Asset Management Plan
Substation Transformers

Part of the Energy Queensland Group

Executive Summary

This Asset Management Plan (AMP) covers the class of assets known as substation transformers, substation regulators and reactors.

Energy Queensland Limited (EQL) manages 1115 power transformers, comprising 537 power transformers in Ergon Energy substations and 578 power transformers in Energex substations.

These assets feature prominently in Safety Net contingency plans required by EQL's Distribution Licences.

Key actions for the lifecycle asset management of assets contained in this AMP include reviewing and aligning approaches to condition assessment, investigating causes of defects, and the increasing the volume of substation asset replacement to address the existing Network Access Restrictions and deliver a long-term sustainable program of replacement.

EQL is also investigating the potential use of alternative insulating oils in transformers, to reduce environmental impact. Emerging issues such as the need for in-situ oil conditioning capability are also being addressed.

Revision History

Revision date	Version number	Description of change/revision
	1.0	Published 5 November 2018
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03/10/2023	3.0	
11/12/2023	4.0	Finalised

Document Approvals

Position title	Date
GM Asset Maintenance	Jan 2024
EGM Engineering	Jan 2024

Stakeholders/Endorsements

Title	Role
Manager Asset Strategy	Endorse
Manager Transformers & Reactive Plant	Endorse
Manager Substation Standards	For Information
Engineering Field Support Manager	For Information

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1 Introduction

Energy Queensland Limited (EQL) was formed 1 July 2016. It owns and manages several electrical energy related companies that operate to support energy distribution across Queensland including the Distribution Network Service Providers (DNSPs):

- Energex, covering the area defined by the Distribution Authority for Energex Corporation Limited, and
- Ergon Energy, covering the area defined by the Distribution Authority for Ergon Energy Corporation Limited.

There are variations between EQL's operating regions in terms of asset base and management practice, as a result of geographic influences, market operation influences, and legacy organisation management practices. This Asset Management Plan (AMP) reflects the current practices and strategies for all assets managed by EQL, recognising the differences that have arisen due to legacy organisation management.

1.1 Purpose

This document details a plan for the responsible and sustainable asset management of substation power transformers on the EQL network. The objectives of this plan are to:

1. Deliver customer outcomes to the required level of service
2. Demonstrate alignment of asset management practices with EQL's Strategic Asset Management Plan and business objectives
3. Demonstrate compliance with regulatory requirements
4. Manage the risks associated with operating the assets over their lifespan
5. Optimise the value EQL derives from this asset class.

This Asset Management Plan will be updated periodically to ensure it remains current and relevant to the organisation and its strategic objectives. Full revision of the plan will be completed every five years as a minimum.

1.2 Legislation, regulations, rules, and codes

This Asset Management Plan is guided by the following legislation, regulations, rules and codes:

- Electrical Safety Code of Practice – Works, 2020 (Queensland Government)
- Environmental Protection Act, 1994 (Queensland Government)
- Queensland Electricity Act, 1994 (Queensland Government)
- Queensland Electricity Regulation, 2013 (Queensland Government)
- Queensland Electrical Safety Act, 2002 (Queensland Government)
- Queensland Electrical Safety Regulation, 2013 (Queensland Government)
- Queensland Work Health and Safety Act, 2011 (Queensland Government)
- Queensland Work Health and Safety Regulation, 2011 (Queensland Government)
- National Electricity Rules (NER), 2023 (Australian Energy Market Commission)
- Ergon Energy Corporation Limited Distribution Authority No D01/99
- Energex Limited Distribution Authority No. D07/98

This Asset Management Plan forms part of EQL's strategic asset management documentation, as shown in Figure 1. It is part of a suite of Asset Management Plans, which collectively describe EQL's approach to the lifecycle management of the various assets which make up the network used to deliver electricity to its customers. Appendix 1 contains references to other documents relevant to the management of the asset class covered in this plan.

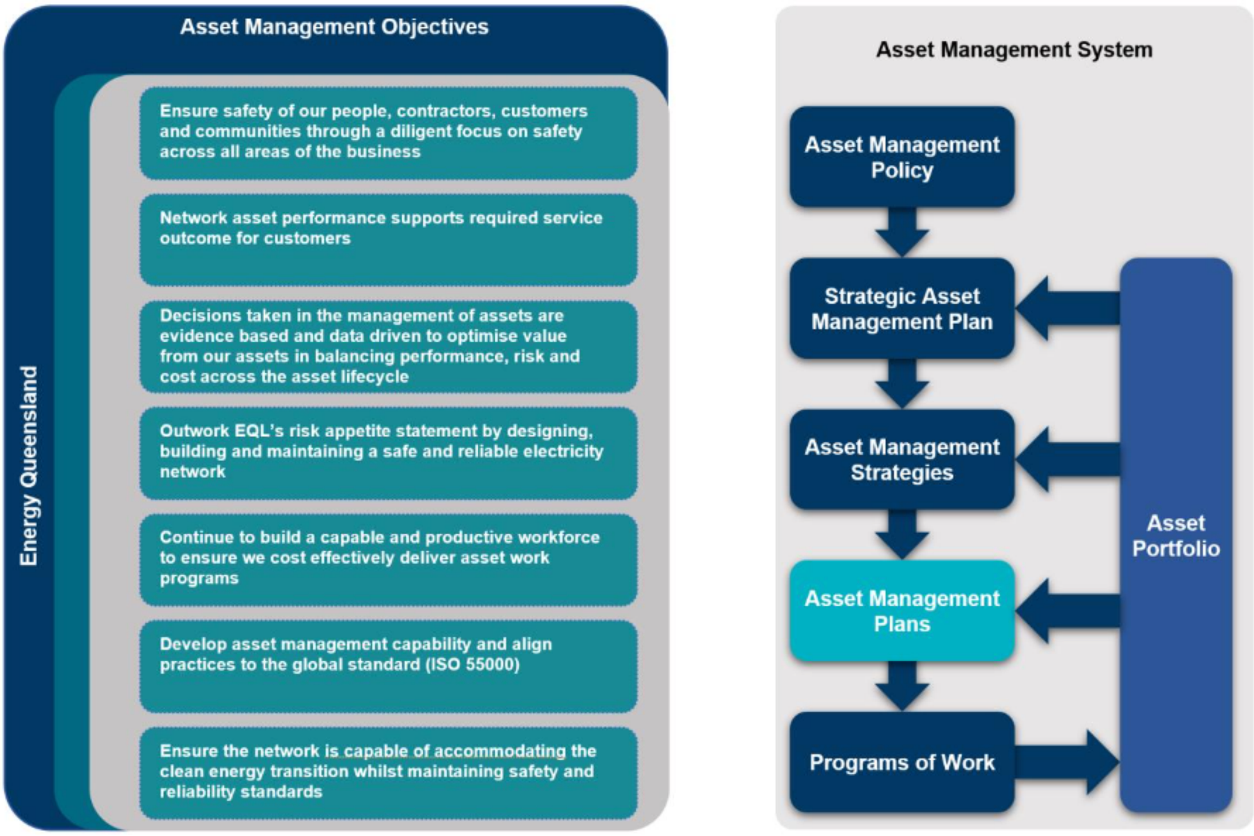


Figure 1: EQL Asset Management System[i]

1.3 Scope

This asset management plan covers the following assets:

- Substation power transformers
- Substation regulators
- Substation reactors
- On-load tap-changers

This AMP relates to EQL owned assets only and excludes any consideration of such commercial services. Whilst the function performed by the regulator and reactor is different from that of a power transformer, the similarities in design and failure modes result in them being treated in a similar way through asset lifecycle management practices.

EQL does not provide condition and maintenance services for third party assets, except as an unregulated and independent service.

1.4 Total Current Replacement Value

Substation power transformers are high capacity, low volume, high-cost assets, and are typically asset managed on an individual basis using periodic inspection for condition and serviceability, and through systemic review of recorded performance.

Based upon asset quantities and replacement costs, EQL substation transformers have a replacement value in the order of $2.07 billion[ii] (Ergon Energy $580 Million[iii], Energex $1.49 billion[iv]). This valuation is the gross replacement cost of the assets, based on the cost of replacement of modern equivalents, without asset optimisation or age assigned depreciation. Below Figure provides an indication of the relative financial value of EQL substation transformers compared to other asset classes.

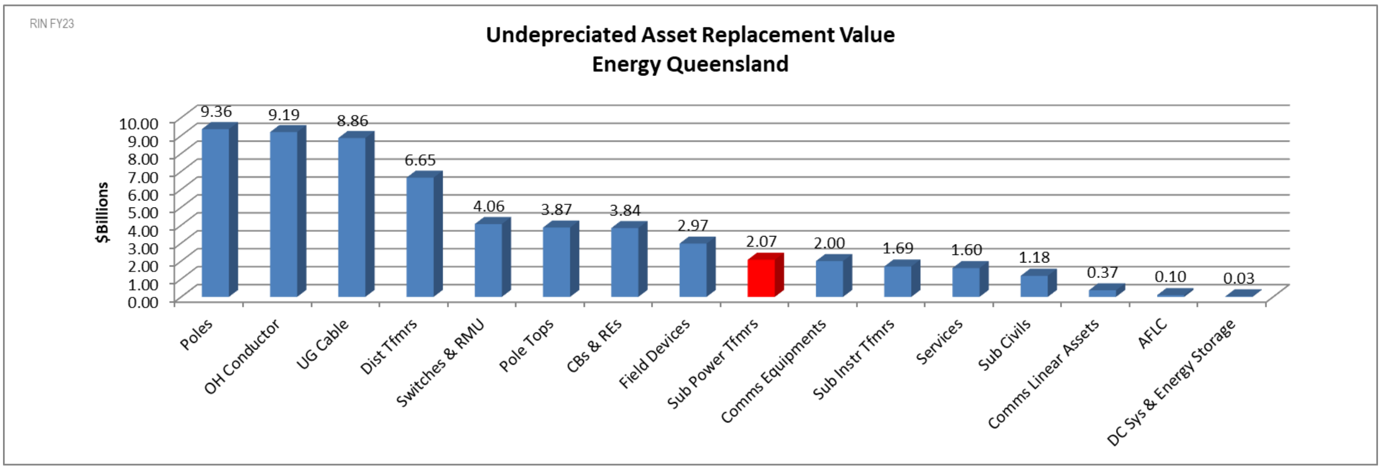


Figure 2: EQL Total Current Asset Replacement Value[v]

1.5 Asset Function and Strategic Alignment

The function of a power transformer is to change the voltage in an electricity network between the levels used for transmission, sub-transmission, and distribution. This enables use of cost-effective infrastructure to achieve efficient transportation of electrical energy across distances. The other assets covered under this management plan contribute to this function either through performing voltage regulation or ancillary functions and are discussed in more detail in later sections.

Below Table details how substation transformers contribute to EQL's corporate strategic asset management objectives.

