ENZ has aligned with this and produces outputs of emissions mapped to the Inventory classifications.

Fossil fuel consumption has been calculated from Inventory fuel combustion emissions by assuming constant emission factors for each fuel. The Energy Balance tables published by MBIE have been used to enrich the model of energy use as it provides non-energy use of fuels and statistics for renewable energy and electricity. There is imperfect matching between fuel consumption values derived from Inventory emissions and the Energy Balance tables due to a difference in methodology – where conflicts exist, fuel totals derived from the Inventory are used.

The Energy End-Use Database created and maintained by the Energy Efficiency and Conservation Authority (EECA) is used to disaggregate fuel use by different end uses, such as space heating, water heating, cooking, and lighting.

Residential, commercial and agriculture sectors

Energy use in the residential, commercial and agriculture sectors (RCA) is disaggregated by fuel and end use. EECA's energy end use database is used as a base year representation of how energy is used in terms of space heating, water heating, process heat, lighting, and other electrical and motive power.

Most of the energy use in residential and commercial sectors is through space and water heating in buildings. Using a building stock model, the demand for useful heat for these applications is projected. A number of dynamics are represented in this model including the construction of new buildings, the retrofit of existing buildings, and the demolition of old buildings. Improvements in energy efficiency which reduce the demand for useful heat are applied by assumption for new buildings and retrofits – this is adjusted by the scenario parameter *Building retrofit rate and energy efficiency improvements*. The assumed population growth inputs to the model through the total number of ICPs (individual connection points).

The extent to which different heating types (fossil gas or electric heating) meet the demand for energy services is based on exogenous phaseout profiles for fossil gas and coal heating. The fossil gas profile is selected using the *Pipe Res, Pipe Com, LPG Res,* and *LPG Com* parameters on the control panel. The coal phase out is implicitly assumed to occur by 2032 for residential, and 2037 for commercial, driven by the 'National Direction' policy on industrial process heat.

There is also functionality to select the heating type based on the relative costs of the two systems – the selection considers the combined appliance and delivered energy costs over the lifetime of each appliance. The appliance component of these costs is built up from the *Cost breakdown for average-sized consumer* detail in the **Param** worksheet and the energy costs are endogenous within **HIP**.

Mobile machinery and off-road vehicles

A large share of the energy use in agriculture is for off-road vehicles and machinery, and the residential sector includes energy use from liquid fuel used in recreational boating. Although there are a diverse range of activities that this term will encompass, it is assumed that electrification of these vehicle types will become increasingly feasible and economic in the future. The model uses the electrification of the heavy truck vehicle class in the **transport** workbook as the basis for projecting the electrification of off-road vehicles and machinery in the **HIP** workbook. Because off-road vehicles may not electrify as quickly as heavy trucks, there is capability to apply a lag to the electrification. The electrification rate of recreational boats are set by assumption. These assumptions are defined in the *Off-road liquid fuels decarb scenarios* section of the **Param** worksheet and set using the *Off-road liquid fuels* parameter on the control panel.

Note that this also applies for motive power use in the industrial sectors.

Energy supply modules

ENZ includes detailed supply modules for electricity and fossil gas and basic modules for oil and coal. The demand for the fuel is built up from the projected consumption from the industrial, residential, commercial, agriculture and transport sectors. Energy losses through fuel delivery are applied on top of this, which then sets the requirement for electricity generation and fossil gas production. These modules meet supply with allocated resources (potential renewable projects for electricity generation and estimates of field potential for fossil gas).

The cost of fuels is built up from the wholesale price of production, the carbon cost from the modelled emissions value, the cost allocation from supply infrastructure, and a retail charge. These prices become inputs into the modelled fuel switching dynamic for the consuming sectors which don’t have exogenous fuel use assumptions.

Industrial sectors

For each industry a projection of activity is made which sets a demand for useful energy. Improvements in energy efficiency are applied which reduce this demand for useful energy and fuel switching transforms the energy supply to lower emissions fuels. The resultant fossil fuel combustion sets direct emissions for the sector and the demand for fossil gas and electricity feed into respective energy supply modules.

The fuel switching dynamics are generally specified exogenously so that factors other than price can be accounted for. There is also functionality to enable price driven fuel switching dynamics which considers the relative costs of continuing to operate fossil fuel assets versus converting to electricity or in some cases biomass. The use of fossil fuels in industry is generally separable into providing process heat or motive power.

