A PRACTICAL FRAMEWORK TO ENHANCE ASSET CIRCULARITY FOR ELECTRIC UTILITIES

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EXECUTIVE SUMMARY

While many electric utilities have ambitious power generation decarbonization goals, few consider resource circularity in climate targets, financial models, supply chain, and inventory management. Traditionally the electric utility sector has utilized the standard "take-make-waste" approach of the linear economy in its supply chain and inventory planning processes. This model puts pressure on scarce raw materials and has higher long-term costs than a circular model. The circular economy model, which emphasizes a "make-use-reuse-refurbish-recycle" approach, **has emerged as an alternative to better manage resource scarcity and support sustainable economic development.**

Motivations for an electric utility to implement circular economy principles include:

- **Globalization and supply chain disruptions:** Electric utility infrastructure is often globally sourced, and disruptions in supply chains of raw materials, manufacturing, warehousing, and shipping are making equipment less readily available and more expensive. Assets with long lead times are becoming even longer. Refurbishing and reusing equipment could help mitigate this risk.
- **Urbanization and electrification:** The rise in urbanization in many developing countries has led to an increase in the demand for electricity. This puts pressure on global supply chains for raw materials. Second-use and refurbished equipment can make green and brownfield projects less expensive and significantly reduce project construction and delivery time by avoiding procurement of items with long lead times.
- **Climate change:** Weather events such as hurricanes, floods, extreme heat, rain, and winter storms cause power outages and disrupt utility service, and incidences of such events are increasing. Response and recovery time after storms is crucial for customers. Refurbished equipment is more readily available, and the associated reduction in materials use and emissions can reduce climate change.
- **Job creation and economic growth:** New economic sectors will emerge as material and resource flows are altered to be reused, refurbished, and recycled, including the advancement of industries for the utilization of recycled materials. Development of this capacity can support local economic development and job creation in regions and localities that traditionally face unemployment challenges.
- **Avoided costs and additional sources of revenue:** Implementing circularity processes can avoid or defer costs of purchasing new assets, and advances in the refurbishment and recycling of existing assets can lead to additional sources of revenue beyond that obtained from scrapping assets.

Despite clear motivations, migrating to a circular approach takes time, has internal organizational challenges, and requires a structured effort. This report introduces an Electric Utility Circularity (EUC) framework for executing circularity for an electric utility and provides actionable steps for stakeholder mapping, business model evaluation, organizational structuring, management practices, technology assessment and resource mapping, human resource needs and skill building, measurement, and accounting. It also provides illustrative examples of how asset planning and maintenance teams can apply principles of a circular economy to common utility assets such as distribution transformers, revenue meters, and components in isolated power systems. This work comprised for electric utilities and asset vendors complements USAID guidance on circularity for the broader energy sector[1].

This white paper introduces the EUC framework and provides examples to demonstrate how the circularity process can be applied by utilities and other energy sector stakeholders to make immediate improvements while also planning larger opportunities across the entire asset value chain. As new technologies are developed and the business environment shifts, this document also serves as a roadmap for how circularity plans can be updated over time.

[1] Clean Energy and The Circular Economy: Opportunities for Increasing the Sustainability of Renewable Energy Value Chains. A USAID report that discusses circularity for solar, wind, and battery storage assets.

LINEAR ECONOMY VS. CIRCULAR ECONOMY

The traditional economic model has been driven by the "linear economy" that follows a "take-make-waste" approach in which resources are taken from the planet, products are made to satisfy consumer demand, and products are discarded as waste after use. This economic model is predicated on the assumption that the earth has infinite capacity to provide and regenerate resources to support the ever-growing demand of consumers, and also that the planet has an unlimited capacity for waste disposal. The resulting behavior is that companies, consumers, and governments extract resources at the rate of 100 billion tons per year, or about 13 tons per person per year, with extraction estimated to occur almost twice as fast as regeneration (Lu, 2017; Circle Economy, 2022). The rate of extraction is projected to rise to over 200 billion tons per year by 2050, or about 20 tons per person per year (Carrying Capacity - World Population, n.d.), thereby worsening the imbalance between resource extraction and regeneration. Further, the world is currently producing about 2 billion tons of municipal solid waste that ends up in managed landfills and unmanaged systems of illegal dumping, unmanaged landfills, and incineration (World Waste Facts, n.d.). Today, an estimated 150 million tons of plastics have leaked into our oceans, and we are adding 10 million tons every year (Parker, 2020). Individual customers or companies may not presently perceive direct effects of the linear economy, but when considering this problem at scale and its accelerating trajectory, this is not a situation we can overlook and expect to maintain our current quality of life and business practices.

The circular economy has emerged as an alternative to better manage resource scarcity and support sustainable economic development. While the linear economy adds stresses on the environment, a circular economy is one that is restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value for as long as possible. In 2016, Finland became the first country in the world to create a national circular economy roadmap (Sitra, n.d.) and their example inspired several other countries in the following years to also create strategies (Hope, 2022). In the utility sector, Enel is a market leader in advancing Economic CirculAbility© to characterize and measure key performance indicators (KPI) for business activities (Enel Group, 2023).

Figure 1 shows asset life cycles for a linear economy and circular economy where each term refers to the following:

- DESIGN: The asset is designed according to circular economy principles.
- MAKE: Materials are used to produce or manufacture the asset based on the design.
- USE: The asset is used in the energy sector.
- WASTE: The asset is discarded into a managed or unmanaged landfill.
- REUSE: The asset is repaired and used again when a utility would typically discard the asset.
- REFURBISH: A broken asset or an asset at end of life is sold to a secondary market, repaired, and resold.
- RECYCLE: The asset is taken apart and its materials are used to create a new asset.