Asset Management Objectives	Relationship of Asset to Asset Management Objectives
Ensure network safety for staff, contractors and the community	Diligent and consistent inspection, maintenance and renewal supports asset performance and hence safety for all stakeholders.
Meet customer and stakeholder expectations	Continued asset serviceability supports network reliability and promotes delivery of a standard quality electrical energy service at optimal cost.
Manage risks, performance standards and asset investment to deliver balanced commercial outcomes	Failure of this asset can result in a public safety risk, disruption of the electricity network, and disruption of customer amenity. Understanding asset performance allows optimal investment to achieve intended outcomes. Asset longevity assists in minimising capital and operational expenditure.
Develop asset management capability and align practices to the global ISO55000 standard	This AMP is consistent with AS ISO55000 objectives and drives asset management capability by promoting continuous and targeted improvement.
Modernise the network and facilitate access to innovative energy technologies	This AMP promotes the replacement of assets at end of economic life as necessary to suit modern standards and requirements.

Table 1: Asset function and strategic alignment

1.6 Owners and stakeholders

The ubiquitous nature of the electrical network means that there are many stakeholders that influence or are affected by EQL's operation and performance. Table 2 lists most of the influential stakeholders that have impacted the strategies defined by this asset management plan.

Responsible Party	Role
Queensland Government	Development of legislative framework and environment for operation of EQL in Queensland. Development of EQL Distribution Authorities.
Queensland Government as sole shareholder of EQL	Owner of company shares, holding equity in EQL and gaining benefits from EQL financial success.
EQL Board of Directors	Corporate direction, operation and performance of EQL and its subsidiaries, in compliance with corporate and Queensland law.
Chief Financial officer	Company Asset Owner – ensuring all EQL investments are consistent with EQL corporate objectives with balanced commercial outcomes
Chief Operating Officer	Overall operational control of EQL networks including maintenance and operation, and execution of project works
Chief Engineer	Overall strategic control of EQL assets, including asset population performance, risk and financial management,
All employees and contractors of Energy Queensland Limited	Performing all duties as required to achieve EQL corporate objectives
All unions that are party to the EQL Union Collective Agreement	Promotion of safe and fair working conditions for all EQL and subsidiary company employees
Queensland Electrical Safety Office	Regulatory overview and control of electrical safety in Queensland

Australian Energy Regulator	Regulatory overview and control of economic performance of EQL under its Distribution Authorities to promote the long term interests of all electrical network customers connected to the National Electricity Market
Powerlink	Queensland Transmission Network Service Provider. Owner and operator of many 110 kV to 330 kV transmission grid assets and 74 bulk supply substations that connect and deliver energy to EQL networks
All consumers, prosumers and generators connecting to the Energy Queensland network	Operating within the electrical technical boundaries defined by legislation, regulation and connection agreements.
All communities and businesses connected to the Energy Queensland network.	Economic prosperity of Queensland

Table 2: Stakeholders

2 Asset Class Information

The following sections provide a summary of the key functions and attributes of the assets covered in this AMP.

2.1 Asset Description

The function of a power transformer is to change the voltage in an electricity network between the levels used for transmission, sub-transmission and distribution. This enables use of cost-effective infrastructure to achieve efficient transportation of electrical energy across distances. Power transformers can also provide an earth reference point.

EQL operates a highly varied population of substation power transformers, as a result of the amalgamation of legacy organisations, and procurement from various suppliers over the last 60 years. The main criteria used to classify power transformers are the following:

- Primary, secondary, or tertiary voltage
- Power rating
- Connection Symbol
- Impedance
- Tap-changer type.

2.1.1 Tap-Changers

In most large transformers (typically greater than 3 MVA), on-load tap-changers (OLTCs), are installed. The function of an OLTC is to change the output voltage of its associated power transformer whilst on-load (i.e. with no interruption to load current) and without any section of the transformer winding short-circuiting. Most tap-changer designs employ one of two switching principles, the high-speed resistor type OLTC and the reactor type OLTC.

Newer generation tap-changers use vacuum interrupters to quench the switching arc, while older generation units employ oil quenching. OLTCs fitted with vacuum interrupters can withstand more operations and require less maintenance than traditional units and are generally considered to be more reliable.

Smaller transformers (typically <3 MVA), and a few (larger) specifically designed transformers, are fitted with de-energised tap-changers, which are designed without load making and breaking capacity, so the transformer must be removed from service to allow switching between the different taps on the tapped winding.

2.1.2 Substation Regulators

A voltage regulator produces a fixed magnitude steady state output voltage, regardless of changes to its input voltage or load conditions. In substations, regulators are typically used to control the output voltage of a fixed tap power transformer. Substation power regulators are usually configured with a star-star connection, to not introduce an additional phase shift. The zero-degree phase shift is important for managing meshed network interconnections which require phasing to match in order to operate.

2.1.3 Substation Reactors

Large substation reactors are typically of similar construction and design to a power transformer and introduce inductive impedance in an electrical circuit. This can be used to compensate for reactive power (shunt reactor) to manage voltage drop, or limit fault current (series reactor) to ensure downstream assets remain within ratings, as well as absorb/limit harmonic voltages.

2.2 Asset Quantity and Physical Distribution

The following sections describe the quantities and physical distribution of distribution transformers and related ancillary assets within the EQL asset base as covered in this AMP.

2.2.1 Substation Transformers

Table 3 data shows the population of substation transformers.

Asset Type	Ergon Energy	Energex	Total
Power transformers	537	578	1,115

Table 3: Substation transformer population

During the lifetime of existing substation transformer assets, there have been several different network asset management companies managing sections of the electricity networks. Each of these legacy electricity companies designed their networks with operating voltages that suited the distances and loads to be serviced at those times. This also determined the power transformation ratios, resulting in a large number of standard voltage levels to be managed across the various legacy asset bases.

A series of design reviews over the intervening years has found it to be generally uneconomic and imprudent to consolidate the voltage levels across the legacy asset base, due to the cost of changing sub-transmission feeder assets and insulation. There have been some small improvements made as a result of network augmentation, driven by large scale changes in rural demographics and industry.

The variation in operating voltage and connection symbol causes unique operational and logistics requirements associated with the management and replacement of these assets, particularly with regards to spares holding and procurement. These aspects are discussed in later sections of the document.

Table 4 summarises the voltage ratios for power transformers in EQL.

Asset Class	Ergon Energy	Energex	Primary Voltage (kV)	Secondary Voltage (kV)
Power Transformers	✓		220 (Unregulated network)	132, 66
	✓	✓	132	110, 11
	✓		132	66, 22
	✓	✓	110	33, 11
	✓		66	33, 22, 11, 6.6, 3.3
		✓	66	11
	✓		33	22
	✓	✓	33	11, 6.6, 3.3

Table 4: Voltage Ratios of Power Transformers in EQL

2.3 Asset Age Distribution

Figure 3 details the age profile of Ergon Energy substation power transformers.

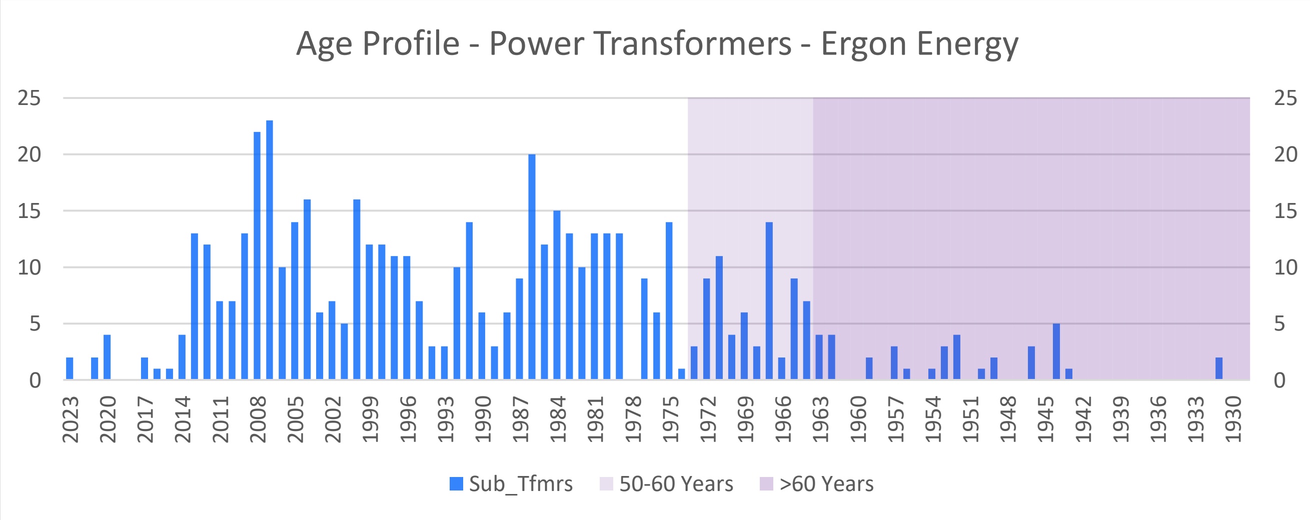


Figure 3: Substation power transformer age profile – Ergon Energy

Figure 4 details the age profile of Energex substation power transformers.

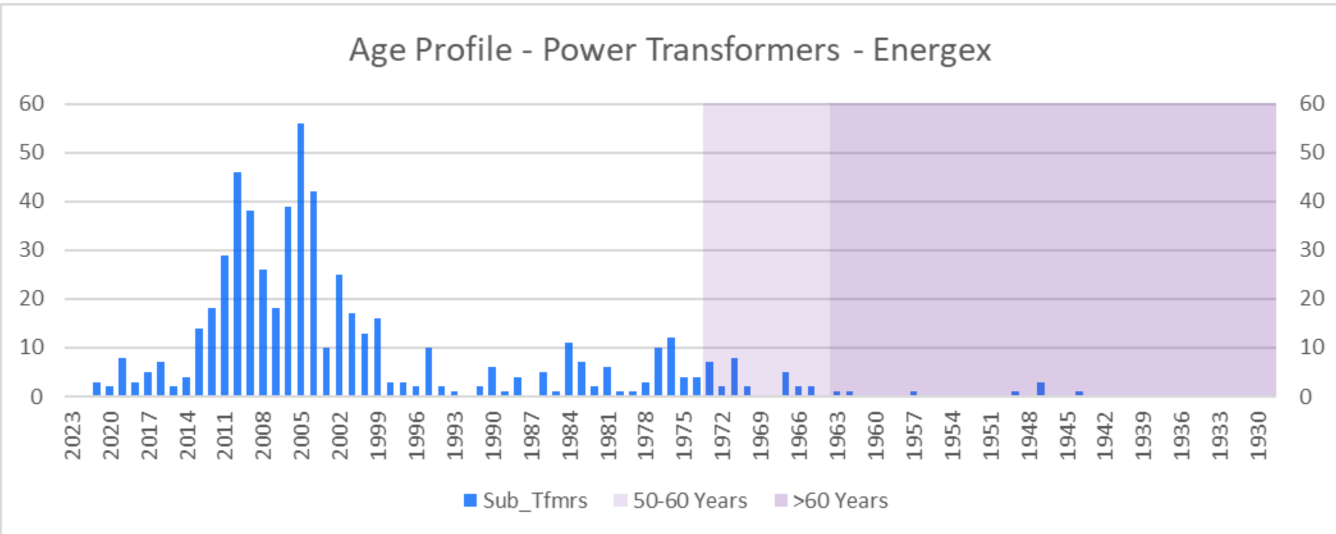


Figure 4: Substation power transformer age profile –Energex region

The age profile for power transformers is also representative of the age profile of the OLTC fleet across Ergon Energy and Energex regions.