Food processing

This module first projects the demand for useful heat at a regional level based on the outputs of the agricultural module of the **land and waste** workbook and using a base year map of process heat demand. This demand is disaggregated into useful heat from coal, fossil gas and diesel for the subsectors of dairy, meat and other food processing based on the EECA energy end use database.

Energy efficiency improvements are applied based on scenario parameters to reduce the demand for boiler heat based on scenario settings. The efficiency improvements cause an increase in electricity demand as it is assumed that some of these measures involve the integration of heat pumps. These are specified using the *Food processing energy efficiency* parameter in the control panel.

The residual heat from coal, fossil gas or diesel boilers can then be converted to biomass or electricity. The module considers the availability of forestry residue and pulp logs which can be used as boiler fuel for each region and projects the costs of delivered fuels.

The fuel switching is driven by exogenous assumptions which are specified using the *Pipe Ind BH, Pipe Ind FH, LPG Ind BH* and *Coal Ind BH* in the control panel.

There is also a price driven functionality that the model can use. In this case the fuel switching considers the relative cost of continuing to operate fossil fuel assets versus replacing boilers or cofiring and paying for an alternative fuel. Fuel switching options are ranked based on the costs of abatement and taken up at the point they become cost effective. This is subject to fuel availability constraints and conversion rate constraints. The assumed emissions value drives much of the fuel switching.

Petrochemical production

This module includes methanol, urea, and historical synthetic petrol production. The future level of activity of this sector is projected based on exogenous assumptions around the timing of plant closure. The two methanol producing trains and the urea plant in Taranaki are modelled explicitly and it is assumed they operate at a constant rate. The sequencing of plant closure, or their continued operation are set by assumption, as well as the option to reopen the mothballed Waitara Valley methanol train. Decarbonisation assumptions for urea production including switching to green hydrogen-based production can also be set by assumption. These assumptions are defined in the *Petro* section of the **Param** worksheet and selected using the *Petrochem scenarios* section in the control panel.

Iron and steel production

This module projects a constant level of future steel making activity with the ability to convert the Glenbrook operation to electric arc furnace and/or green hydrogen-based production. The timing and extent to which these processes are adopted are defined in the *Steel scenarios* section on the **Param** worksheet and selected using the *Steel scenario* parameter on the control panel.

Adoption of either of these processes has a flow on effect to the electricity system. In both cases demand for fossil gas and coal decrease and increase the demand for electricity. Further to this they also reduce or remove the self-cogeneration currently operating at the Glenbrook Steel Mill, further increasing demand from the grid.

Cement and lime production

This module projects a constant level of future activity for domestic cement, lime, and glass production. Substitution of coal with tyre-derived-fuel (TDF) and biomass is applied and reduces the emissions from process heat. The biomass uptake and TDF substitution levels are exogenously specified. These assumptions are defined in the *Cement scenarios* section of the **Param** worksheet.

The emissions from the combustion of fossil gas and diesel are fixed as these are considered high-temperature applications which are difficult to substitute. Industrial processes and product use (IPPU) emissions which result from the calcination reaction are also constant.

Aluminium production

The future activity of the aluminium smelter is projected based on exogenous assumptions around closure or continued operation. These scenarios are selected using the *Tiwai exit from* parameter on the control panel. There is also functionality for the smelter to convert to a zero-emissions process using zero carbon anodes. This is selected using the *Tiwai green anodes from* parameter on the control panel.

Wood, pulp, and paper production

It is assumed that this sector maintains a constant level of activity and demand for useful energy into the future.

Fuel switching from fossil gas and coal to biomass for process heat is specified exogenously. These follow the same fossil fuel phase out profiles as are used for food processing.

There is also a price driven functionality that can be used within the model. A cost of abatement for fuel switching is calculated based on the relative delivered energy prices. As the emissions value approaches this cost of abatement for fossil gas and coal conversion, the share of biomass increases. Rate constraints set the maximum speed at which the fuel share can change and is assumed that some proportion of fossil gas will always be required for high temperature process heat applications. A large proportion of pulp sector fossil gas use is consumed at the Kinleith plant and its conversion to a high efficiency recovery boiler is exogenously specified and varied between scenarios using the scenario parameter *Kinleith HERB date.*

The wood processing sector also consumes significant amounts of diesel for motive power applications. These applications become electrified within the model using the mobile machinery and off-road vehicles fuel switching dynamic described in the Residential, Commercial, and Agriculture section of this manual.