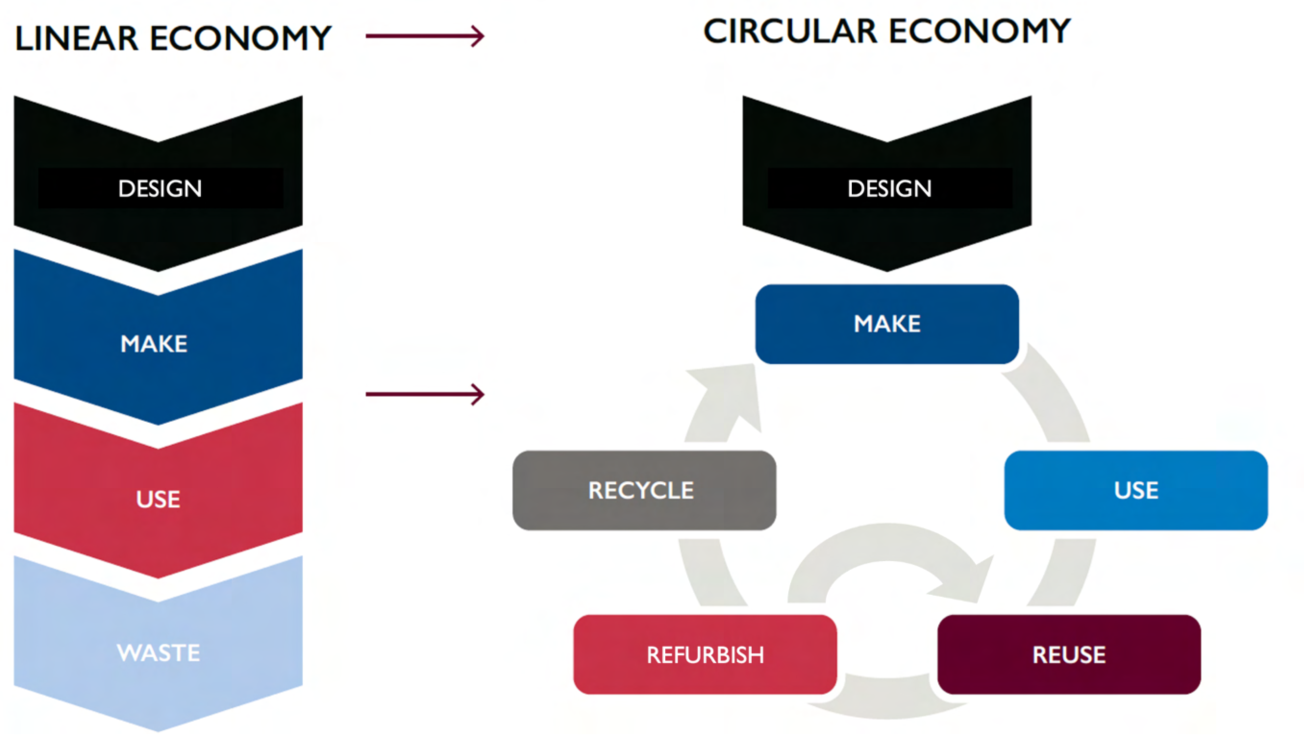


FIGURE 1: The transition from a linear economy life cycle to a circular economy life cycle (adapted from USAID, 2021).

Benefits of “going circular” for a company include optimizing use of materials, accessing new revenue streams, avoiding or deferring costs, expanding stakeholder engagement and value streams, and mitigating risk from supply shocks. Globally, the financial savings of the circular economy are estimated at $1 trillion USD per year (Buch et al., 2018). Circular economy business models include maximizing the useful value of materials and products through proactive design for longevity, reusability, disassembly, modularization and remanufacturing, recycling, system integration, dematerialization of products, and product-service systems (MacArthur, 2012). In a circular economy, manufacturers would utilize materials that are easier to recycle and reuse, either for the manufacture of the same product or for a different product.

EXTERNAL MOTIVATIONS FOR ELECTRIC UTILITIES

Global investment in the electric power sector is estimated to rise to $1.5 trillion USD per year by 2035, an industry that is characterized by the extensive use of non-biodegradable synthetic materials (steel, plastics, concrete, glass, synthetic rubber) and minerals (copper, aluminum, iron, lithium, cobalt, rare earth elements)

(McKinsey, 2022). Circularity can provide the sector significant financial savings and reduce the depletion of scarce resources. It also provides an opportunity to reduce the generation of carbon dioxide and other greenhouse gasses (GHG) from equipment fabrication and supply that contribute to climate change. Finally, circularity aids in the development of processes to remake and refurbish assets which could reduce inventory and supply chain risks that may arise from natural disasters, health epidemics, or conflict.

Globalization and supply chain disruptions. The electric power sector is of strategic importance to all countries, not just economically, but also with respect to national security (Department of Homeland Security 2015). Stressors to the global flow of goods such as trade disputes or conflict can compromise supply chains for critical electric grid infrastructure. For example, trade disputes between the United States and China temporarily affected the import of steel into the United States, an important component used in the manufacture of transformers and motors for electric vehicles (Bekkers and Schroeter, 2020). Circularity planning including reuse and refurbishment increases resilience to these stressors and decreases the need for new goods.

Geography. Electric power infrastructure varies by region and design preference. For example, large electric power transformers have to be custom designed and can easily weigh between 200,000 and 800,000 pounds (Department of Energy, 2012). Circularity of such assets within a locality or region can drastically reduce lead times for assets, and further simplify site testing, commissioning, and logistics.

Urbanization. In regions of Asia, Africa, and Latin America, rapid urbanization is accelerating demand for power that is leading to an extensive densification of national grids, and this push is making global supply chain and labor supply constrained (Henderson and Turner 2020). These projects are usually biased away from the use of refurbished equipment because most utility cost recovery mechanisms only permit a return on investment (ROI) for new equipment. These projects could be less expensive and create less pressure on supply chains if refurbished equipment could be utilized instead. Further, second-use assets can enable lower cost connections and accelerate electrical access for low-income customers that do not fit the standard cost recovery model.

Climate Change. Circularity can immediately reduce emissions generated from electrical asset fabrication, supply chain, and disposal. According to the United States Environmental Protection Agency (EPA), emissions from upstream and downstream supply chains, referred to as scope three emissions, account for over 90% of all emissions (Klein, 2021). Reducing the creation of new goods and simplifying logistical requirements is critical to reducing climate change. Further, a utility or vendor that can refurbish and remake assets will have greater "storm stock" available, and hence have increased readiness to respond to natural disasters with benefits to reliability metrics and resilience goals.

Job Creation and Economic Growth. By implementing reuse, repair, refurbish, and recycle processes, circularity planning can reduce waste and could offer economic opportunities worth nearly $4.5 trillion by 2030 (Accenture, 2015). This could also lead to the creation of 6 million jobs within the same time period (ILO, 2018). Circularity provides a means to achieve economic growth and development goals especially as many countries begin post-pandemic recovery planning.

INTERNAL CHALLENGES FOR ELECTRIC UTILITIES

In addition to these external motivations, electric utilities have their own internal challenges to advancing circularity practices, and these challenges manifest in multiple inter-connected ways.

Business Case and Measurement. Fundamental to acquiring buy-in from key decision makers, circularity initiatives need to be built with a strong business case foundation. However, initial conversations can be stymied if individuals and organizations begin with the perception that investing in people and the planet will come at the expense of profits. Moreover, business measures such as ROI and internal rate of return (IRR) do not work well for circularity because those measures are typically applied to individual business units that incentivize short-term value, and thereby limit awareness of the larger opportunity to be gained across the full value chain.

Organization Structure. Most organizational structures in utilities do not empower functional teams for maximum impact because circularity may not be an executive-level priority. This relegates circularity initiatives to a departmental or operational level, or worse, to be a separate function with little empowerment and no authority. In many organizations, sustainability and circularity teams are typically put under Services departments of the Distribution process, and tasked with liquidation of defective and obsolete assets. This approach adds circularity as a “special project” to existing responsibilities without clear performance measures, incentives, or reward systems, and this can cause underperformance of teams.

Skills and Resources. Electric power circularity requires a holistic process mindset to understand the entire supply chain across the organization and facilitate optimal, collective decision making across all functional units and business elements. Most electric utilities are structured by function, and decision making is typically prioritized by operation and hierarchy. The separate functional units may not have the skills and resources to orchestrate an organization-wide circularity effort.

Value Compartmentalization. Today, circularity opportunities for utilities have been focused mainly on recycling of scrap, or “low hanging fruit”, without trying to identify holistic opportunities across the entire value chain. This conventional practice is present in generation, transmission, distribution, and retail business functions. Each business function has structured behaviors that reinforce the unidirectional flow of value – in a supplier to customer relationship – with a linear flow of decreasing value until goods are finally salvaged. This linear approach to asset flows and narrow allowance for business relationships leads to value compartmentalization. For example, supply chain issues during the COVID-19 pandemic caused increased lead time and costs for transformers, and this motivated Engineering and Services departments to devise ways to repair and refurbish assets for reuse, and while this reduced value gained as scrap material, the shift increased overall value to the utility by improving restoration time and avoiding a greater financial burden of procuring new transformers. While circularity benefited the company as a whole, the compartmentalization of value could mean that individual business units face reduced metrics and thus are hesitant to adopt circularity practices unless value systems are adjusted.