2.4 Population Trends

Ergon Energy have a significantly higher quantity of older substation transformer and regulator assets. This is likely due to the typically lower loads that the assets have been required to supply, and the resultant extension on their useful life. While life extension of the asset is desirable, the proportion of assets that have exceeded the expected life presents a risk that needs to be monitored and managed in order to meet asset management objectives.

In Energex, a large number of transformer assets were installed between 2004 and 2010 as a result of substantial load growth in the region. A significant number of older transformer assets were removed as a result of this growth, as they could not meet demand within prescribed security standards.

Ergon Energy began purchasing power transformers with vacuum tap-changers in the early-to–mid 2000's, while Energex did so in 2000. The OLTCs in the EQL network are progressively being replaced with vacuum type units as they reach end of life, as vacuum type units are more reliable, they typically require lower maintenance, and are able to withstand more operations between maintenance cycles than oil OLTC units.

2.5 Asset Life Limiting Factors

Table 4 describes the key factors that influence the life of the assets covered by this AMP, which as a result have a significant bearing on the programs of work implemented to manage the lifecycle.

Factor	Influence	Impact
Oil quality	Gradual increase in contaminants leading to deterioration of materials and components used in construction; particularly the oil, paper insulation, gaskets, and bushings.	Reduction in insulating capability, creation of "sludge" enabling winding hot spot development, deterioration of winding insulation performance, leading to reduction in useful life
Environment	Outdoor, corrosive, or coastal environments result in degradation of the physical asset and components; particularly the tank, bushings, gaskets, and instrumentation.	Reduction in useful life and component failure.
Loading	Heating of the winding resulting in degradation of the paper insulation. Loading above cyclic rating can lead to very rapid deterioration.	Accelerated ageing leading to reduction in useful life. Internal fault leading to failure (potentially catastrophic).
Through-Faults	Electrical and mechanical stress on internal windings	Stress cycles leads to accumulative physical damage, ultimately causing internal fault leading to failure (potentially catastrophic)
Moisture	Degradation of paper insulation and oil. Combined with heat, even at low loadings, can result in bubble inception.	Accelerated ageing leading to reduction in useful life. Internal fault leading to failure (potentially catastrophic).
Obsolescence	Inability to source components required to maintain or repair the asset; particularly the indications and control, OLTC and bushings.	Unable to return to service in the event of a failure resulting in early replacement.
Operations (moving components – OLTC)	Mechanical wear on moving components and degradation of insulation associated with the arcing products caused by switching operation.	Drives maintenance required to replace or repair consumable components such as contacts and oil. Accelerated ageing leading to reduction in useful life.

		Internal fault leading to failure
Design	Varies based on make and model and only becomes apparent through operational experience. Typically associated with materials used (e.g. oil) and designs of components and mechanisms (e.g. tap-changers).	Operational remediation to ensure expected life Early replacement.
Oil quality	Gradual increase in contaminants leading to deterioration of materials and components used in construction; particularly the oil, paper insulation, gaskets, and bushings.	Reduction in insulating capability, creation of "sludge" enabling winding hot spot development, deterioration of winding insulation performance, leading to reduction in useful life
Environment	Outdoor, corrosive, or coastal environments result in degradation of the physical asset and components; particularly the tank, bushings, gaskets, and instrumentation.	Reduction in useful life and component failure.

Table 5: Substation Power Transformer life limiting factors

3 Current and Desired Levels of Service

The following sections define the level of performance required from the asset class, measures used to determine the effectiveness of delivering corporate objectives, and any known or likely future changes in requirements.

3.1 Desired Levels of Service

This asset class will be managed, consistent with corporate asset management policy, to achieve all legislated obligations and any specifically defined corporate key performance indicators, and to support all associated key result areas as reported in the Statement of Corporate Intent (SCI).

Safety risks associated with this asset class will be eliminated "So Far as Is Reasonably Practicable" (SFAIRP).

This asset class consists of a functionally alike population that differs in age, brand, technology, material, construction design, technical performance, purchase price, and maintenance requirements. The population will be managed consistently based upon generic performance outcomes, with an implicit aim to achieve the intended and optimised life cycle costs contemplated for the asset class and application.

All inspection and maintenance activities will be performed consistent with manufacturers' advice, good engineering operating practice, and historical performance, with intent to achieve longest practical asset life overall.

Life extension techniques will be applied where practical, consistent with overall legislative, risk, reliability, and financial expectations. Problematic assets such as very high maintenance or high safety risk assets in the population will be considered for early retirement.

Assets of this class will be managed by ongoing individual condition assessment and maintenance, and proactively replaced near to and prior to calculated end of life. End of economic asset life will take into account ongoing maintenance and retention costs, replacement costs and benefits, potential future maintenance and retention costs, and risk, and be determined principally by Condition Based Risk

Management (CBRM) analysis techniques. Replacement will be considered on a project specific basis, and holistic analysis of nearby assets will be performed to support optimal life cycle cost and customer impact.

3.2 Legislative Requirements

The assets described in this AMP are not specifically referenced in legislation, and therefore are expected to achieve general obligations surrounding asset safety and performance and service delivery. These obligations include compliance with all legislative and regulatory standards, including the Queensland Electrical Safety Act 2002 and the Queensland Electrical Safety Regulation 2013

The Queensland Electrical Safety Act 2002 s29 imposes a specific Duty of Care for EQL, which is a prescribed Electrical Entity under that Act:

1) An electricity entity has a duty to ensure that its works—
    a. are electrically safe; and
    b. are operated in a way that is electrically safe.
2) Without limiting subsection (1), the duty includes the requirement that the electricity entity inspect, test and maintain the works.

Under its distribution licences, EQL is expected to operate with an economic customer value-based approach to reliability, with Safety Net measures aimed at managing low probability high consequence outage risks. EQL is expected to employ all reasonable measures to ensure it does not exceed minimum service standards (MSS), assessed by feeder type, as:

- System Average Interruption Duration Index (SAIDI), and
- System Average Interruption Frequency Index (SAIFI).

Safety Net targets are described in terms of the number of times a benchmark volume of energy is undelivered for more than a specific time period.

Loss of substation power transformers is usually a significant event and may require Safety Net contingency plans to be exercised.

3.3 Performance Requirements

Assets in this AMP are considered critical in nature as they are of high value, require significant lead time to procure, and failure events have the potential to result in safety consequences, as well as substantial and extended customer load interruption. As a result, these assets are proactively managed on an individual basis with the intent of replacement prior to failure.

Maintenance and testing of substation power transformers is conducted regularly, with performance against defined criteria monitored, and issues addressed to ensure these assets reach the end of their economic life.

Defects identified via inspection programs are classified and prioritised according to the EQL Substation Defect Classification Manual. Identified defects are scheduled for repair according to a risk-based priority scheme (P1/P2/C3/no defect). The P1 and P2 defect categories relate to priority of repair, which effectively dictates whether normal planning processes are employed (P2), or more urgent repair works are initiated (P1). Additionally, a classification of C3 aims to gather information to inform or create a “watching brief” on possible problematic asset conditions.

The following sections provide a summary of performance against these measures as a defect rate.

Power transformers are the greatest potential source of major oil spills in substations, since they typically contain the largest quantity of oil. Spills may be caused by electrical failure, leaks, vandalism, sabotage, or accident. All insulating fluids, even those that are non-toxic and readily biodegradable, can damage the environment, so any spills must be contained within the substation.

Substation power transformers carry substantial volumes of mineral oil, typically between 1,000 and 39,000 litres.

The overriding principle of a substation oil containment system is that it prevents oil escape from the substation, whether it be from leaky or ruptured plant.

Substation oil containment systems shall be designed in accordance with the requirements specified in AS 2067 and in relevant parts of AS 1940.

There is duty to notify of environmental harm and to inform the administering authority and landowner or occupier when an incident has occurred that may have caused or threatens serious or material environmental harm under the Environmental Protection Act 1994.

3.4 Current Level of Service

There are no records of Dangerous Electrical Events (DEE) associated with substation transformers in EQL. This is due to the inherent level of safety built into the design of the units installed such as pressure relief valves and the protection systems which are used to limit exposure to fault current.

Whilst performance history in EQL has been free of DEEs there have been numerous incidents in other organisations of catastrophic failure of substation transformers leading to major fires and flying debris. As such safety remains an important measure of performance which EQL continues to monitor.

Figure 5 and Figure 6 documents the recent transformer failure history in Ergon Energy and Energex. Previous years, almost half of all significant failures were related to OLTC issues.