Mining and construction

Demand for useful energy in mining and construction is assumed to increase proportionally with GDP and population respectively. Most of this energy demand is for motive power and ENZ models the conversion of diesel motors to electric motors by applying the off-road vehicles and machinery fuel switching dynamic described in the Residential, Commercial, and Agriculture section of this manual.

Process heat makes up a small proportion of sector fuel usage and is modelled using the exogenous phase out profile specified on the control panel using the *Pipe Ind FH* parameter.

Other industry

This industry collates the residual energy use which is not represented in the previous sectors. A growth in demand for energy in this sector is projected which is based on the historical relationship with population. The growth projected in this sector therefore depends on the exogenous population projection used as a macro driver for this modelling.

Fuel switching energy use in other industry is based on detailed dynamics represented in other parts of the model. For process heat, the exogenous phase out profiles are followed. For motive power applications the off-road vehicles and machinery fuel switching dynamic described in the Residential, Commercial and Agriculture section of this manual is applied.

Fossil fuel production

Although not outlined explicitly in the **HIP** worksheet, fugitive emissions from the production and distribution of fossil gas are accounted for in ENZ. It is assumed that these emissions remain proportional to relevant proportions of fossil gas volumes. For example, fugitive emissions from the distribution of fossil gas are proportional to total distribution pipeline volumes.

New industrial segments

The model includes functionality to account for new industrial electricity demand. In particular, future electricity demand from new data centres can be specified using the *New load: Data centres* parameter on the control panel. The scenarios for this are defined in the *new industrial electricity demand* section of the **Param** worksheet.

Key linkages

The **HIP** workbook provides outputs and accepts inputs from all the other model workbooks. By including these key linkages ENZ can build up a systems perspective of emissions. The main links are depicted in Figure 2 and are summarised as follows:

- Regional agricultural production of milk solids and meat is an input from the **land and waste** workbook. This sets the requirement for process heat from the food processing sector which is modelled in **HIP**.
- Regional harvest of pulp logs and the availability of forestry residue is an input from the **land and waste** workbook. These sources of biomass are utilised as boiler and kiln fuel for industrial process heat and for the production of liquid biofuels.
- The demand for electricity for the electrification of transport is an input from the **transport** workbook. This sets the requirement for electricity generation which is modelled in the **HIP** workbook. The **HIP** workbook calculates the price of electricity which feeds back through into **transport** workbook and influences electrification of transport.

The Transport (Tpt 2.0) workbook

ENZ includes road transport, rail, shipping, and aviation, with the latter two split into domestic and international. Road vehicles are divided into light passenger vehicles (cars and SUVs), light commercial vehicles (vans and utes), motorcycles, buses, medium trucks (defined as less than 30 tonnes gross vehicle mass (GVM)) and heavy trucks (over 30 tonnes GVM). ENZ models the dynamics of the transport fleet, such as vehicle scrappage and the pattern of usage over a vehicle's life, based on fleet statistics published by the Te Manatū Waka Ministry of Transport. The model also includes different fuel types: fossil fuels, electricity, hydrogen, and biofuels or other synthetic fuels.

ENZ models the main levers which influence emissions, including transport demand and the size and makeup of the vehicle fleet, based on factors driving them, such as population. It also accounts for projected improvements in vehicle efficiencies.

ENZ takes account of behavioural change, including mode shift for passenger and freight transport and reduced demand for travel. These behavioural changes are input as scenario assumptions; ENZ does not model changes in travel behaviour in response to factors such as changes in fuel prices. ENZ draws on underlying regional travel data and projections from the Ministry of Transport and aggregates these into five broad regions: Auckland, Waikato, Wellington, Canterbury, and the rest of Aotearoa.

Mode shift and Travel and freight demand

The Transport workbook uses the Ministry of Transport's Transport Outlook base case, updated in 2020 for baseline travel demand projections. This outlook gives the demand for household travel, commercial travel, freight, and domestic aviation by region in 5-year intervals. The outlook data is located in the Mode worksheet of the transport. passenger travel is aggregated into 5 regions (Auckland, Waikato, Wellington, Canterbury, Rest of NZ). Freight and commercial travel are aggregated at a national level.

ENZ includes the functionality to change the share of modes which satisfy the demand for travel. The *Passenger mode shift* scenario parameter selects between the mode shift scenarios defined in line in the *Scenario build step 3* section of the Mode. Mode shifts are defined at a regional level for passenger person-kilometre-travel across the categories of pedestrian, cyclist, micro-mobility, local train, local bus, local ferry, motorcycle, and taxi/vehicle share. Light vehicle travel makes the up the residual travel demand. For national freight, travel can shift from road to rail and costal shipping based on the *Freight mode shift* scenario parameter. Note that mode shares changes are specified as relative the MoT baseline at 5-year intervals.