Accounting. Liquidation of defective assets may be counted as revenue without considering the cost of its original purchase price. Liquidation prices will always be less than the acquisition price of the asset but accounting liquidation as additional revenue does not capture the avoided cost of new asset acquisition. For example, it is financially better to refurbish an asset for 20% of the purchase price, and avoid 100% of the purchase price, than recovering 5% of the purchase price in liquidation of the asset as scrap. Due to a lack of clarity in standards, even accounting for circularity efforts and climate footprint is fraught with challenges.

Suppliers and Vendors. If suppliers and vendors are not aligned and incentivized to support an organization's circularity goals, the effort will not produce the desired results. Mandating circularity efforts in a utility without buy-in from suppliers and vendors may lead to greenwashing operations. Agreements with suppliers and vendors need to be adjusted to indicate requirements for proof of recycling or verification, thereby reducing risk of a utility incidentally outsourcing its liabilities to a recycling organization that does not manage assets in the way intended. Further, in looking at refurbishment, scrap could be sold to the highest bidder to produce other marketable products versus recycling into utility products that add value and reduce costs to the utility industry.

Circularity Pathways. Circularity pathways are largely guided by the salvage value of an asset and ease of circularity. Figure 2 provides an illustrative example with typical circularity pathways, and these should be updated for local market forces and use cases by applying processes introduced in this document. Assets such as solar panels and wind turbine blades are difficult to liquidate, have low salvage value, and hence commonly end up in landfills; aluminum and copper wires and cables have high value but are usually unable to be repaired and safely reused and thus tend to be recycled; transformers can be easily and safely refurbished and reused; lead acid batteries deteriorate in performance but the raw materials can be easily recycled as exhibited in strong recycling supply chains in many areas of the globe.

Resilience and Reliability Concerns: Refurbished and previously used equipment have been degraded, and may fail at a higher rate than new equipment. However, implementing circularity will improve overall asset stock volumes, and improve metrics across the entire asset class and utility performance, and improve resilience of the utility generally. Such outcomes can be improved by quality assurance, testing, and performance evaluation practices.

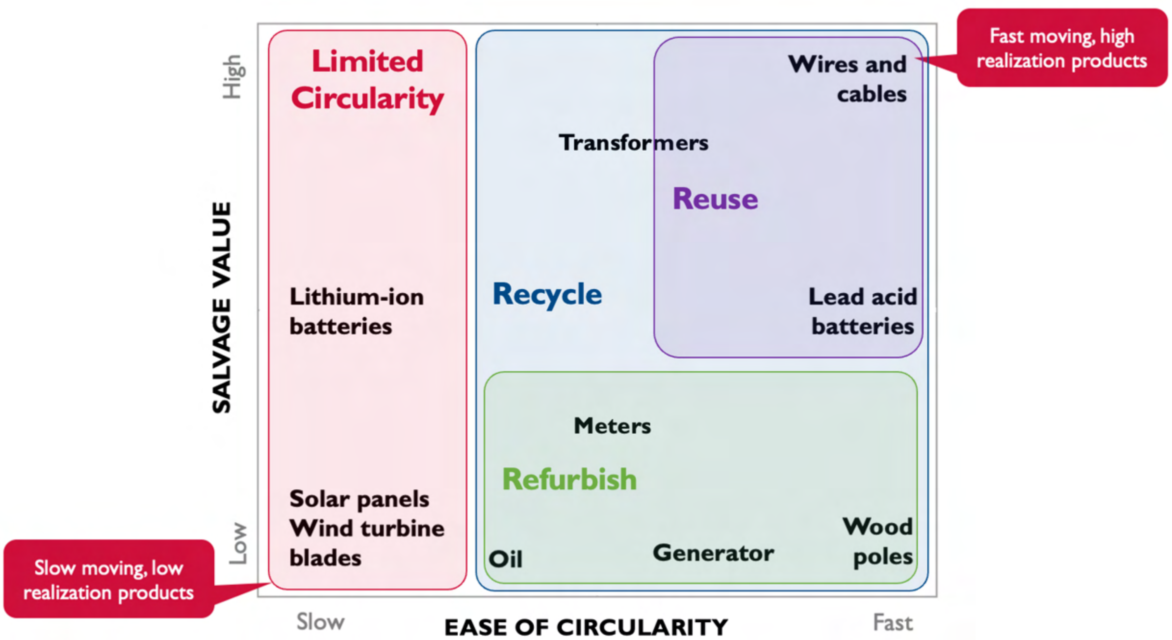


FIGURE 2: Liquidation speed and salvage value influences circularity pathway for electric utility assets. Example circularity pathways shown for illustrative purposes, and these should be updated for local market conditions and use cases by applying the Electric Utility Circularity (EUC) framework.

ELECTRIC UTILITY CIRCULARITY (EUC) FRAMEWORK

While many electric utilities have ambitious power generation decarbonization goals, few utilities consider resource circularity in climate targets or financial models. Furthermore, as described in the previous section, there exist many challenges in today's circularity practices. The Electric Utility Circularity (EUC) framework has been created to combat these challenges and provide guidance. Shown in Figure 3, it provides a systematic approach for a utility to establish circularity and maximize benefits. Six steps are completed sequentially, supported by four cross-cutting activities that occur concurrently and collaboratively throughout the overall approach.

The EUC framework incorporates elements from the USAID 5Rs framework (USAID's 5Rs Framework highlights five key dimensions of systems: Results, Roles, Relationships, Rules and Resources) with business concepts from customer discovery, lean startup, customer development process, and business model creation (USAID, 2016). Systems thinking is used throughout to characterize specific actors of the sector (e.g., organizations, individuals), the rules governing the sector (e.g., policy, regulation), assets (e.g., natural resources, physical built environment), and their relationships to one another. Collaborating, Learning, and Adapting (CLA) practices are used throughout to ensure that, "programs are coordinated with others, grounded in a strong evidence base, and iteratively adapted to remain relevant throughout implementation," with complementing details provided in the USAID CLA Toolkit (USAID, 2021).

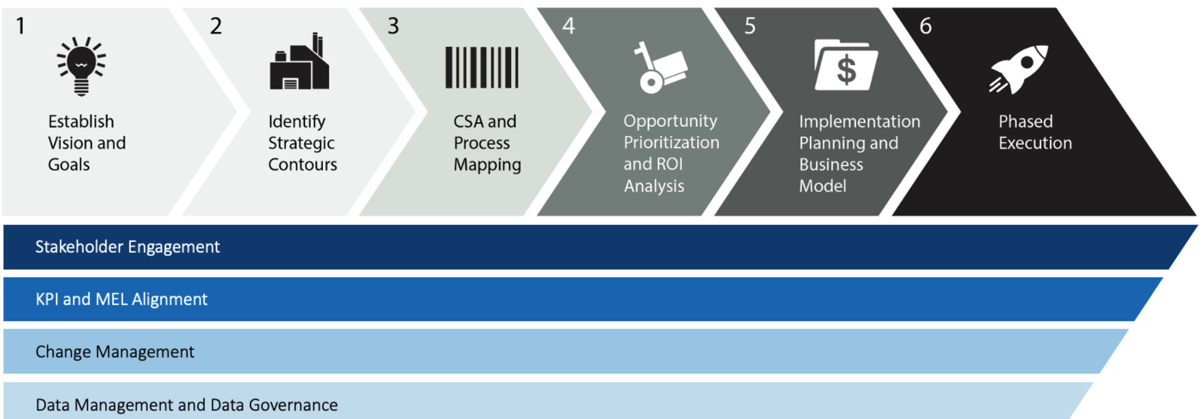


FIGURE 3: Electric Utility Circularity (EUC) framework for utilities to implement circularity.