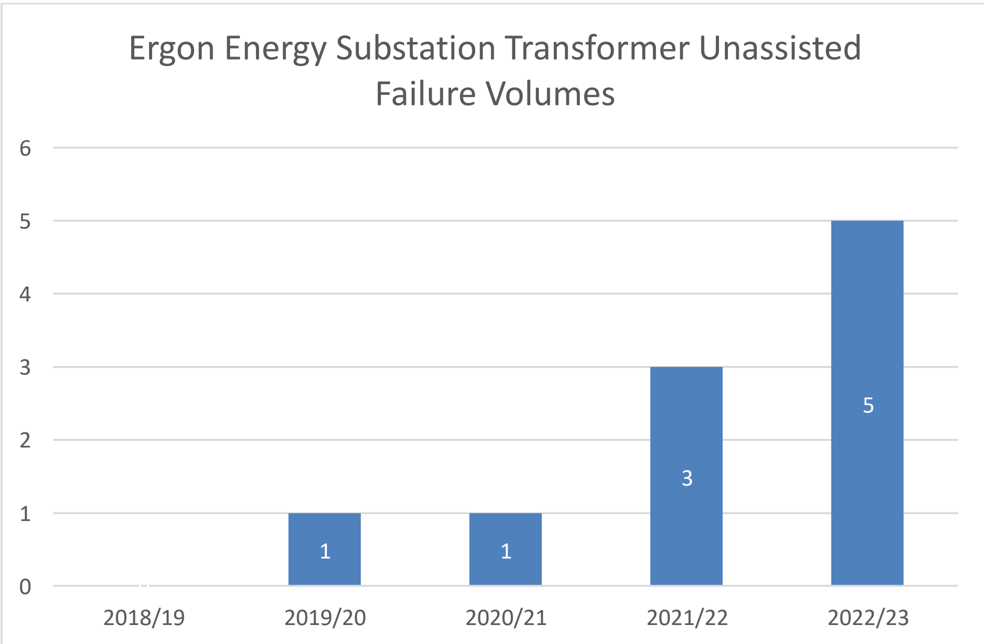


Figure 5: Substation power transformer significant failure history – Ergon Energy

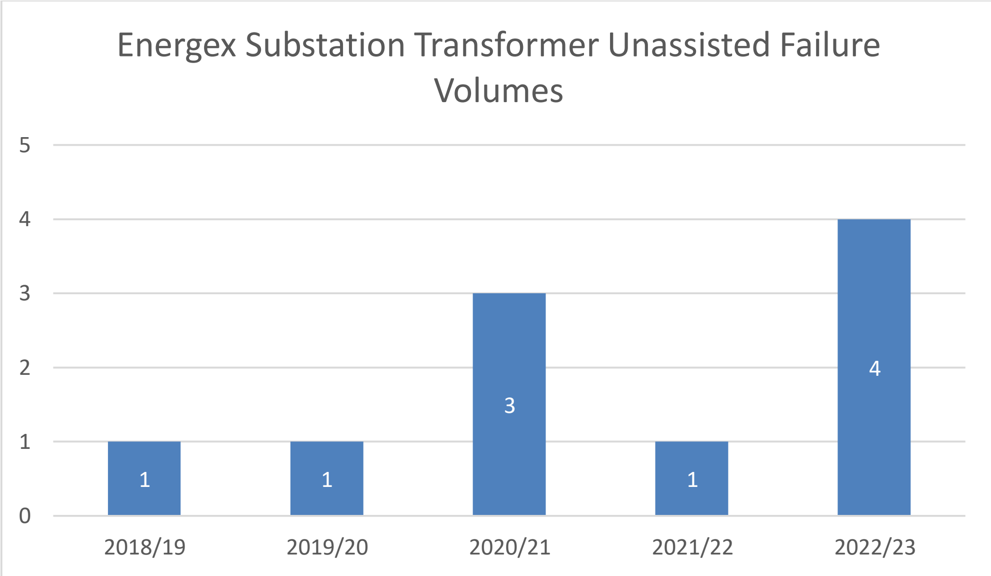
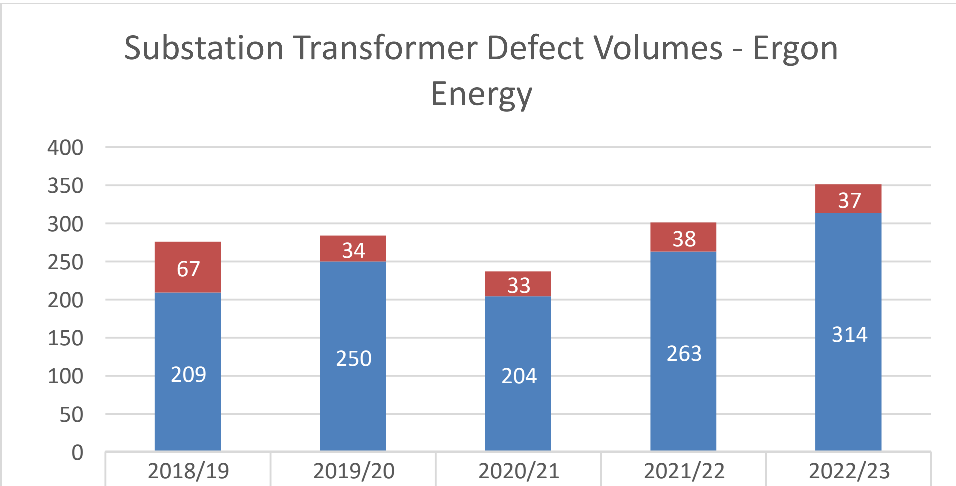


Figure 6: Substation power transformer significant failure history – Energex

Figure 7 and Figure 8 detail the historical trend of defect replacement and refurbishment works that have been conducted on these assets. The trend is normalised against the asset population in each region to provide a relative performance indication. The P0, P1, and P2 classifications relate to priority of work required, which effectively dictates whether normal planning processes are employed (P2), or more urgent repair works are initiated (P1 and P0). Due to the run-to-failure strategy employed, the defects recorded result in transformer replacement.



	2018/19	2019/20	2020/21	2021/22	2022/23
P1	67	34	33	38	37
P2	209	250	204	263	314

Figure 7: Substation transformer defect performance – Ergon Energy Region

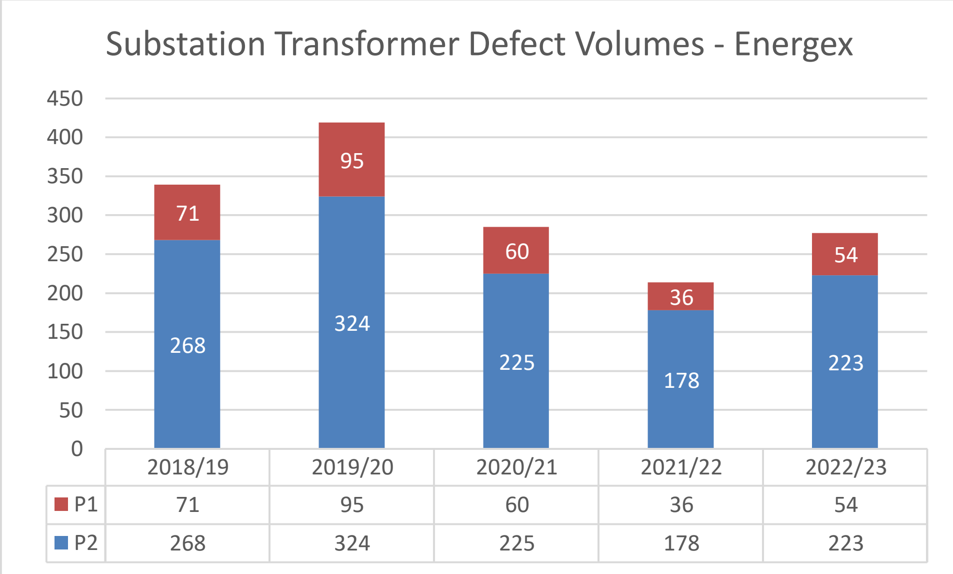


Figure 8: Substation transformer defect performance – Energex Region

The historical data currently available in Ergon's Northern and Southern regions has been improved by several years implementation of Maintenance Strategy Support System (MSSS) history records.

The condition of substation earthing transformers is tested due to their impact upon substation performance, but they are still typically operated to near-failure before replacing. There are no recorded DEE events associated with earthing transformers or substation service transformers.

3.5 Risk Valuation

Valuing the consequences of manifested risk supports understanding and comparison of ongoing and potential asset management strategies. Valuing the consequences of safety related risks is also an essential part of confirming EQL's compliance obligations for the Queensland Electrical Safety Act.[1]

[1] A consequence of Electrical Safety Act (Qld) s28 requiring a decision about whether a safety remediation/mitigation cost is "grossly disproportionate" to the risk.

4 Asset Related Corporate Risk

EQL has a Duty to ensure its assets are electrically safe. This safety duty requires EQL to act So Far as is Reasonably Practicable (SFAIRP) to eliminate safety related risks, and where it is not possible to eliminate these risks, to mitigate them SFAIRP[2]. Risks in all other categories are managed to levels As Low as Reasonably Practicable (ALARP)

Figure 9 provides a threat-barrier diagram for substation transformers. The "threats" (or hazards) presented in the diagram are applicable to all asset types covered in this document. Many threats are unable to be controlled (e.g., lightning), although EQL undertakes several actions to mitigate them SFAIRP/ALARP.

Failure of a transformer risks public and staff safety in several ways, most notably:

- Explosive failure leading to projectile motion of objects, including ceramic and metal shards.
- Significant oil fire, with associated heat and toxic gas impacts.

The following sections detail the ongoing asset management journey necessary to continue to achieve to high performance standards into the future.

The risk of fires within a substation is minimal, primarily owing to the presence of crushed rock within the substation, which makes it not applicable for this asset class.

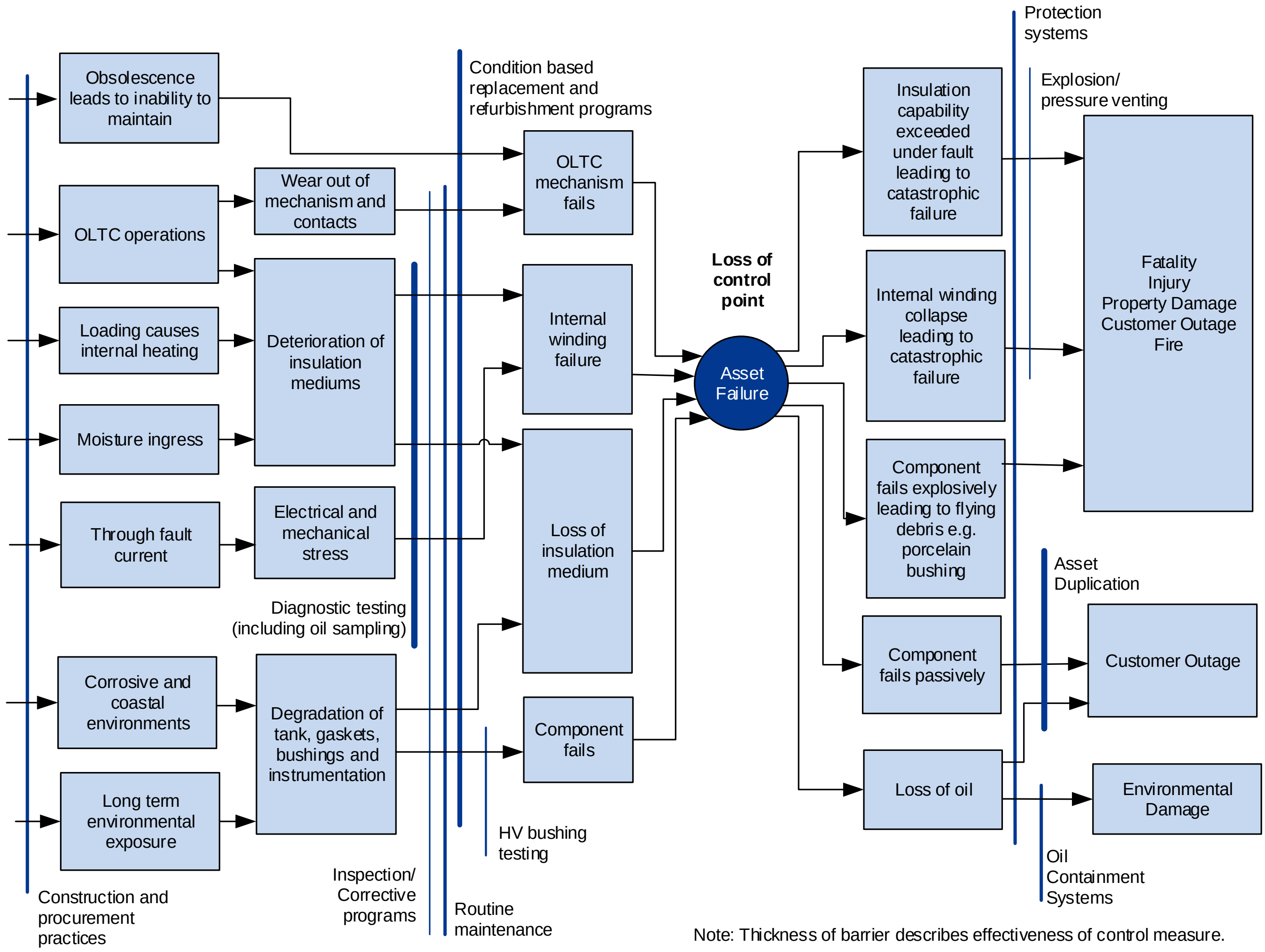


Figure 9: Threat Barrier Diagram for substation power transformers

[2] QLD Electrical Safety Act 2002 s10 and s29

5 Health, Safety & Environment

The following sections detail some of the health, safety, and environmental risks which may be associated with the management of this EQL asset base.