Vehicle travel is based projected 2023 vehicle kilometres travelled (VKT) projections from Mot. mode shift affects. We are mode shift is applied reference road VKT is adjusted based on the percentage difference in VKT/ capita and/or VKT/gross domestic product (GDP).

Additional, reductions in vehicle travel due to demand reductions can be applied in the **Param** sheet. The Commission's scenarios considered only reductions in travel demand applied evenly across all regions.

Demand reduction can also be applied to domestic and international aviation. This is based on percentage change the annual average growth rate.

Road transport

ENZ includes representations of the following vehicle classes:

Vehicle class	ENZ abbreviation
Light passenger vehicle (car, SUV)	LPV
Light commercial vehicle (van, ute)	LCV
Medium trucks	MT
Heavy trucks	HT
Bus (includes public transport buses and coaches/other)	Bus
Motorcycles	MC

The travel demand projections are translated into vehicle-kilometres travelled (VKT) for these vehicle classes in the *Resultant scenario projections of travel* section of the **Mode** worksheet. This translation applies assumptions and changes to the split between LPV and LCV use for passenger and commercial travel (this accounts for the use of utes for household travel). The *Passenger mode shift* scenario parameter is used to drive these changes.

A vehicle stock model which accounts for turnover the vehicle fleet is set out in the **Road** workbook. The number of vehicles for each vehicle class is calculated based on the total projected VKT divided by the VKT/vehicle. The VKT/vehicle projection used in the model is based on the MoT base case. Note that it demonstrates an increase in the VKT/vehicle (i.e., a greater utilisation of vehicles) due to the increasing proportion of PKT met by rideshare and other means. A short run adjustment factor is added to give a lag between reductions in VKT and reductions in the size of the vehicle fleet in scenarios with significant VKT reductions.

The annual rate of vehicle scrappage, which applies to the stock model, can be either specified as a percentage of fleet size for each vehicle type or calculated dynamically based on VKT. Dynamic scrappage uses historical patterns in scrappage and adjusts it based on changes in VKT and a factor that determines the degree of response. This results in higher scrappage rates where VKT growth is low. The annual number of vehicles entering the fleet is calculated as the difference between the total number of vehicles and the number scrapped.

New vehicles entering the fleet can be either:

- petrol internal combustion engine (*petrol)*
- diesel internal combustion engine (*diesel)*
- battery electric (*BEV*)
- plug-in hybrid electric vehicle (*PHEV*)
- fuel cell electric vehicle (FCEV).

The selection of vehicles entering the fleet in ENZ can be based on their relative total cost of ownership (TCO). For each vehicle class the TCO is projected for all vehicle types in the *Project costs and performance of vehicles entering the fleet each year* section. This builds up capital, fuel and carbon costs, road user charges, maintenance, and other costs.

Average internal combustion engine (ICE) vehicle purchase costs have been derived by combining StatsNZ import value data and MoT fleet statistics. This is set out in the **Param** workbook .

Electric vehicle costs are built up from battery and other costs. Future battery costs are projected in the *EV battery cost and range* section of the **Param** workbook

Electric vehicles

One of the most significant aspects of the transport modelling in ENZ is the uptake of EVs. EVs may be either pure battery EVs or plug-in hybrids, or FCEV.

ENZ assumes that consumers choose between conventional vehicles and EVs based on the total cost of ownership of each type of vehicle over an assumed five-year ownership period. The major driver of EV uptake is the assumed decline in battery costs. These are based on projections by Bloomberg New Energy Finance Limited's Electric Vehicle Outlook 2023. These figures suggest, for example, that the cost of batteries for a typical light passenger vehicle will decline from about NZD$13,000 in 2022 to NZD$5850 in 2030.

We also modelled the effects of the Clean car discount and Standard. Both, policies are assumed to affect the capital cost difference between EVs and ICE vehicles. The amount of difference created by the clean car standard is dependent on the emissions of vehicles entering in the previous year.

