CIRCULÉIRE

CIRCULÉIRE'S CIRCULAR ROAD & RAIL GOOD PRACTICE SECTORAL GUIDE

IRISH MANUFACTURING RESEARCH

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About CIRCULÉIRE

CIRCULÉIRE, the National Platform for Circular Manufacturing seeks to accelerate Ireland's transition towards a net-zero carbon circular economy. A key objective of the programme is to demystify, de-risk and deliver circular business model innovation for Irish industry.

Want to learn more about CIRCULÉIRE? Visit our website at www.circuleire.ie or contact circuleire@imr.ie

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Acronyms

CEAP – Circular Economy Action Plan

CRM – Critical Raw Material

DECC – Department of the Environment, Climate and Communications

EC – European Commission

EEA - European Environment Agency

EDI - Electronic Data Interchange

ELV – End of Life Vehicle

ELT – End of Life Tyres

EOL – End of Life

EU – European Union

EV – Electric Vehicle

GHG – Greenhouse Gas

HGV – Heavy Goods Vehicle

HDVs – Heavy Duty Vehicles

HDOR – Heavy Duty and Off-Road

IMR – Irish Manufacturing Research

LCA – Lifecycle Assessment

LCVs - Light Commercial Vehicles

SRMs - Secondary Raw Materials

WAPCE – Waste Action Plan for a Circular Economy

Executive Summary

Ireland's road and rail transportation sector is a critical pillar of the nation's infrastructure and economy, providing essential mobility services to millions of people and businesses. The sector is an important contributor to economic growth, employment, and competitiveness, and is considered a key driver of the Irish economy. Irish road transport alone accounted for some 159.4 million tonnes of freight being transported nationwide in 2019 (IGEES, 2020). Indeed, the freight and logistics industry is the largest employer within Ireland's goods transportation industry – employing some 103,000 people, and contributing an estimated €6.5bn to the economy (CSO, 2021).

In spite of transportation sector's obvious importance to the economy, our currently linear and road-dependent transport systems poses considerable environmental challenges. The transportation sector in Ireland is responsible for a substantial portion of the country's greenhouse gas (GHG) emissions - accounting for 20% of total GHG emissions in 2019 (DECC, 2021). These emissions contribute to climate change and air pollution, particularly in urban areas where the majority of Ireland's population lives and works.

Meanwhile, while rail freight also plays an important role, providing essential transportation services for passengers and goods, and is considered a more sustainable transport option, it has lagged behind in recent years, with a drop of 32.9% in overall tonnage in 2019.

Accordingly, the Irish government has set ambitious targets for reducing GHG emissions from transport, aiming for a 51% reduction by 2030 (Oireachtas, 2021). However, clean fuel innovations alone are insufficient in transitioning us from a linear to a truly sustainable circular economy.[1] These targets can only be met with a transition to low-carbon alternatives such as electric vehicles and biofuels, and considerable scaling up of sustainable public transport and rail, as well as adoption of circular business model innovations by Ireland's transportation sector.

It is critical that a wholesale circular economy approach is adopted across the road and rail sectors to help accelerate Ireland's green and sustainable transition, whilst creating novel business opportunities, technologies and innovations in the process. To support the transition to a more sustainable and efficient transportation system, key Government Strategies, such as the Rail Freight Strategy 2040 (see more in Section 1 below) are looking to increase Ireland's overall share of rail freight in the years ahead by expanding and electrifying Ireland's railway network.

Moreover, investing in and supporting the transition to a net-zero circular economy for Ireland's transportation sector will likely have multiplier effects, creating

[1] As is noted later in this guide, the CRMs needed for EV batteries can pose considerable environmental and environmental challenges. For instance, CRMs like lithium and cobalt are incredibly resource and carbon intensive to mine, particularly when virgin materials are used. Meanwhile limited recycling infrastructure means it can be difficult to effectively recover and reuse these hazardous materials.

benefits that are far-reaching for businesses in other key industries who depend on the sector for the transportation of their people, goods and services. In short, the adoption of circular approaches by the road and rail sectors could help reduce the scope 3 GHG emissions across multiple sectors related to their transportation, logistics and supply chains.

This Circular Road and Rail Good Practice Sectoral Guide is intended for those involved in the transportation sector, from heavy-goods manufacturers to logistics and transportation businesses, rail network managers, policy makers and key decision makers. However, far beyond commercial operators and stakeholders who have a direct interest in advancing the circularity of the sector, this Guide may serve to inform and inspire those commercial operators who rely on the sector to service their transportation and logistics needs.