1. **Establish Vision and Goals:** This step outlines and clarifies what the utility is trying to achieve such as reduced scope three[2] greenhouse gas (GHG) emissions, increased readiness to respond to natural disasters, avoided costs and reduced costs, additional revenue streams, reduced reliance on foreign materials and asset providers, or more. This circularity vision must be aligned with company goals, ingrained in leadership's agenda, and include key stakeholders such as customers and investors to assure inclusivity, buy-in, and long-term viability. Policy should also be used as a guide.

2. **Identify Strategic Contours:** Strategic contours are the filters or guides that make circularity initiatives more practical for maximum effectiveness. They are the realities of the physical, social, institutional, and political environment where circularity efforts can be instituted for greatest impact with least resistance (or effort). Examples of strategic contours include regulated vs. deregulated electricity markets, impact of climate change on the utility (e.g., wildfires and floods), political climate and its impact on policy and governing, government ownership and governance of key assets in the

[2] Scope 3 emissions are the result of activities from assets not owned or controlled by the reporting organization, but that the organization indirectly affects in its value chain.

utility value chain, existing resource streams, and industry or manufacturing needs in the region that could utilize recycled or refurbished equipment.

3. **Current State Assessment (CSA) and Process Mapping:** This step begins by completing a life-cycle mapping for selected assets. That life-cycle assessment is complemented by identifying the stakeholders, businesses, policies, and environmental considerations related to each step in the life cycle. The resulting landscape awareness allows a team to look for synergistic opportunities that may not be apparent if focusing on only individual steps of the value chain (value compartmentalization), and the team selects the desired scope of the "system boundary" to explore in detail and execute within.
4. **Opportunity Prioritization and ROI Analysis:** In the near term, utilities can work internally and with partners to prioritize actions to reuse and refurbish assets for immediate benefit. Stakeholders identified during CSA development can also participate in a co-creation process to identify opportunities and actions to transition into a circular economy, and thereby unlock new opportunities for cost avoidance and revenue gain that also reduces emissions and waste. Initial business cases are developed to show cash flow and ROI for each opportunity. Warranties and performance guarantees by the vendor, energy services provider, and utility are important to diverting waste generation from faulty, but repairable, equipment.
5. **Implementation Planning and Business Model:** Immediate progress can often be made within the utility to deliver near-term impact while opportunities with greater impact that involve more actors take longer planning. The key is to build a phased implementation plan that delivers immediate benefit and builds into something greater. Each opportunity undergoes a business model evaluation and a feasibility assessment with variable stages of incremental advancement.
6. **Phased Execution:** At this stage the circularity team should utilize an agile approach of project management to implement projects that deliver quick returns and build on each success.

Four essential cross-cutting activities occur concurrently to support the framework: (1) stakeholder engagement, (2) key performance indicator (KPI) alignment and monitoring, evaluation, and learning (MEL) processes, (3) change management, and (4) data management and governance.

Stakeholder engagement should include utility engineers, planners, technicians, management, equipment vendors, recycling service providers, and potential off-takers of refurbished equipment or recycled materials. Governmental institutions and policy makers need also be engaged for early buy-in to advance circularity practices that disrupt existing value structures. Standards institutions, investors, workforce development organizations, and supply chain / channel companies are further necessary stakeholders, and become engaged as priorities are developed and scope takes shape. These stakeholders are valuable to gain perspective on the overall landscape or "problem space" and will be engaged throughout the framework in developing the life-cycle assessment, business model, and execution strategy.

Key performance indicator (KPI) alignment and monitoring, evaluation, and learning (MEL) processes are essential for establishing goals and tracking progress throughout the organization and value chain. KPIs may exist as disparate goals for business units, utility leadership, energy sector generally, and government. Any substantive differences may require change to seek greater alignment and perhaps a common set of goals, and thereby enable various stakeholders and actors to work more collaboratively to attain broader goals. As the financial incentives are tied to circularity and business performance, a change in behavior will occur. Monitoring progress, evaluating approaches, and learning from progress and challenges will allow organizations to refine KPIs and processes for better effect.

Change management refers to the process of guiding organizational change to realize value, from the earliest stages of conception and preparation, through implementation and finally to resolution or sustainment. Change management is essential to institutionalizing a change in culture and process. The team implementing change management should be a cross-cutting unit that interacts with all aspects of the organization so that teams are not disconnected or disempowered.

Data management and data governance is a key enabler for MEL. As any project is executed, circularity results need to be documented not only for audit and stakeholder buy-in, but also for continuous improvement. A secure data management and data governance plan must be put in place to ensure consistency, repeatability, sustainability and accountability for business case purposes.

Figure 4 provides a process map that integrates circularity life cycle processes (Figure 1) and the EUC Framework approach (Figure 3) together for electricity services and electricity products. In addition to circularity life cycle activities (design, make, reuse, refurbish, recycle), conventional business activities are brought to attention that can be leveraged to receive the most value out of circularity processes.