There are also non-price barriers to EV uptake, such as consumer range anxiety and lack of vehicle charging infrastructure. These barriers are discussed in more detail in Chapter 6: Reducing emissions from transport, buildings and urban form of *Inaia tonu nei.*

In addition, there is a bias against EVs built into the consumer choice function. This causes conventional vehicles to take a larger share of the market than EVs, even when the total operating costs of EVs (including penalties) and conventional vehicles are the same. This bias reduces as EVs gain in market share. There are also limits in the model on the speed at which the EV shares of newly registered vehicles can increase.

Assumptions are also made for the number of vehicle kilometres travelled by each class of vehicle in the reference case to reflect assumed travel type shifts for both travellers and freight.

Aviation

The aviation module projects emissions, fuel consumption, system costs for both domestic and international aircraft. It applies a basic stock model to both domestic and international aircraft.

The categories of aircraft are:

Network	Sub-network	Commercial availability	Fuel
Domestic	Regional	Today	JetFuel
Domestic	Regional	2030	H2
Domestic	Regional	2030	Battery
Domestic	Jet	Today	JetFuel
Domestic	Jet	2035	H2
International	Short-haul	Today	JetFuel
International	Short-haul	2035	H2
International	Long-haul	Today	JetFuel
International	Long-haul	2040	H2

Representative aircraft models are used to establish operating parameters, start date for commercial availability and cost. These are specified in the **Param** worksheet

ENZ assumes that the performance and cost of new aircraft will reduce over time. For battery electric aircraft, the rate of cost improvement is linked to vehicle battery pack cost declines.

Scenario assumptions about new aircraft efficiency are split between new aircraft entering the fleet and improvements to existing aircraft. These are combined within the model to give an overall fleet efficiency improvement by aircraft type.

Uptake of new aircraft is by assumption in the **Param** worksheet. The user specifies the share of travel that a particular in five-year increments with intervening years determined by linear interpolation.

Shipping and rail

Shipping and rail module projects emissions fuel consumption and fuel costs. ENZ allows for the reputation of different alternative fuels these can be specified as a share of existing energy demand met by a particular alternative fuel.

Low carbon liquid fuels

The model includes the option to displace liquid fossil fuel with low carbon liquid fuel (LCLF) – this is enabled b*y specifying blending ratios and fuel prices in the ASS sheet. Blending ratios can be specified for road, rail, aviation, and shipping.* The effect of LCLF blending on fuel cost is factored into TCO calculations for road transport. Amount of low carbon liquid fuel used is shown in the outputs tab and the results file.

The Land and Waste workbook (LnW.xlsx)

The LnW workbook includes:

- Land used for agriculture, forestry, horticulture, and other uses.

- Emissions from agriculture, with detailed representation of the dairy and sheep and beef sectors.
- Key measures from agricultural sector including, stocking rates, production, productivity, and other measures
- A range of mitigation technologies.
- Emissions and removals by forests.
- Production metrics for agriculture and forestry.
- Available biomass supply by region.
- Emissions generated by waste.
- Detailed breakdown of waste volumes and where it is being direct i.e., landfills.
- Landfill gas capture coverage and rates are modelled.

Description of the Land and waste worksheets

- **Ctrl** outlines scenario parameters
- **Inputs (In)** contains key input data arrays sourced from the Ministry for Primary Industries (MPI), including breakdowns of historic and projected emissions and underlying activity data. It also contains assumptions for all other agriculture parameters, along with other fixed assumptions and data inputs.
- **Land use (LU)** contains assumptions for the land use change parameters in the control panel and calculates land areas for the chosen scenario. Contains other fixed assumptions and data inputs related to forestry.
- **Forestry (Frst)** calculates emissions and removals from forests and regional wood harvest volumes for the chosen scenario.
- **Agriculture (Ag)** calculates emissions and other outcomes of interest for the dairy and sheep and beef sectors for the chosen scenario.
- **Waste Inputs (W_In)** contains key input data arrays sourced from the Ministry for the Environment, including historic and projected waste placement.
- **BioCH4** contains analysis that drives estimation of the costs of anaerobic digestion and compositing facilities, as well as various other 'standalone' analysis on various issues relationg to BioCH_4 that don't feed into the model but were used in developing various assumptions.
- **Waste Assumptions (W_Ass)** contains other technical assumptions used in the emissions modelling.
- **Waste Mitigation (W_Mit)** contains the assumptions for the scenario parameters in the control panel and converts the selected scenario values into annual time series.
- **Waste (Wst)** performs the calculations of emissions from all solid waste categories.
- **Waste Outputs (Out_W)** compiles the emissions results and other output arrays.
- **Out** brings together all outputs from previous sheets

Land use

The module starts from a baseline scenario of future land use. This is based on the MPI's latest available emissions projections under current policy settings (the Government's 'With Existing Measures' scenario or 'Base case'). For these projections, MPI uses its Pastoral Supply Response Model, forestry projections model, and other information to project changes in agriculture and forestry activity. MPI then uses the Agricultural Greenhouse Gas Inventory model to project emissions. The input data from MPI are found in the **Inputs** worksheet.