5.1 Polychlorinated Biphenyls (PCBs)

Polychlorinated Biphenyls (PCBs) are a known environmental threat because they are toxic, persistent and have a bioaccumulation tendency. Although they have been banned since early 1980s, they can still be found in the Australian network due to the use of common filling equipment during manufacturing and oil handling processes.

Oil is considered to be PCB free if the concentration is less than 2 ppm. Oil with PCB concentration greater than 50ppm is considered scheduled waste and must be disposed of only via authorised companies. Figure 10 shows PCB levels of EQL power transformers, it should be noted that there are no transformers with over 50 ppm levels of PCBs.

Continual testing for PCBs is an important step in the EQL PCB Free Strategy. Therefore, it is recommended that EQL perform fleet-wide testing every ~10 years; 2020 (underway), 2030, 2040, and 2050. This process will be undertaken until a full inventory of PCB liquids and equipment stock has been completed and confirms minimised cross-contamination of PCB has occurred.

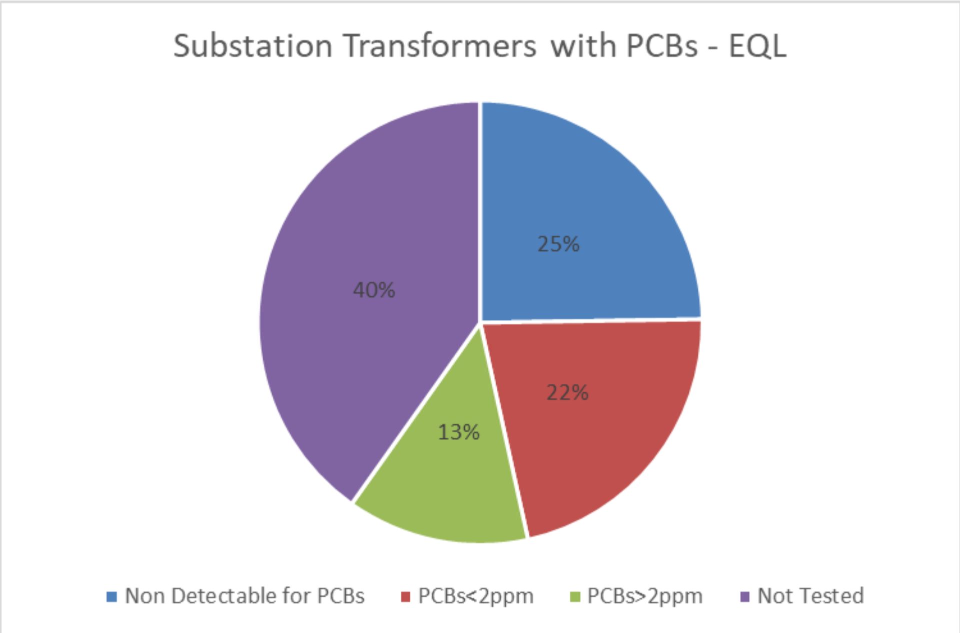


Figure 10: Substation transformers containing PCB

5.2 Working at heights

Ensuring safety while working on power transformers is a top priority. EQL has safety protocols for tasks at elevated heights, covering various elements like ladders, handrails, harnesses, and tie-down points. Within EQL's existing system, tie-down points, handrails, and maypoles are included. Maypoles serve as secure anchor points for harnesses, enhancing safety during maintenance and inspections. Nonetheless, issues arise with the availability of maypole connection points on every transformer, and manoeuvring the maypole itself onto the transformer can be challenging.

It's important to note that work in the area is progressing as EQL collaborates with a manufacturer to develop a permanent height safety solution. Furthermore, EQL is committed to implementing fall restraint systems or anchors for a fall arrest system to safeguard workers accessing any part of the transformer where the risk of a fall exceeds two meters or where a falling worker could impact a hazardous projection. This system will fully comply with Queensland Work Health and Safety

Regulation. The adoption of these safety measures significantly reduces the risk of accidents, thus cultivating a safer work environment for all involved.

6 Current Issues

The following sections outline current issues that have been identified as having the potential to impact EQL's ability to meet corporate objectives.

6.1 Oil Quality and Contamination

6.1.1 Water Content in Paper Insulation

Moisture ingress has been observed as a key cause of defects from the data recorded in EQL. Moisture results in deterioration of the transformer insulation and can lead to the reduction in useful life or asset failure if not addressed. Insulation degradation cannot be repaired, replaced (except for rewind) or reversed.

There are currently a number of transformers and oil filled reactors that exceed the maintenance acceptance criteria P2 level for moisture derived from routine oil test results.

The numbers of units exhibiting issues indicates a potential need for review of current maintenance and inspection practices. A review of maintenance activities will be undertaken to identify and address any opportunities to reduce the number of units experiencing moisture ingress. This will include a review of the adequacy of the breather systems and the practices for changing the silicon desiccant.

Assets already identified as containing high levels of moisture in EQL are being addressed by a program of oil dry-out where it is viable, using on-site dry-out units. These mobile units are attached to in-service transformers, and actively work to remove moisture from transformer oil. Typically, each unit is applied to a "wet" transformer for a period of around three months, with most observable improvement in oil moisture content occurring in the first two weeks. Once the dry-out unit is removed, moisture equilibrium between oil and insulation is achieved after 6 weeks. EQL currently owns 13 on-site dry-out units. The dry-out program cycles the mobile units between sites in a movement plan that is prioritised based on the observed moisture in the transformers. The condition of the transformers is re-evaluated on completion of the program to determine the impact on residual life for the asset population.

If the issue is not addressed through maintenance, it will lead to reduction in useful life for the units affected and result in an increase to the asset replacement forecast.

This is a cost-effective means of extending transformer life, to deliver customer outcomes and mitigate risk.

6.1.2 Moisture in On-Load Tap-Changers

A current issue with OLTCs is the problems of low breakdown voltage and high moisture. These problems are often from seals and inadequate breather sizing. It's also important to note that maintenance oil handling can make these issues worse. To maintain the OLTCs' reliability and avoid costly downtime, repairs and resamples, it's crucial to take proactive steps. Regular maintenance, like checking and replacing seals and making sure breathers are the right size, replacing oil, can help solve these problems. Additionally, keeping an eye on DGA, moisture levels and breakdown voltage through oil sampling can help catch issues early and prevent major breakdowns.

6.2 Bushing Failures

A bushing is an insulated device that allows the conductor that connects the transformer to the network to pass through the grounded outer metal tank of the transformer. These components are critical in transformers and typically require replacement once or twice during the transformer's life. Periodic inspections and condition testing are performed on all bushings above 66 kV, aligning with industry best practices and manufacturer recommendations.

It's worth noting that there are three primary bushing types: Resin Bonded Paper (RBP), Oil-Impregnated Paper (OIP), Resin Impregnated Paper (RIP) Resin Impregnated Synthetic (RIS). Historically, EQL used RBP and OIP types, as it was the predominant bushing technology available.

However, failures of OIP bushings in service tend to be explosive, either putting the substations and surrounding equipment or personnel risk. A transformer cannot be re-energised until the failed bushing is re-tested and, if required replaced, and such an incident can lead to complete transformer failure.

In response to these challenges and in light of recent failures, EQL is in the process of eliminating oil-filled bushings and porcelain outer shells, thereby reducing the likelihood of fires and the risk of projectiles in case of a bushing failure. To mitigate these risks, when necessary, all three bushings should be replaced with RIP/RIS bushings in a proactive replacement strategy.

This practice aligns with industry advice to help reduce the risk of fires and explosions in transformers by avoiding the use of OIP bushings for any in-service replacements and new transformers.

6.3 Un-bunded Power Transformers

Ergon Energy has approximately 140 sites with un-bunded power transformers, 5 of which are in sites deemed to be of high risk with concerns regarding their potential environmental impact. While power transformers are un-bunded, there’s a risk that oil leaks or spills can contaminate soil and water tables or spread beyond substation perimeters into sensitive water or terrestrial receivers like agricultural land, waterway ecosystems or nature conservations. A significant discharge of oil from a leaking transformer at a substation is an offence under the Environmental Protection Act 1994.

As the projects to construct permanent power transformer bunds are in progress, supplementary risk management measures have been implemented to address potential oil spills at these sites. Within the Management Plans for un-bunded power transformers, a range of control measures have been established, with a strong emphasis on the prompt response of staff to identify and address any new leaks.

6.4 Transformer Protective Coating Issues

For new transformers, all internal and external surfaces of structures and equipment, other than those specifically excluded, shall be finished with an appropriate protective coating system. The painting and preservation systems are expected to require no recoating within 25 years, i.e., Very High Durability per ISO 12944-1 or AS 2312. However, EQL have found several issues involving the corrosion protection system on new transformers, with paint failing to adhere properly to transformers, resulting in little protection to the transformers main tank, leading to sever rust and corrosion issues. This problem affects both Ergon and Energex networks, with some assets deteriorating to defect levels, necessitating immediate intervention to prevent further degradation.

Currently the proposed work scope includes addressing oil leaks, replacing corroded cable boxes, abrasive blasting to remove poorly adhering paint and properly applying very high durability painting and preservation systems. However, the outages to achieve such rectification works could be up to two weeks.

External painting contractors are required for abrasive blasting and painting, with a focus on meeting or exceeding the EQL Transformer Specification.