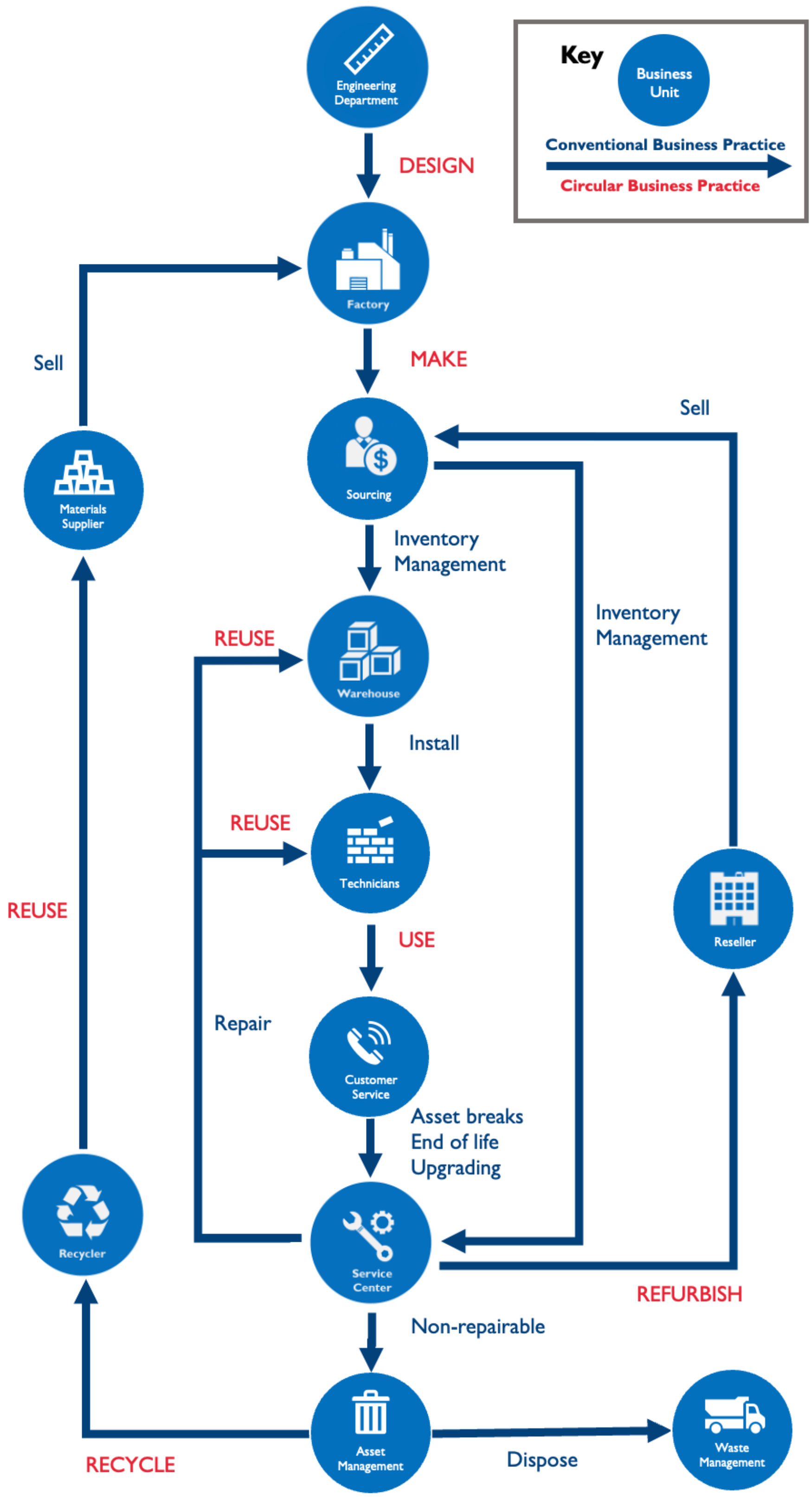


FIGURE 4: Circularity pathways for an electric utility asset.

EXISTING APPLICATIONS OF CIRCULARITY TO POWER SECTOR COMPONENTS

Electric utilities and energy technology providers are already applying circularity principles today. The following case studies highlight current practices, show early benefits and impact, and illustrate how the EUC Framework can be applied to further improve utility business models and enhance resource circularity. The electric meter and transformer provide examples for energy services companies or traditional utilities that operate and/or own power distribution infrastructure, and the example of isolated power systems for off-grid customers demonstrates applications of circularity for energy product companies such as solar home system retailers.

Electric Meter

Utilities are increasingly looking to upgrade analog meters to digital meters (AMR)[3] or smart meters (AMI)[4] to increase visibility, identify outages, quantify non-technical losses, and implement time-of-use tariffs. This shift in the electric industry is creating significant numbers of used analog meters, which have immediately viable circularity pathways including reuse as second-hand meters or recycling for salvage value. Let's look at an example for recycling:

> A utility could liquidate a meter and sell it as scrap materials. The Smart Meter National Programme (SMNP) in India, managed by the Energy Efficiency Services Limited (EESL), a Joint Venture of Public Sector Undertakings (PSUs) under Ministry of Power, is a nationwide effort to install about 250 million digital smart meters across the country (EESL, n.d.). In July 2021, Patna Electric Supply Undertaking (PESU), the utility responsible for providing electric power to customers in the city of Patna, Bihar, announced they had installed about 76,000 digital smart meters, replacing old analog meters (Rumi, 2021). Looking at this case, PESU's 76,000 replaced analog meters, with the meters weighing about 5 lb, produces a total of about 380,000lbs of scrap including brass, copper, aluminum, circuit board, steel, glass, and more. Taking a simple average cost of $1 per pound of scrap (iScrap App, 2022), the scrap materials generated from each meter can result in approximately $5 revenue and a total of $380,000 for PESU in this illustrative case.

Used analog meters can also be reused for other customers within the utility's service territories that may not require an upgrade, and lack the energy use or income to recover the cost of a new digital meter. The avoided cost could save $50-200 per connection, depending on the purchase price of a new meter, and enable a utility to expand energy access while also deferring investments in digital meters until another capital expenditure phase. Used meters have a cash value in secondary markets of $0.6 to $2 per unit (GovDeals, 2023), which presents a

[3] Advanced meter reading (AMR).

[4] Advanced metering infrastructure (AMI).

small value for resale revenue, but a high value in the avoided cost of digital meters for new connections to low-income households.

Case Study: Enel Circular Smart Meter

Enel S.p.A is an Italian multinational electric utility that serves more than 63 million customers in over 30 countries, that launched a sophisticated circular economy process in 2015, in part as a response to the 2015 Paris Agreement and EU's Circular Economy Package released in the same year (Enel Group, n.d.). The Enel Circular Economy Model is comprised of five pillars: circular inputs, products as a service, shared platforms, useful life extension, and new life cycles. Enel applied these pillars to the development and implementation of its Circular Smart Meters. Enel began installing smart meters for its customers in 2001 to replace the analog electro-mechanical meters. In 2017, the company developed a version 2.0 of the smart meter, called the Open Meter, which apart from measuring energy consumption also provides customers with important information on their energy use and other tools to inform their decision-making processes with regards to their energy use (Enel Group, 2022).

<u>Circular Inputs:</u> Enel utilizes easily recyclable and reusable materials as its inputs for the manufacturer of some of its products. The company's Circular Smart Meter, which it started manufacturing in 2020, is made from 100% recycled plastic and advanced rapidly through six months of research and development.

<u>Products as a Service (PaaS):</u> Enel has shifted towards a business model in which consumers only pay for the time of services they receive from a product, enabling the company to increase utilization of that product as they are able to offer it to other customers. The Circular Smart Meters provide Enel the opportunity to pilot new business models such as advanced energy efficiency and management services for its customers through the meter's AMI.

<u>Shared Platforms:</u> Enel can manage multiple products across various customers on a shared platform decreasing replication and unnecessary redundancies in its operational process.

<u>Useful Life Extension:</u> Enel has instituted modular design concepts and predictive maintenance processes that extend the useful life of products while also avoiding unnecessary maintenance in lightly used assets.

<u>New Life Cycles:</u> Continuous improvement preserves the value of products or assets at their end of life by the systematic application of refurbishment principles. This way Enel can reuse products per its PaaS model, increasing utilization in the process. Each Circular Smart Meter results in a savings of 7 kg of CO2 over the course of its useful life (15 years) and 1.1 kg of virgin material (Enel Group, 2022).

The success of the Circular Smart Meter led the company to form a wholly-owned subsidiary, Gridspertise, in 2021 that will be responsible for the manufacturing and distribution of the meters to other utilities. In January 2022, Gridspertise announced it had signed agreements with utilities in Italy, Malta, and San Marino to supply over 650,000 Circular Smart Meters (Enel Group, 2022).

Electric Transformer

Electric utilities are experiencing a shortage of transformers due to supply chain shocks and the increased incidence and severity of weather events (Hiller & Blunt, 2022). In the United States, lead times for transformers in 2022 have quadrupled, and the prices for new transformers in some cases have increased by 500% (Hiller & Blunt, 2022; GRID 20-20, 2022). In Kenya, rolling blackouts persisted in 2022 as the utility Kenya Power experienced shortages of over 2,100 transformers (Transformers Magazine, 2022). This has prompted utilities to refurbish old transformers to extract additional value, rather than scrap or recycle. Let's look at some data:

> Transformer lifetimes can be significantly extended with preventative maintenance and a design that allows for repair. The average lifetime of a transformer is between 35 to 40 years and can be extended to operate up to 70 to 100 years with preventive maintenance and component replacement (Glover et al., 2017). According to a whitepaper by Emerald Transformers, a company which specializes in recycling and refurbishing transformers, a refurbished transformer could save a utility between 30% and 70% of the cost of a new one (Emerald Transformers, n.d.).