Land use scenarios in ENZ are exogenously specified. In the control panel, the user selects settings for the following individual land use parameters:

- Exotic afforestation
- Native afforestation
- Deforestation (both exotic and native forest)
- Land use change to horticulture
- Land retirement (conversion of agriculture and forest land to other purposes, e.g., urban)

The assumptions tied to these parameter settings are specified in the **Land use** worksheet. The model calculates changes relative to the baseline scenario and makes area adjustments to the different land use categories using specified area balancing assumptions.

Agriculture

The agriculture sector is split into dairy, sheep and beef, and other agriculture (which includes other livestock, horticulture, and cropping). The first two are explicitly modelled in ENZ with a range of mitigation options. Sheep and beef farming as modelled as a single sector, using a weighted population metric to aggregate sheep and cattle numbers. Other agriculture is largely fixed as in the baseline scenario with adjustments for changes in land area only.

Livestock population

Baseline livestock population numbers out to 2050 are taken from the MPI emissions projections. Data from the New Zealand Dairy Statistics 2019/2020 are also used to project milking cow population from total dairy cattle. National average stocking rates are calculated based on total population and land area.

In the control panel, the user can select a different trajectory for average stocking rates with the *Stocking rate scenario* parameter. The assumptions for each parameter setting are specified in the **Ag assumptions** worksheet (section titled 'Future stocking rate scenarios').

Milk and meat production

Baseline milk and meat production are projected based on the MPI emissions projections and used as an input in the **Inputs** worksheet. For milk, MPI provides total liquid milk production in litres. This is converted to total production of milk solids by linear extrapolation of the historic trend in milk solids per litre of milk. The Commission has estimated baseline meat production using historic and projected carcass weights provided by MPI along with livestock slaughter statistics. The model uses and reports estimated meat production from sheep and beef farming only – as a measure of output for the sector – excluding meat from dairy cattle and other livestock types such as deer.

In the model, production per animal (referred to as 'productivity') is first calculated based on two scenario parameters selected in the **Inputs** worksheet:

- *Baseline productivity*: this defines an exogenous rate of improvement in production per animal which can decline over time. The standard setting used has been manually calibrated to match the total baseline production inputs described above.[1]
- *Stocking rate-production relationship*: this defines a parameter for an equation relating changes in average stocking rate to changes in productivity. This assumes production per animal can increase up a curve towards a maximum value as stocking rate is reduced. The

[1] Hardcoded values for the annual change in production per animal are used for the first 2-3 years of the projected period to match the MPI baseline.

scenario parameter defines the starting point on the curve, which determines the extent to which production per animal can be increased relative to the starting value.

This calculation takes place in the **Agriculture** worksheet. Total production is then calculated by multiplying production per animal by total population.

Production by region is estimated for use as an input into the food processing energy module (cross-reference to HIP section). This is based on a mapping of regional production data from the New Zealand Dairy Statistics 2019/2020 and Beef & Lamb New Zealand Benchmarking Data 2018/2019. The calculation assumes regional shares of total production remain constant in the future.

Modelling livestock emissions, before impact of technologies

Emissions from livestock are first estimated in the absence of any low-emissions technologies that change how feed consumption and livestock numbers drive emissions. The effects of such technologies are then superimposed as described in the next section. This takes place in the **Agriculture** worksheet.

ENZ uses a simplified modelling approach which aims to emulate the emissions outcomes of MPI's more detailed Agricultural Greenhouse Gas Inventory model. The approach assumes a quadratic relationship between total CO_2-e emissions per head (E_h) and production per head (P_h):

$$E_h = aP_h{}^2 + bP_h + c$$

The model is calibrated by fitting coefficients (a, b, c) to the historic and projected baseline emissions data from MPI using the least squares method. For sheep and beef, there is a control panel parameter, *Meat emissions relationship*, which selects between a quadratic or linear relationship (a=0). The Commission has used the latter as it provides a better fit to the projected emissions.