7 Emerging Issues

The following sections outline emerging issues which have been identified as having the potential to impact EQL’s ability to meet corporate objectives in the future.

7.1 Corrosive Sulphur

In the past couple of decades, there has been extensive research into power transformer failures associated with the presence of corrosive sulphur (CS). A global rise in early failures of relatively young transformers owing to what is referred to as corrosive sulphur is connected to the presence of Dibenzyl Di-sulfide (DBDS) in transformer oil. This issue triggers the growth of copper sulphide (Cu2S) within insulation, leading to flashovers and internal damage. Transformers at risk typically operate at high temperatures and have low oil oxygen levels.

There is an additional problem where sulphur ions interact with silver tap-changer contacts, forming silver sulphide (Ag_2S), resulting in oil contamination and flashover failures. A failure of an 80 MVA 110 kV transformer in November 2012 and sister transformer in 2023 (Energex network) is considered likely (albeit not conclusively proven) to have been caused by silver sulphide contamination of silver-plated tap-changer contacts.

Treatments with passivators, which are additives designed to capture sulphur, can be employed to tackle this issue, and avoid the need for a complete oil replacement. Nonetheless, the effectiveness of these passivators is still under evaluation in ongoing trials.

Testing for DBDS, CS and testing for passivator will continue.

7.2 Inadequate Oil Containment and Oil Water Separation

During routine inspections, EQL have detected instances of oil leaking out of containment bund walls and discharge of oily water from oil-water separators. It is evident that further efforts are necessary to identify and rectify any oil containment deficiencies, ensuring alignment with the updated EQL Oil Containment Standard. In conjunction with the maintenance program, EQL will need to address the specific challenges related to esters regarding oil containment and separation. Some ester types have higher density rendering gravity separation and other existing solutions impractical. Hence, EQL must explore alternative solutions to effectively address the unique challenges posed by esters.

7.3 Proportion of Population Approaching End of Life

EQL has a large population of substation power transformers that are approaching end of life. To manage network risk, maintain current levels of customer service, and ensure sustainable programs in the longer term, the rate of replacement and/or projects to extend the life of substation power transformers will need to increase.

The increase in the number of replacements will require substantial capital investment and will present operational challenges, particularly in the areas of procurement and resources to undertake the works. The program of transformer replacement will be managed on a risk basis within the portfolio of capital expenditure required for EQL. The program of transformer replacement will be optimised within broader constraints to ensure it is deliverable and sustainable, with replacements aligned with other major site works for efficiency wherever possible.

Forecast programs of replacement to manage this issue have been developed in accordance with the CBRM methodology. Refer to Section 9.6.2 for further information. Assets that cannot be replaced due to constraints in this program will require additional operational expenditure to manage the network risk.

7.4 Alternative Liquids to Mineral Oils

Alternatives to mineral oils are now available for use in high-voltage equipment, both in new designs or retro-filling existing designs.

These alternative liquids offer an opportunity to enhance safety and reduce environmental impacts. EQL is incorporating esters as an option and effective alternative to mineral oil, mainly because of their advantages in fire safety and biodegradability.

EQL’s plan acknowledges the operational and maintenance challenges associated with ester-filled power transformers, including the use of different ester liquids, sampling procedures, aging assessment, oil handling, end-of-life determination, preservation methods, bunding and water separation. and the management and disposal of these fluids.

EQL are actively conducting a trial to assess the suitability and technical compliance of these ester-based solutions. EQL's current focus is on the seamless integration of this innovative technology into our operational framework.

7.5 Capability for Bi-directional Power Flow

With increasing distributed generation on the distribution network, there is a potential problem related to excessive reverse flows and lower substation voltage setpoints resulting in power transformers hitting the limits of their bucking tap range. There is also the possibility of increasing boost requirements, due to the future growth of electric vehicles adding to evening peak loads. This requires new buck and boost tapping ranges for power transformers within EQL. This can only be addressed by changing the specification of new transformers.

It's worth noting that some existing tap-changer types were designed and manufactured without considering the possibility of bidirectional power flow and some assets may now have operating restrictions. EQL continues to identify assets that may have the potential to handle such flows, depending on individual transformer and tap-changer parameters.

8 Improvements and Innovation

The following sections outline any improvements or innovations to asset management strategies relevant to this asset class, being investigated by EQL.

8.1 Oil Conditioning

Contaminants and particulates in transformer oil develop into sludge, causing overheating and degradation of winding insulation due to loss of oil flow and cooling. The contaminated oil typically also becomes acidic which further degrades the insulation paper. The insulating properties of contaminated oil become reduced which, if untreated, eventually leads to flashover and winding failure.

Replacing the oil can mitigate the failure risks, but this can be logistically challenging and expensive. It also introduces additional oil handling and other environmental management risks. Oil conditioning (removal of particulates and gases) can assist, but at the expense of loss of DGA chemical accumulative history. This can affect the interpretation of future DGA which may indicate that the transformer is in better health than may be the case.

In-situ oil conditioning stands as a viable technical alternative. The costs for the unit can be recovered after only a couple of applications, rendering it a cost-effective choice when contrasted with full oil replacement.

8.2 Digitalisation and Digital Twins

Soon, EQL envisions implementing digitalisation and digital twin concepts for power transformers, aiming to enhance their monitoring, maintenance, and overall performance.

EQL also faces the task of addressing end-of-life transformer monitors and the availability of spare parts. A proposal from Grid Control and Standards introduced a proactive approach. This approach suggests replacing a portion of the currently in-service transformer monitoring systems with the new standard solution (currently under development), with the removed units intended for spare parts retention.

Digitalisation allows for real-time monitoring of power transformers by integrating sensors that collect data on parameters such as temperature, load level, dissolved gas in oil, bushing tap current, vibrations, and partial discharges. By continuously monitoring the transformer's condition, potential issues or abnormalities can be detected early on, allowing for timely maintenance and preventing costly failures.

From there, digital twins can be created for power transformers, representing their physical counterparts in a virtual environment. The digital twin can simulate different operating scenarios, monitor performance, and predict future behaviour. Data analytics such as physics-based models, AI algorithms, hybrid models, and statistical tools help identify optimisation opportunities, evaluate the impact of operational changes such as dynamic overloading, and test maintenance strategies without affecting the physical transformer. Prognostics involve forecasting the future performance and health of the transformer, estimating the remaining useful life, and assessing the probability of failure.

8.3 Oil Temperature Indicator (OTI) and Winding Temperature Indicator (WTI) Settings

Following a review existing Oil Temperature Indicator (OTI) and Winding Temperature Indicator (WTI) settings as well as relevant Australian standards, Asset Capability and Utilisation are consolidating the standard philosophy and temperature settings for power transformers across EQL. EQL will need to adjust the settings for the OTI and WTI to address issues related to flashover temperatures and the consideration of moisture levels. This adjustment aligns with commonly recommended settings and is crucial for optimal transformer performance and safety.

In service transformers within the manufacturer’s warranty period will be set as per the manufacturer’s recommendations. For transformers no longer under warranty the revised settings will need to be incorporated into future routine maintenance activities. The new settings will need to be recorded.

8.4 Further Progression Towards Risk Based Maintenance Management

EQL generally employs condition-based maintenance practices, including simple cycle driven periodic inspections and tests. With the development of individual asset history data, EQL may find opportunities to rethink maintenance practices, to better target solutions for problematic asset types and reduce inspection and maintenance for more reliable asset types. This will have many benefits, including increased in-service time, decreased maintenance costs, and ultimately better overall reliability for customers without compromising on staff and public safety.

8.5 Post-Mortem Forensic Examination

EQL has transformers in service today that are reaching or have already exceeded their anticipated asset life. However, while a transformer is actively in service, the ability to collect data is often restricted. This limitation makes it challenging to draw definitive conclusions about the assets condition. When a transformer is permanently taken out of service and scrapped, an opportunity arises to conduct a post-mortem analysis, allowing for direct measurements and observations to be made. For most scrapped transformers, it is possible to determine the extent of degradation by running several tests looking at the asset's critical components and the condition of the solid insulation. The most valuable information can be obtained from post-mortem forensic examination of transformers when scrapped.

Therefore, the primary objective of conducting post-mortem analysis is to provide valuable insights and, consequently, update future policies. A post-mortem analysis can identify the underlying cause of failure, detect any issues that have arisen during service due to weaknesses and find correlations between the findings and the operating and maintenance practices.

The information derived from a post-mortem analysis extends beyond the individual unit itself. It may provide insights into the condition of other transformers (e.g., the same design, from the same factory). Additionally, it could reveal the impact of different operating and maintenance approaches have on the transformers over time.

8.6 Health Index and Risk Monetisation

To support / justify the increased replacement volumes and resolve the economic limitation of Ergon Energy, EQL has:

- Developed a condition-based risk quantification modelling tool to establish optimum replacement volumes.
- Committed to adopt an economic, customer value-based approach when it comes to ensuring the safety and reliability of the network. To substantiate the advantages of this approach for the community and businesses over the modelling period, we have employed Net Present Value (NPV) modelling. This commitment is in line with their efforts to minimize the impact on customer prices.
    - A cost benefit analysis has been conducted to confirm that the substation transformer replacements are prudent capital investments.

9 Lifecycle Strategies

The following sections outline the approach of EQL to the lifecycle asset management of this asset class.

9.1 Philosophy of Approach

Substation transformers are considered critical in nature as they are of high value, require significant lead time to procure, and failure events have the potential to result in safety consequences, as well as substantial and extended customer load interruption. The critical nature of these assets combined with the relatively low population makes it prudent and cost effective to manage them on an individual basis and to replace them when they are approaching end of life and prior to failure.

The condition of substation transformers are proactively monitored through a combination of inspection and testing. One key condition assessment technique is Dissolved Gas Analysis (DGA). Oil samples are collected on a routine basis, with results analysed over the life of the asset to provide insight into the internal condition and remaining life. This testing is also used to determine whether maintenance or refurbishment of the asset is required to ensure that the unit continues to function as required to the end of its economic life.

9.2 Supporting Data Requirements

The following sections detail some of the data quality issues that can impact efficient asset lifecycle assessment and management.

9.2.1 Maintenance Strategy Support System (MSSS)

Maintenance Strategy Support System (MSSS) dataset is building over time and starting to provide the systemic information necessary to support improvements in inspection and maintenance practices. This is a data record system for all defects and failures, incorporating a requirement to record the asset component that failed, the damage found, and the cause of the failure. There is an expectation that this will also support and influence standard design and procurement decisions.

9.2.2 Condition Assessment Data

In order to assess transformer condition, an ongoing regime of inspection and testing is required, with a need for commensurate data records to support population issue identification as well as individual asset performance.

EQL's use of CBRM provides a platform for defining economic end of life for substation power transformers, regulators, and reactors, as well offering significant potential for condition-based and reliability-centred maintenance and inspection practices.