Refurbishing and reusing transformers also increases stock volumes for utilities and resellers, thereby increasing overall sector resilience to climate stressors and weather events that damage transformers in operation, and further reduces emissions generated by replacing failed transformers with new transformers. Although transformers have high value as scrap in copper and electrical steel that comprise 50% weight of a unit (Department of Energy, 2012), there are well-defined markets with vendors and utilities refurbishing transformers to avoid the cost and long lead time of a new transformer.

Case Study: Salt River Project (SRP) Transformer Circularity Process

Salt River Project (SRP) is an electric and water utility that serves 2 million people in the Phoenix Metropolitan Area, Arizona in the United States. SRP uses an Evaluate, Repair and Reuse, Refurbish and Recycle circularity practice for distribution transformers. Approximately 25% of distribution transformers screened by SRP are repaired and reused, with the remaining 75% sent to be refurbished or recycled.

<u>Evaluate:</u> Transformers are removed from service due to faults or when they are at end of life. Technicians evaluate transformers to check for rust, degradation of components, and obsolescence. Data from the evaluation is fed into a decision-making tool to recommend if the unit should be repaired using internal labor and resources, or sent to external organizations for refurbishment or recycling. The tool recommends actions based on the status of the unit, market costs and lead times for transformer replacement, replacement part cost and lifetime, replacement part availability, transformer stock owned by SRP, and labor time and labor rates. Some organizations embed this analysis as part of another step in their circularity process, however, for SRP, evaluation is a distinct step in the circularity process that also identifies which departments are involved (technicians, engineers, purchasing) in future steps. Output information from the tool is actively used to update the circularity process with respect to changes in equipment pricing and lead times.

Repair and Reuse: SRP's transformer shop includes an internal workforce of technicians to re-gasket various units, process oil, and replace worn out or faulty parts such as fuses or windings in old transformers and then reuse those transformers. Once a transformer is repaired, it is relabeled and placed back into circulation. SRP also processes and treats transformer oil through gasification and filtration techniques, and since 2010, the company has not purchased any new transformer oil thereby reducing cost and environmental impact. SRP also has an inventory of used transformer components including fuses, lids, seals, transformer doors, handles and switches, among others. These components are reused and replace faulty parts from transformers taken out of service and brought to the shop for repairs.

Refurbish and Recycle: Transformers that are unable to be repaired in-house are sold to an external company at a set price per pound, that can then refurbish or dismantle components and recycle materials. SRP will retain certain parts of the transformer that are still in working condition and use those parts for the repair of other transformers.

Isolated Power Systems

Increasing amounts of electricity and energy services are provided through stand-alone, off-grid systems such as solar home systems and mini-grids. Companies and cooperatives serving off-grid customers will be essential to providing sustainable energy access to all by 2030 and fulfilling UN Sustainable Development Goal 7 (United Nations, 2022). Circularity principles can also be applied to this growing class of electric companies that may operate as a traditional utility with tariff-based cost recovery models or operate as an energy technology provider with agreements to sell, lease, lease-to-own, or rent technologies for energy access. Innovative business models have emerged to service these off-grid and/or remote customers that incorporate circularity principles to reduce e-waste and increase equipment lifespans (GOGLA, 2023). Some examples of these new business models and companies that utilize them include:

Company sells power generation equipment: In this business model companies sell their power generation products to customers either through outright purchases or financing schemes, with guaranteed warranty on the products. When the equipment fails, customers can call upon companies to send service technicians to fix equipment or return equipment to companies for a replacement. The close association of company business models to equipment performance and disposition enhances circularity. Companies may sell a full power system kit or specialize in parts of a system. For instance, Victron Energy sells full solar home system (SHS) kits or individual power system products with a standard five year warranty on hardware (Victron, 2023).

Company provides power generation equipment and also appliances as a complete system: This business model involves the sale of commonly used appliances such as televisions, refrigerators, and lighting alongside electric power kits, usually a combination of solar photovoltaic (PV) panels and a battery storage unit. Sun King, formerly known as Greenlight Planet, offers such systems to customers on a Pay-As-You-Go lease-to-own (LTO) scheme. Customers pay as low as $0.22 per day, and fully own the systems after one year of payments, enjoying free electricity thereafter (Sun King, 2023). Designing products with fewer materials is essential in this model.

Company retains ownership of the system and sells electricity: This model involves customers and energy service companies signing an energy supply or power purchase agreement for electricity. Assets are completely financed and owned by the energy service companies but located on the customer's site. This model is becoming very common among commercial and industrial (C&I) customers in Sub-Saharan Africa that cannot rely on the intermittent power provided by the incumbent on-grid utility. According to the Africa Solar Industry Association (AFSIA) among all business segments, C&I has the highest year-to-year growth of 61.5%. Daystar power, which provides this type of service to C&I customers in Ghana, Nigeria, Senegal, and Togo, is one of the major providers of this service. Similar models exist for SHSs provided to residential customers. In this model, companies maintain ownership and control of the energy assets and are able to manage their disposition more appropriately to increase circularity. One example of this would be Kingo, a Guatemalan start-up company that sells solar home systems (SHS) to remote communities primarily in Central America (Kingo, 2023).

Case Study: ENGIE Energy Access Circularity Model

ENGIE Energy Access is a full-service energy provider with 1,800 employees and 2 million customers in nine countries in Sub-Saharan Africa (ENGIE, 2023). The vertically integrated company utilizes extensive circular economy planning frameworks for all energy products and services including SHSs, mini-grids, and DC electric solar appliances. ENGIE Energy Access also guides industry trends as co-chair of the Circularity Working Group GOGLA (a global association for the off-grid solar energy industry) (GOGLA, 2023). ENGIE Energy Access implements a circularity model with four pillars: Warranty, Repair and Replacement, Refurbishment, and Disposal and Recycling.

Warranty: Customers receive a 4-year warranty on SHSs and a 2-year warranty on solar DC appliances. The warranty allows customers to have faulty equipment inspected at no charge and repaired or replaced in part or in full to meet performance expectations. Customers gain confidence in their investment and the company brand, which further improves asset recovery rates. This diverts faulty equipment from landfills and unmanaged waste disposal. Assets are recaptured for refurbishment and/or recycling. Every country has a call center to address customer needs and warranty claims. Over 92% of customers are satisfied with the company and its services (including warranty). Warranty claims are compiled monthly and quarterly, and escalated to suppliers to improve product design, thereby reducing fault and repair needs, and improving estimates for spare parts procurement needs.

Repair and Replacement: ENGIE Energy Access has over 1,500 commissioned maintenance and repair technicians to swap/exchange, fix, and perform minor repairs of faulty equipment. These technicians are distributed in each country and can be dispatched for fast, in-field diagnostics. Field technicians can resolve 50 to 60% of reported issues during a maintenance visit to the customer, hence avoiding premature product swaps. More extensive diagnostics and repairs are completed at country-level warehouses. Items that cannot be repaired, but are still under warranty, are replaced free of charge. Over 200,000 SHSs and appliances are diagnosed and fixed annually. Mini-grid systems are inspected quarterly, and preventative maintenance is completed quarterly to reduce need for major repairs.

Refurbishment: Refurbishment also occurs in country-level warehouses. These facilities operate at over 90% capacity utilization, equipped with a technical staff able to conduct deeper component level repairs (circuitry, component swaps, soldering/desoldering). Refurbished products are returned to the field to support warranty swaps. 60 to 70% of product swaps are utilizing refurbished items. As of 2023, resale of refurbished equipment takes place in four of the nine markets for ENGIE Energy Access.