The total emissions per head determined by the above formula are broken down into contributions from enteric fermentation, manure management and agricultural soils in line with the MPI baseline data.

Technologies to reduce livestock emissions

ENZ includes control panel parameters for the following low-emissions technologies:

- Low-methane breeding for both sheep and dairy
- Methane vaccine for sheep and beef, and dairy
- Methane inhibitors, Bovaer and vaccines (combined impact)[2]
- EcoPond

The settings for the first three parameters are specified in the **Input** worksheet under the 'Mitigation technology scenarios' heading. The total emissions reduction effect for each technology – accounting for technology effectiveness and adoption rate – is specified in five-year intervals separately for the dairy and sheep and beef sectors. This is expressed as a percentage reduction for

[2] Methane inhibitors, bovaer and vaccines are assumed to be mutually exclusive, so cannot both be applied to the same animal. This combination is only present in the High Technology and High Systems change scenario

the relevant emissions category (enteric fermentation for low-methane breeding and methane inhibitors and vaccines; agricultural soils for nitrification inhibitors[3]).

Fertiliser use and emissions

In ENZ, reductions in fertiliser emissions can occur through the modelled impact of changes in dairy stocking rates and production on fertiliser use, and through increased use of urease inhibitor.

Total use of nitrogen fertilisers in the baseline scenario is derived from the MPI projections data in the **Input** worksheet under the 'Fertiliser' heading. Historic shares of fertiliser use for dairy farming, sheep and beef farming, exotic forestry, horticulture, and arable cropping reported by StatsNZ are used to estimate the historic fertiliser use per hectare for each land use. An assumed future annual rate of reduction is set to provide a good match with MPI's total projected fertiliser use.

For dairy farming, changes in fertiliser use per hectare are modelled in response to changes in stocking rate and productivity[4]. The model calculates dry matter consumption and estimates the initial feed surplus relative to baseline. Reductions in use of supplement, fertiliser, and grazing off to eliminate the feed surplus are calculated based on specified assumptions. This takes place in the **Agriculture** worksheet.

The share of urea fertiliser coated with urease inhibitor is set using the *Urease inhibitor* parameter in the control panel. Settings for this are specified in the **Input** worksheet, in the form of a target usage level and year.

Total fertiliser use and emissions across the different land uses are calculated in the **Out** worksheet. Emissions from liming are assumed constant in line with the MPI projections, with the breakdown by land use type assumed to be the same as for nitrogen fertilisers in 2019.

Forestry

As described earlier in the *Land use* section, trajectories for exotic and native afforestation and deforestation are exogenously specified. The chosen scenario settings feed through into the **Forestry** worksheet.

Modelling emissions and removals

Emissions and removals by forests are calculated using a modified activity-based approach, as used in Aotearoa New Zealand's Nationally Determined Contribution under the Paris Agreement. This approach is described in the Commission's 2021 advice to Government, *Ināia tonu nei* (see section 10.3, Accounting for land emissions). It uses "averaging" for harvested forests, where newly afforested land is credited with CO_2 removals up until its long-term average carbon stock (across multiple harvest cycles) is reached.

The calculations use age-based carbon yield tables, soil carbon and biomass carbon stock factors sourced from New Zealand's Greenhouse Gas Inventory 1990-2019. The methodology is consistent with the Inventory, apart from the use of averaging. ENZ precisely replicates results from MPI's forestry projections model.

[3] Nitrification inhibitors are assumed to only affect nitrous oxide emissions from animal excreta and have no effect on emissions from fertiliser use.

[4] Changes in fertiliser use per hectare for other land uses are not currently modelled in ENZ

Regional breakdown of exotic forest area

ENZ estimates exotic forest area across nine regions for the purpose of modelling regional biomass availability.

Historic afforestation is allocated among regions based on reported areas of post-1989 forests by planting year in the National Exotic Forest Description (NEFD). Future afforestation is allocated assuming the same estimated regional distribution as the total exotic forest estate in the first year of the projected period. Deforestation is allocated based on the region's share of the national area of forest at the assumed deforestation age.

Total area of pre-1990 and post-1989 forest by region is built up from a starting area in 1990 and the annual areas afforested and deforested.

Wood harvesting

Historic harvest areas up to 2018 are sourced from the NEFD and the Ministry for the Environment's forestry model. Future annual harvest areas are projected using a simple method to smooth out large interannual fluctuations due to the age profile of New Zealand's exotic forests. First, a rolling 20-year average area available to harvest is calculated. Second, a limit is applied on how much the harvest area can change from year to year. A final harvest area is then calculated which allows for any shortfall to be made up for in subsequent years.