The data required for asset assessment includes routine inspection and maintenance records as well as test result records relating to internal condition. Data collection may require commissioning information as a benchmark, historical DGA sampling results, and electrical test results. In order to collect this information accurately and efficiently, the in-field asset management devices and systems of record must be configured accordingly and provide the necessary functionality.

EQL is currently replacing the legacy Enterprise Asset Management systems under a renewal project. This presents an opportunity to ensure that the new systems are configured to meet the data requirements necessary to support the asset management objectives including provision for online condition monitoring sensor information.

9.3 Acquisition and Procurement

Substation power transformers are typically procured on an as needed basis driven by condition-based replacement, network augmentation, and replacement of assets which have failed in-service, with the exception of critical spares contracts for these assets typically span at least several years for various logistical and pricing reasons and are based on technical specifications guided by the needs of the network. The contract periods determine the opportunity available to change technical specifications and improve asset performance by engineering out identified defects, standardising products, or implementing newer technologies.

EQL ensures that asset lifecycle management objectives and analysis is considered during technical specification and contract renewal as a part of standard process.

9.4 Operation and Maintenance

Operation and maintenance include planned and corrective maintenance. Operation and maintenance procedures are supported by a suite of documentation which describes in detail the levels of maintenance applicable, the activities to be undertaken, the frequency of each activity, and the defect and assessment criteria to which the condition and testing are compared to determine required actions. The relevant documents are included in Appendix 1 for reference.

The following sections provide a summary of the key aspects of the asset lifecycle.

9.4.1 Preventive maintenance

Preventive maintenance consists of inspection, testing, and routine maintenance activities as follows:

- In-Service Condition Assessment – periodic inspection of external condition and operational checks of ancillary equipment to identify defects. Inspections are also used to collect condition data for performance/risk analysis and replacement programs.
- Out of Service Condition Assessment – electrical testing undertaken to determine the condition of components that cannot be accessed while the asset is in service. This includes high voltage testing of the transformer bushings for voltages 66 kV and above.
- Non-Intrusive Maintenance – a combination of detailed inspection, functional checks, electrical testing, and routine restoration activities intended to restore serviceable items to an acceptable condition. Non-intrusive maintenance does not require access to components inside the main tank, conservator, or bushings.
- Intrusive Maintenance (tap-changer only) – a combination of detailed inspection, functional checks, electrical testing, and routine restoration activities intended to restore serviceable items to an acceptable condition. Intrusive maintenance requires access to components inside the diverter/selector switch tanks.
- Specialist Survey (oil sampling) – collection of oil samples from the main tank and tap-changer to enable dissolved gas analysis and other chemical tests. The oil sampling and testing program, combined with subsequent analysis, provides information such as moisture content, indications of thermal hot spots, oil acidity and breakdown voltage, and types of incipient faults such as electrical discharge activity.
- An online partial discharge survey and a thermographic survey of all assets within the substation site complement the routine visual inspection.
- Moisture removal from oil – use of low-level heating units on in-service transformers. The units are mobile and shifted around the population on a priority basis to manage high moisture content transformers, as identified by DGA analysis.

9.4.2 Corrective Maintenance

Corrective maintenance is generated from preventive maintenance programs, ad-hoc inspections, public reports, and in-service failures. Minor corrective actions usually occur during routine inspection and maintenance activities to avoid scheduling another visit to the site. Subsequent scheduling of required corrective actions that did not occur at the time of inspection is performed as specific corrective maintenance activities.

The triggers for corrective and forced maintenance include:

- Defects found during the inspection and maintenance activities
- Fault indication on protection and monitoring equipment located on the transformer or associated circuit breaker (post-trip)
- Poor voltage regulation
- Oil re-sampling recommended when the DGA analysis results indicate an emerging abnormal plant condition.
- Other equipment failure symptoms.

9.4.3 Critical Spares

The critical nature and long delivery timeframes of substation power transformers supports the requirement to hold a stock of critical spare units that may be used to replace (permanently or temporarily) an asset that has incurred damage due to a fault or failure. There are no spares held for OLTCs, however, in some specific instances recovered units may be retained to provide a direct replacement for similar in-service units. Sub-components such as bushings are kept as maintenance spares.

Spares holdings for these asset classes are determined through assessment of the populations, failure rates and provisioning period in order to provide a high probability of a spare being available when required. This requirement is balanced against the cost of holding spares and the risk associated with not having a spare available. Consideration is also given to the storage location of spares in this category due to the logistics associated with transporting them when required across the state.

EQL maintains a register of the spare assets which includes their storage location and asset attributes. Spares are regularly maintained to ensure they remain serviceable and ready for use.

The variation in voltage ratio, power rating, connection symbol, impedance, and voltage tapping range creates complexity in the calculation of spares holdings for substation power transformers. The management dilemma is to balance the requirement to hold a minimum number of units in every category versus the risk of exceeding reliability and Safety Net performance standards in the event of a failure. Inevitably, this translates to a complex cost benefit analysis that must account for a substantial variation in types, voltages, and capacities, as well as logistical challenges, such as transport restrictions in place for the very large size transformers because of the asset's inherent weight and size in relation to the capacity of local bridges and roads, traffic restrictions and local availability of suitably rated cranes and trucks.

9.5 Network Access Restrictions

Network Access Restrictions (NARs) are a process control used to limit access to assets and sites where safety risks have been identified, and where the assets must remain in service to continue to provide supply to customers. Typically, a NAR will involve either an exclusion zone being set around the asset while in-service, or requirements to switch the asset out prior to accessing the site. Other circumstances may require procedures to be undertaken in addition to the usual safety mitigations associated with a task being performed.

Whilst an NAR is an effective short-term risk mitigation method, the restrictions imposed on operations are significant. Additional costs are incurred to undertake routine work at substations where NARs are in place, to maintain the exclusion zones and undertake work safely. Similarly, the cost of asset replacement projects increases substantially to accommodate the staging requirements necessary to work at the site for an extended period. Outage durations and therefore customer impacts associated with undertaking work at sites with NARs are also extended significantly because of the additional requirements. NARs are not considered an appropriate risk mitigation for long term management of safety issues and so ultimately asset replacement or defect rectification is required to return the site to a fully operational state.

To deliver a sustainable program of works and balance network risk, customer outcomes and cost, it is necessary at this stage to increase the volume of substation asset replacement to address the sites with existing restrictions, and to ensure that the assets are removed from the network prior to requiring NARs to be implemented. Programs of replacement will be forecast in accordance with the methodologies outlined in Section.

9.6 Refurbishment and Replacement

The following sections outline the practices used to either extend the life of the asset through refurbishment or to replace the asset at the end of its serviceable life.

9.6.1 Refurbishment

Energy Queensland expects zone substation transformers to operate for at least 60 years. Therefore, refurbishments and life extension of power transformers offers several benefits to EQL, including improved total expenditure by avoiding costly replacements, a more manageable program of work through spreading out maintenance tasks and asset replacements, and extending the asset life to match the remainder of the substation for future rebuild.

An economic assessment of the cost and potential useful life is used to determine whether refurbishment is viable. Refurbishment activities are determined via assessment of the condition and can vary in complexity, from resolving corrosion issues and moisture removal, through to component replacement or a full rewinding of the asset.

As mentioned earlier in this document, EQL has identified various condition-related problems within its substation power transformers, including concerns related to moisture, oil leaks, rust, corrosion, as well as issues involving tap-changers and bushing components. Refurbishment provides an alternative to complete replacement of the asset and assists in reducing the impacts of the increasing program of replacement. It also provides an opportunity to introduce components with higher reliability and lower maintenance cost, to reduce operational costs.

EQLs new standard for Refurbishment of Power Transformers describes the circumstances in which power transformers can be refurbished in-situ under capital expenditure and the options for scope inclusions in the life extension refurbishment. This standard considers both proactively initiated and reactively initiated in-situ power transformer refurbishment.

The three main criteria are:

1. Whether a project/activity addresses safety or environmental non-compliance, adds capital value, capacity, or functionality to the asset,
2. Reduces related operating costs or
3. Extends the current remaining life of an asset by greater than 5 years.

9.6.2 Replacement

EQL has proactive replacement programs for substation power transformers. Where practical, timing of replacement is coordinated with other necessary works occurring in the substation to promote works efficiencies. Replacement is also coordinated with network augmentation requirements to deliver the lowest net present value cost to customers and avoid duplication of works.

EQL uses CBRM to forecast the end of useful life of substation transformers. This process combines asset data, engineering knowledge, and practical experience to define the current and future condition, performance, and risk for modelled assets. Refer to the Condition Based Risk Management Application Document for further detail on the CBRM process. In-service failure rate provides a measure of the performance of the proactive replacement programs initiated from CBRM and is used as an ongoing calibration input for the models.

EQL employs REPEX modelling to support the CBRM modelled outcomes. REPEX models employ asset age as an indicator of asset condition and combine the population age profile with ages of assets recently replaced at end of economic life to suggest likely long term replacement expectations assuming existing practices and strategies remain unchanged.

CBRM modelling begins with a “Health Index” (HI), developed to represent asset condition, which is regularly assessed as part of the various maintenance and inspection tasks. Figure 11 shows the relationship between the HI, remaining life, and the probability of failure.

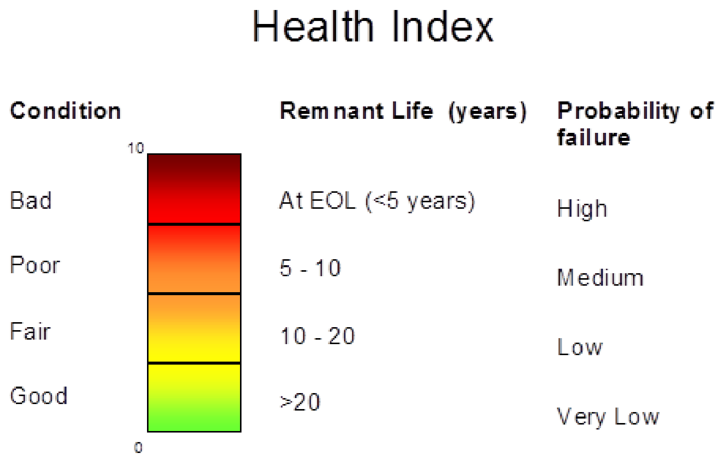


Figure 11: CBRM Health Index

A higher HI value represents a more degraded asset, with corresponding higher likelihood of failure. In turn this reflects as a higher risk of inability to achieve the basic customer energy delivery service.