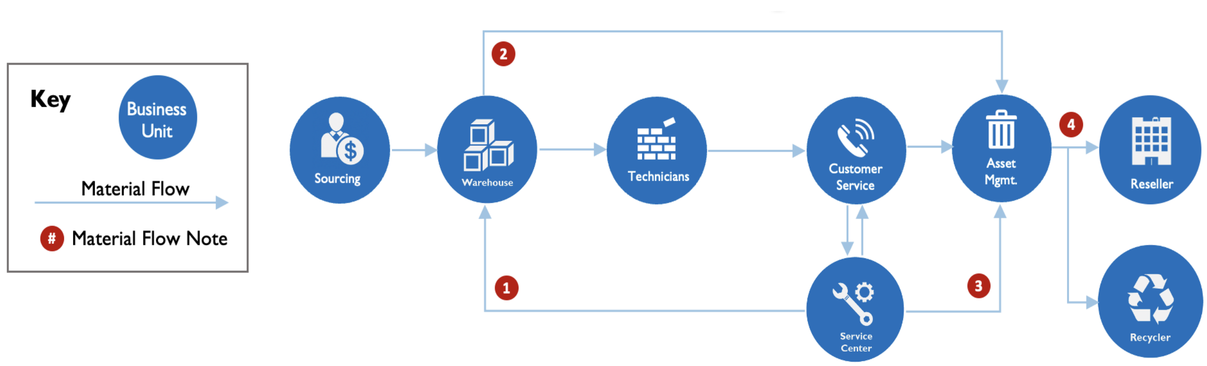
Disposal and Recycling: ENGIE Energy Access contracts vetted recycling and disposal partners to properly handle products at end of life. Nearly 800 tons of mixed waste fractions were recycled in 2021 and 2022 (ENGIE, 2023).

BUSINESS CASE FOR THE EUC FRAMEWORK

Existing utility practices, particularly in resource constrained developing country markets, have made significant progress towards circularity goals by creating solution sets for specific needs. However, these practices often do not take a holistic view and miss out on greater value and avoided costs. The following example of an electric meter life cycle illustrates how value is lost by taking a siloed approach to asset recovery instead of applying systems thinking and application of the EUC Framework.

Lost Value in the Electric Meter Life Cycle

An electric meter (analog or digital), like any other product, goes through a process of vendor selection, contract negotiations, sourcing, inventory management, warehousing, installation, servicing, and end of life management. Most analog meters are being replaced by digital or smart meters, primarily in developing countries due to the pre-paid feature enabled by digital meters for increased revenue collection rates. The process and associated activities shown Figure 5 for the electric meter illustrate a subset of the full process in Figure 4. The top half of the chart maps the process left to right whereas the bottom half of the chart indicates the relative cost of each activity for analog, digital, and smart meters.



	Sourcing	Reseller	Recycler
Type of Meter	Cost (USD)	Salvage Value (USD)	Scrap Value
Analog with Glass Cover	$30-$35	$0.6-$2	Low
Digital with Glass Cover	$50-$60	$0.6-$2	Medium
Smart with Plastic Cover	$150-$300	N/A	Highest

1. Spare parts and repaired equipment go back to inventory
2. Equipment is disposed due to overstock or damage
3. Non-repairable equipment is disposed
4. Equipment and parts sold

FIGURE 5: Electric meter example circular product life cycle focused on asset recovery.

If you follow the product life cycle of an electric meter in Figure 5, the circularity value is being exclusively captured at the last stage of the process through the process of repair/refurbishment or scrap sale/recycling.

Scrap sale is more prevalent and follows the conventional thinking of take-make-waste. Let's rethink this approach using a circularity mindset:

> In 2018, in the United States market, 5.4 million analog and digital meters were decommissioned as part of upgrades or repairs (U.S. Energy Information Administration, 2022). Thinking of an asset recovery model, used meters can be sold at $0.6 to $2 per unit, meaning the 5.4 million units would net a salvage value of between $3.2-$10.8 million (GovDeals, 2023). If those units were disassembled and sold as scrap, they would fetch recyclers a revenue of $27 million (iScrap App, 2022), assuming simple average of scrap metals and their market rate within a meter gives us about $1/lbs, or $5 per unit[5], and noting the cost of labor and disassembly would need to be factored into the business model. However, taking a different perspective with a circular economic model, let's consider if those used meters or their parts displace the purchase of new meters in a secondary non-US market at an average price of $50 per meter. Then the financial gain across the energy sector is much higher at $270 million in avoided costs, less any costs for the used meters, repair, boxing, certification, etc.

The above example indicates that the strategy of using only asset recovery as the cornerstone of circularity is flawed because the value generated is too small and, as mentioned in the Internal Challenges section, post-sale scrap tracking is often lacking and hence organizations cannot quantitatively convince stakeholders of outcomes.

Expanding Value with the EUC Framework

A well-executed EUC Framework can create value across the entire value chain and easily dwarf the compartmentalized value from just asset liquidation.

Sourcing. Working with suppliers to co-create circularity strategies can help reduce carbon emissions across the entire supplier ecosystem, including transportation of goods. The legacy supplier selection process can be modified to make it more circular, ethical, and strategic. Vendor reassessments across numerous industries have demonstrated that such an exercise will yield at least a 10% cost savings in material purchasing (Ogden, 2003). This exercise can even include buying refurbished products as a sourcing channel to complement existing new products, thereby reducing the total cost of acquisition and complementing circularity.

Warehouse and Inventory Management. Accurate demand and supply planning can reduce inventory by up to 15% without impacting service levels (Prijic, 2020). This will utilize less warehouse space, less energy to run warehouses, and less personnel. As products start to come in for storage, warehouse automation and green design efforts have shown that they can reduce warehouse energy consumption and costs by as much as 20%-50% (Partridge, 2011).

Warranty and Service. Ethically sourced products that are built to be more repairable and of better quality leads to reduced scrap in the energy efficient and automated warehouse. The domino effect of efficiency and decarbonization continues with application of predictive maintenance technologies that lead to less scrap and more repair because problems are caught before a product fails. This approach has been measured to increase

[5] Brass screws at $1.70/lb, copper wire at $2.65/lb, aluminum wire at $0.20/lb, circuit boards at $1.55/lb, and steel at $0.32/lb (iScrap App, 2023)

meter life by 20%-40% and lower total cost of ownership (Liska, P., & Djakam, E., 2018). Predictive maintenance can decrease warranty and services cost by up to 20%, and spare parts and maintenance costs by up to 25%.

Repair, Refurbish, and Recycle. Repairable and 100% recyclable meters reduce up to 7 kg CO2 emissions over its lifetime (Enel Group, 2022). This scrap reduction may equate to up to 5% of the total new inventory.

People. Studies have shown that sustainable companies with circularity practices have lower attrition and happier employees resulting in 16% increase in productivity (Whelan & Fink, 2016).

The cumulative value illustrates that all financial savings, cost avoidance, efficiency improvements, and employee productivity gains equate to much more value than the revenue from liquidation of assets. These changes are business-driven and lead to a circular and sustainable organization through application of the EUC Framework. And further, application of the Framework helps to restructure organizational value systems and create unit-level KPIs that empower a cross-functional workforce to be more aligned to reach utility-level and organization-wide goals in circularity.

TABLE 2: Example circularity benefits to business functions of an electric utility (references above).