The volume of wood harvested by region is then calculated. This calculation uses a yield table for the total recoverable volume (TRV) for a reference site, with regional multipliers to reflect different average growing conditions. The volume of pulp logs harvested is split out from the TRV for assessing their potential use for bioenergy.

Biomass supply

ENZ calculates the potential regional biomass supply of harvest residues and export pulp logs for use as bioenergy.[5] Potential harvest residue supply is calculated based on an assumed amount recoverable as a percentage of TRV. For pulp logs, existing domestic pulp log demand is estimated and subtracted from the total volume harvested to estimate the volume of pulp logs that would otherwise be exported. The volume of wood biomass is converted to energy content and fed into the **HIP module**.

Waste

The Waste worksheets calculate greenhouse gas emissions from disposal, biological treatment and burning of solid waste. It uses the same methodology as New Zealand's Greenhouse Gas Inventory 1990-2019 and projections of future waste activity by the Ministry for the Environment. Mitigation measures included are waste reduction, waste recovery/diversion, and increases in the coverage and capture efficiency of landfill gas (LFG) capture systems.

Waste generation

In ENZ, waste is categorised by destination landfill types and waste types as shown in the table below.

Historic and projected baseline waste generation across these categories is sourced from the Ministry for the Environment. This is based on MfE's latest available emissions projections under current policy settings (the Government's 'With Existing Measures' scenario). The exception to this is

[5] Functionality exists in the model to include wood processing residues, but this is not currently used.

for non-municipal landfills, where the projected waste generation for organic waste types has been assumed constant at estimated 2019 levels.[6]

The *Waste reduction* parameter in the control panel selects a scenario for reduction in the quantities of waste generated across the different categories. The assumptions for each parameter setting are specified in the **Waste mitigation** worksheet. These are expressed as a percentage reduction relative to the baseline waste generation in the year. For this and the other parameters in the waste module, setting to zero gives the baseline scenario.

[6] The latest MfE emissions projections did not include a projection of non-municipal waste generation as the projection was instead based on extrapolation of the emissions trend. Future waste generation levels were assumed constant given difficulties projection forward from noisy and unreliable historic data.

Table 1 - Waste and landfill types

Waste types	Landfill types: Municipal Sub-categories by wet/dry climate, open/closed landfills, and sites without LFG capture	Non-municipal	Farm fills Sub-categories by farm type: Dairy, Other livestock, and Horticulture & arable
Food	x	x	
Garden	x	x	x
Paper	x		x
Wood	x	x	x
Textile	x		x
Nappies	x		
Sludge/biological	x	x	
Inert	x	x	x
C&D[7]		x	
Bulk/miscellaneous		x	x
Industrial		x	x

Waste recovery/diversion

ENZ includes four options for waste recovery: recycling, compost, anaerobic digestion, and use for boiler fuel. The *Waste diversion* parameter in the control panel selects a scenario for the proportion of waste recovered across the different categories. The assumptions for each parameter setting are specified in the **Waste Mitigation** worksheet. These are expressed as a percentage reduction of the residual waste that would be sent to landfill, after accounting for reduced waste generation.

Landfill gas capture

Improvements in LFG capture are represented through two control panel parameters, *LFG capture coverage* and *LFG capture rate*. The first determines the proportion of methane generated that is subject to an LFG system, while the second determines the proportion that is captured by the system. The assumptions for each parameter setting are specified for each landfill category in the **Waste Mitigation** worksheet.

Modelling waste emissions

The calculations of emissions take place in the **Waste Output** worksheet.

Emissions from solid waste disposal to landfills are calculated using a First Order Decay model. This is the same approach used in New Zealand's Greenhouse Gas Inventory based on Intergovernmental Panel on Climate Change (IPCC) guidance. Values for all parameters used in the model, such as degradable decomposable organic carbon content and decay constants, are sourced from the Inventory and contained in the **Waste Assumptions** worksheet.

Emissions from composting, anaerobic digestion, and open burning of farm waste are calculated using simple emissions factors. The emissions factor for open burning of farm waste is a weighted average based on the assumed composition of waste burned.

[7] Construction and demolition waste.

Emissions from uncategorised landfills, incineration, and wastewater treatment and discharge are not explicitly modelled, and are assumed unchanged from the baseline scenario. These are relatively small sources of emissions, and no mitigation options are currently included in ENZ.