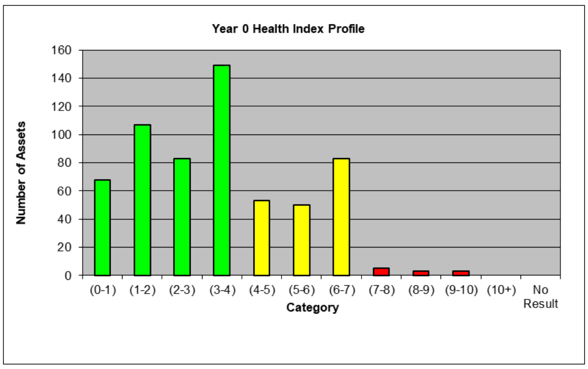
EQL considers assets as potential candidates for replacement when HI reaches 7.5. The oldest substation transformers in the population that have exceeded their technical life are also considered as potential candidates for replacement to avoid an unsustainable build-up of very aged assets.

Replacement of potential candidate assets is subsequently considered based on network requirements and in alignment with other network drivers such as augmentation and customer requested works to ensure the final option to address identified limitations is the most cost effective from a whole of network perspective.

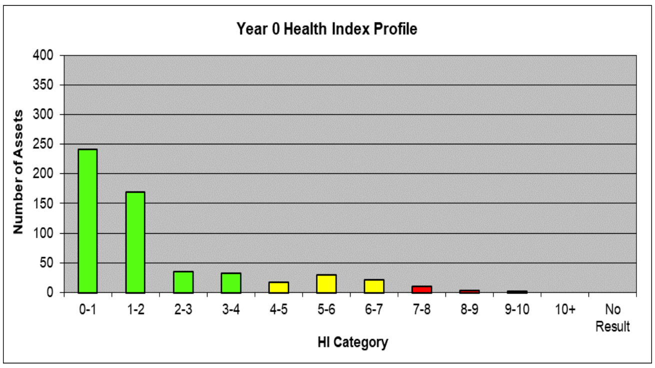
EQL's risk framework is applied to forecast and target the assets for replacement going forward. The projects are prioritised based on risk and the program is reconciled against corporate expenditure targets to produce the forecast requirement.

Figure 12 details a CBRM derived summary of overall condition of all substation transformers, using a traditional traffic light scheme where green represents healthy condition and red represents extremely degraded condition. Model Year 0 represents year 2023 and model Y7 represents year 2030.

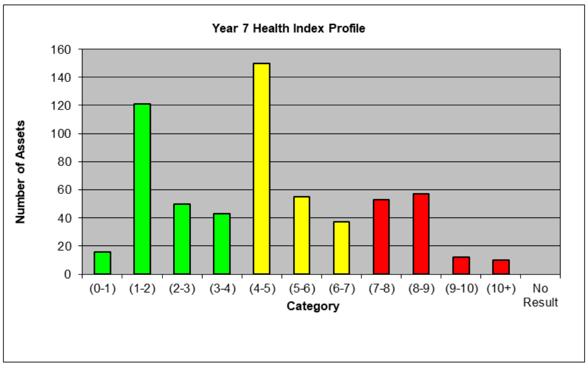
CBRM has projected the likely condition of the population in 2030 assuming age related deterioration and the intended programs have been implemented. Figure 12 identifies that overall population condition (health) is expected to degrade slightly, even allowing for the proposed replacement programs. The strategies and areas of focus identified are specifically intended to mitigate this degradation.



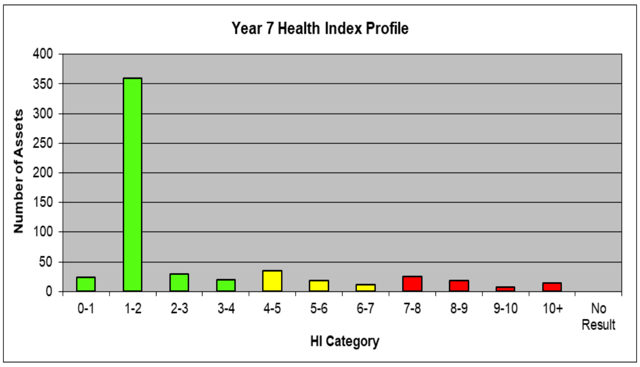
Ergon Energy (2023)



Energex (2023)



Ergon Energy (2030)



Energex (2030)

Figure 12: Population Condition – current and projected for 2030

The intended programs are reflective of the top-down pressure to constrain customer price impacts and the commitment to continue to look for efficiencies in program delivery and asset performance improvement. It reflects a risk position which balances the achievement of asset management objectives and customer service levels and ensures a level of investment which avoids future regret based on the uncertainty associated with the capability new technologies may bring.

9.6.3 Program Requirements and Delivery

The programs of maintenance, refurbishment, and replacement required to outwork the strategies of this AMP are documented in Network Program Documents and reflected in corporate management systems. Programs are typically coordinated to address the requirements of multiple asset classes at a higher level such as a substation site or feeder to provide delivery efficiency and reduce travel costs and overheads. The Network Program Documents provide a description of works included in the respective programs as well as the forecast units.

Program budgets are approved in accordance with Corporate Financial Policy. The physical and financial performance of programs is monitored and reported on a monthly basis to manage variations in delivery and resulting network risk.

For Ergon region, the key program which reflects the replacement volume forecast in the 2020-25 regulatory period is:

- Targeted substation power transformer replacement (Condition and risk)

For Energex, the key programs that reflect the replacement volume forecast in the 2020-2025 regulatory period are:

- C2040 Targeted substation power transformer replacement (Condition and risk)

9.7 Disposal

At the time of the disposal of any asset containing oil, EQL test for presence of PCBs to determine the appropriate disposal methodology in accordance with the Part 6 (Management of PCBs) of the Queensland Environmental Protection (Waste Management) Regulation 2000.

Assets that have reached end of life are salvaged for useable components to provide maintenance spares before being sold for scrap or disposed of accordingly.

Assets that are recovered prior to end of life due to augmentation or other network requirements but that would not be cost effective to re-install in the network may be sold to other organisations (such as mining companies).

10 Program Requirements and Delivery

The programs of maintenance, refurbishment, and replacement required to outwork the strategies of this AMP are documented in Network Program Documents and reflected in corporate management systems. Programs are typically coordinated to address the requirements of multiple asset classes at a higher level, such as a substation site or feeder, to provide delivery efficiency and reduce travel costs and overheads. The Network Program Documents provide a description of works included in the respective programs as well as the forecast units.

Program budgets are approved in accordance with Corporate Financial Policy. The physical and financial performance of programs is monitored and reported on a monthly basis to manage variations in delivery and resulting network risk.

Appendix 1. References

This table details all documents currently authorised/approved for use in either organisation that supports this Management Plan.

Organisation	Document Number	Title	Type
Ergon Energy Energex	EPONW01 EX 03595	Network Asset Management Policy	Policy
Ergon Energy Energex	PRNF001 EX 03596	Protocol for Network Maintenance	Protocol
Ergon Energy Energex	PRNF003 EX 04080	Protocol for Refurbishment and Replacement	Protocol
Ergon Energy Energex	STNW0330 EX 03918	Standard for Classifying the Condition of Network Assets	Standard
Ergon Energy Energex	STNW1160 EX STD00299	Maintenance Acceptance Criteria	Manual
Ergon Energy Energex	NA000403R328 EX 00294	QLD Electricity and Metering Manual	Manual
Ergon Energy Energex	STNW1125 EX 01105	Standard for Power Transformers	Standard
Ergon Energy Energex	STNW1126 EX 04131	Standard for On-Load Tap-Changers	Standard
Ergon Energy Energex	STNW1128 EX04133	Standard for Neutral Earthing Resistors and Reactors	Standard
Ergon Energy	EP26	Risk Management Policy	Policy
Ergon Energy	EP51	Defect Management Policy	Policy
Ergon Energy	SGNW0004	Network Optimisation Asset Strategy	Strategy
Energex	00569	Network Risk Assessment	Procedure
Energex		Work Category Specification 5.6.	
Energex		Work Category Specification 12.3	

Appendix 2. Definitions

For the purposes of this Asset Management Plan, the following definitions apply:

Term	Definition
Condition Based Risk Management	A formal methodology used to define current condition of assets in terms of health indices and to model future condition of assets, network performance, and risk based on different maintenance, asset refurbishment, or asset replacement strategies.
Corrective maintenance	This type of maintenance involves planned repair, replacement, or restoration work that is carried out to repair an identified asset defect or failure occurrence, in order to bring the network to at least its minimum acceptable and safe operating condition. An annual estimate is provided for the PoW against the appropriate category and resource type.
Distribution	LV and up to 22 kV networks, all SWER networks
Forced maintenance	This type of maintenance involves urgent, unplanned repair, replacement, or restoration work that is carried out as quickly as possible after the occurrence of an unexpected event or failure; in order to bring the network to at least its minimum acceptable and safe operating condition. Although unplanned, an annual estimate is provided for the PoW against the appropriate category and resource type.
PCB	Polychlorinated Biphenyls are synthetic chemicals manufactured from 1929 to 1977 and was banned for use in 1979 in transformers, voltage regulators and switches
Power transformer	A static piece of apparatus with two or more windings which, by electromagnetic induction, transforms a system of alternating voltage and current into another system of voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power IEV ref 421-01-01
Preventative maintenance	This type of maintenance involves routine planned/scheduled work, including systematic inspections, detection and correction of incipient failures, testing of the condition and routine parts replacement designed to keep the asset in an ongoing continued serviceable condition, capable of delivering its intended service.
Sub transmission	33 kV and 66 kV networks.
Transmission	Above 66 kV networks.

Appendix 3. Acronyms and Abbreviations

The following abbreviations and acronyms appear in this Asset Management Plan.

Abbreviation or acronym	Definition
ALARP	As low as reasonably practicable
AMP	Asset Management Plan
AUGEX	Augmentation Expenditure
CBRM	Condition Based Risk Management
CT	Current Transformer
DEE	Dangerous Electrical Event
DGA	Dissolved Gas Analysis
EQL	Energy Queensland Limited
HV	High voltage

Abbreviation or acronym	Definition
ISCA	In-Service Condition Assessment
LDCM	Lines Defect Classification Manual
LV	Low Voltage
LVR	Low voltage regulator
MSS	Minimum Service Standard
MSSS	Maintenance Strategy Support System
MVAr	Mega-VAr, unit of reactive power
NER	Neutral Earthing Resistor
NEX	Neutral Earthing Reactor
OLTC	On-load tap-changers
OTI	Oil Temperature Indicators
PCB	Polychlorinated Biphenyls
REPEX	Renewal Expenditure
RIN	Regulatory Information Notice
SDCM	Substation Defect Classification Manual
SFAIRP	So far as is reasonably practicable
WCP	Water Content of Paper
WTI	Winding Temperature Indicators
WTP	Wet Transformer Profile

Appendix 4. End Notes for Revision and Updates of Data Sources

[i] EQL Strategic Asset Management Plan 2020-25, January 2019
[ii] Total Value Chart V3.11.xlsm
[iii] Total Value Chart V3.11.xlsm
[iv] Total Value Chart V3.11.xlsm
[v] Total Value Chart V3.1.xlsm