Functions	Business Value	Comments
Sourcing	Avoided cost up to 10% of goods	Sustainable, repairable, circular products, supplier re-selection
Warehouse and Inventory Management	Less warehouse space by 10%-15%; 20%-50% energy reduction	Better warehouse design, reduced inventory leads to reduced space required and less energy consumption
Warranty and Service	Cost reduction by 20% and spare parts inventory reduction by 25%	Predictive diagnostics leads to less failure, less technician visits, less spare parts inventory, less scrap
Repair, Refurbish, and Recycle	Reduction of total inventory by up to 5% due to reduced scrap	Repairable products with extended life will reduce total scrap
People	16% increase in productivity leading to less hiring, and more empowered workers	New generation of workers prefer to work with companies that support circularity and sustainability

RISKS AND MITIGATIONS

The electric power industry is a large, strategic focus for countries that can prioritize business-as-usual and comfort for known circumstances. Below are some risks that could arise from implementing a circularity strategy and how they can be mitigated.

1. The first risk comes from taking on too big of a challenge and wanting to do it all at once, not having the resources, or the will to do it. The best remedy is to start small, demonstrate tangible results, and build on successes.
2. Buy-in from all key stakeholders in the value chain is particularly acute where sponsorship is not from the government, or from the CEO's office. The best remedy for this is to get the right sponsors and work with them to change their performance measures so they are tied to the success of the project.
3. In smaller, or developing countries, political influence, or pushback can be substantial. With continuous education and a quantifiable business value proposition, minds can be changed. It is important to have a realistic plan backed by a strong, quantifiable, and irrefutable value proposition to counter this resistance.
4. Lack of data to build a value proposition and track results of existing projects can also become a major obstacle. This investment in data storing, tracking and governance is an essential requirement before the start of the project to ensure that the business model and message are viable.
5. Improper planning can lead to measuring the wrong things, and/or measuring things wrong. The fix to this is to develop measurement processes for a limited number of key measures across the entire process. This exercise needs to be done with all key stakeholders.
6. The final risk is misaligned incentives and this is an offshoot of circularity not being on the CEO's agenda. If the circularity and sustainability measures are on the agenda of the prime minister, the energy minister, or the CEO of a company, the downstream decision makers and practitioners will all align accordingly.

GETTING STARTED

The EUC framework provides electric utilities and associated stakeholders with an actionable guide to mitigate supply chain uncertainties, increase warehousing of critical assets, reduce climate impacts by deferring and avoiding asset replacement, reduce operating expenses, and introduce mechanisms to secure additional revenue. Realizing the breadth and scale of this value can take time to plan and execute. Priorities established through the EUC framework may emphasize opportunities with immediate benefit, and utilities and vendors can use those successes to motivate longer-term and more ambitious opportunities that yield larger benefits.

Here are some ways to get started with immediate progress and near-term outcomes:

- Prioritize assets such as transformers, revenue meters, and conductors that can be more readily refurbished and recycled with existing technology and training (refer to Figure 2).
- Identify the stakeholders and business units for each part of the EUC Framework (refer to Figure 3).
- Utilize the circularity pathway examples for utility assets (refer to Figure 4) to create the process flow for a selected technology.
- Review historical data on asset maintenance and replacement to identify assets that have increasing numbers of outages, unplanned maintenance events, or replacement incidences. This research may uncover increased degradation or failures that warrants circularity planning if supply volumes cannot replace assets.
- Review historical data on asset volumes for use, supply, and warehousing to determine changes in overall throughput and stock volumes, which can uncover risks if storage volumes are decreasing, particularly in locations that need to reserve "storm stock" in case of natural disasters.
- Assess costs associated with asset procurement to replace broken or damaged assets.
- Perform routine and preventative maintenance.
- Estimate the avoided costs by performing preventive maintenance.
- Forecast total volume estimates of assets for new expansion planning and existing asset replacement to understand and coordinate overall resource flow requirements.
- Identify recycling and second-use off-takers for assets and raw materials, including local and regional actors.
- Identify relevant or related policies on materials utilization, recycling, climate change, cost recovery models, and related issues that affect strategic contours and priorities.

CONCLUSION

Circularity is a process and a journey of continuous improvement that must evolve with changes in technology, business environment, materials availability, and policy.

The EUC Framework provides a structured approach for utilities and energy sector stakeholders to design strategies and implement solutions. The best place to start is with an empowered champion and small beginnings. Starting small will realize immediate value and gain buy-in for more ambitious efforts. A phased approach helps stakeholders experience circularity as a process, not a product or end-state, and establishes a culture that collaborates, learns, and adapts to continually advance outcomes.

Processes and solutions will be market dependent, and differ by location, materials selection, existing resource chains, vendors, policies and regulations, costs of comparison goods and materials, and other factors. Sharing experiences and learnings through utility networks will help us all learn and grow, and advance upon our shared values for enhancing energy access, equity, reliability, renewables, and cost reduction for a net-zero carbon and circular future.

Take one product and map it out and identify if the business case passes muster on dimensions of circularity, decarbonization and profitability. The first one will be the hardest, but concrete results will make believers and subsequent initiatives will become easier. Let the journey begin!

GLOSSARY

Term	Definition
ASSET	According to Energy Education, an asset is a store of value that has the ability to provide benefit in the future to whoever owns it. There are many types of assets, stocks, bonds, equipment, buildings, and people and the skills they possess. Assets are bought, sold, or created by an entity so that over time they will yield some form of benefit, a higher value, more efficiency etc.
CIRCULAR ECONOMY	According to the Environmental Protection Agency, it is an economic system that "keeps materials, products, and services in circulation for as long as possible." A systems focused approach that "reduces material use, redesigns materials, products, and services to be less resource intensive, and recaptures "waste" as a resource to manufacture new materials and products".
DECARBONIZATION	According to Terrapass, the process of moving away from energy systems that produce carbon dioxide and lowering the amount of greenhouse gas emissions produced by human activities.
DEPRECIATION VALUE	According to *The Economic Times*, the measured decrease in monetary value of an asset over time due to use, wear and tear or obsolescence.
DEMATERIALIZATION	In a circular economy, this is the process of delivering the same product or service using a percentage or none of the mass or material types, i.e., digitization or optimization, according to the*Circular Economy Guide*.
ELECTRIC METER	According to *Enertiv*, a device capable of measuring the amount of electricity consumed by a space or piece of equipment.
LINEAR ECONOMY	According to *Santander*, "the traditional model where raw materials are collected and transformed into products that consumers use until discarding them as waste, with no concern for their ecological footprint and consequences".
LIQUIDATION	According to *Investopedia,* converting property or assets into cash or cash equivalents by selling them on the open market. This is usually done at the end of a business to recover losses or pay off debts.
LIQUIDATION VALUE	According to *Investopedia*, the monetary value of an asset or net value of all assets of a business, once it has been liquidated or sold, presumably at a loss to historical cost.
ORIGINAL VALUE	The value of an asset before succumbing to any depreciation.

TRANSFORMER	According to *Encyclopaedia Britannica*, electrical components that transfer electric energy from one circuit to another, either increasing (stepping up) or reducing (stepping down) the voltage. Used to facilitate safe energy transfer from a utility provider to their intended customers.
SUPPLY CHAIN	According to *Supplain*, the network between an organization, its suppliers, and consumers that include all the transactions involved globally in transforming raw materials into marketable products.
VALUE CREATION	According to *Digital Leadership*, "the process of turning labor and resources into something that meets the needs of others".

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