The Guide aims to provide industry stakeholders with an overview of industry-led circular innovations that are shaping the transport sector in other parts of the world, and to highlight the opportunities to circularise the sector here in Ireland. For policymakers, it aims to draw attention to some of the key policy strategies which are helping to advance circular economy in the transportation and mobility sector in other jurisdictions.

The Guide identifies key enablers in how we can build a more circular transportation sector nationally. Key enablers identified from the case studies and wider literature include supportive policy, regulatory and R&D investment frameworks that encourage circular innovation in the transport sector. Elsewhere case studies profiled underscore the importance of creating conditions conducive to supporting pre-competitive collaboration amongst stakeholders with different expertise, interests, competencies, and capabilities as essential to addressing the complex challenges of circularity in the transportation sector. Other companies profiled in this guide have demonstrated the value of leveraging digital technologies and data-sharing to boost industry-led circular innovation. Examples such as Transition-One have made good use of ICT technologies to achieve circular outcomes, whilst enhancing their business's efficiency and cost-effectiveness.

The Guide presents an example of some of the key market and policy/regulatory barriers that are slowing down or disincentivising the transition to circular practices within the transportation sector.

Key market barriers highlighted include:

- Linear costs are not properly accounted for in the current market, which can make it difficult for circular transportation business models to compete with traditional (linear) market incumbents.
- The capital-intensive nature of vehicle development and manufacturing processes encourages the automotive industry to sustain linear business models that treat vehicles as a product, rather than a service.
- The benefits of investing in circularity can be diffuse and not easily captured by any single entity through current business models (WEF, 2020).

Regulatory and policy barriers

- Current policies, regulations and legislation don't account for lifecycle considerations or go far enough in incentivizing holistic circular and sustainability outcomes. For instance, regulatory CO2 performance metrics only cover tailpipe emissions, while end-of-life legislation focuses on recycling but lacks specific quality requirements, thereby disincentivizing the need to design for high-value recycling and product life extension (WEF, 2021). Meanwhile, where feasible, retrofitting schemes ought to be introduced and promoted over scrappage schemes that promote linear consumption patterns (which could support better environmental and just transition outcomes).
- Elsewhere, regulations can have unintended consequences. OEMs and suppliers must comply with a multitude of regulations when designing and planning new vehicles. These well-meaning regulations can pose an obstacle to circularity; for instance, by complicating the use of reused and remanufactured parts in the production of new vehicles (WEF, 2020).

The final section profiles some best practice regional examples, and outlines some of the key recommendations that will enable more circularity for the sector in Ireland. The key recommendations include the following:

1. Ensure all transportation and mobility policies adopts an integrated approach to circularity and lifecycle thinking
2. Strategic planning for future circular transportation infrastructure (e.g. EV charging stations and large-scale public transportation projects) must also consider circular and sustainability principles in decision-making and procurement processes.
3. Look to meaningfully align sustainable, circular transportation policies with just and fair transition outcomes. A key example is Italy's RETROFIT National Decree which aims to simultaneously lower the economic barriers to EV access while growing jobs in the repair economy, by stimulating the market for "converting conventional vehicles with combustion engines into retrofitted electric cars, efficient, zero emissions and zero fuel consumption" (INTERREG, 2018). In so doing, the legislation reduces the economic barriers to circular vehicles and stimulates the growth of green and circular repair jobs within the automotive industry.
4. Incentivise positive behaviour change and continue to increase infrastructure investments needed for the public and businesses to adopt more active, low-carbon and sustainable modes of transport and circular consumption.
5. Promote cross-sectoral collaboration and experimentation to advance Ireland's circular transportation system. International best practices such as the Dutch 'road as a service' deep demonstrator project, 'De Circulaire Weg' programme ('The Circular Way' – as profiled in CIRCULÉIRE's (2021) Circular Construction & Built Environment Good Practice Sectoral Guide) offer interesting examples of how large-scale public-private experimentation can be used to advance learning and practice in support of this goal.

Table 1.1 Overview of case studies

Cluster	Case study name (include project/website links)	Region covered	What are the top 3 CE Strategies?	What is the TRL of the initiative?
Cluster 1: Clean Fuels and Multi-Modality	**Savonlinja** fuels their buses with Neste Renewable Diesel	Savonlinja, Finland	Valorisation of organic waste material	TRL 8
	Alke electric zero emission vehicles for logistics	Italy	Low emission vehicle; Product Life Extension	TRL 9
	Aberdeen City Council adds UK's first hydrogen fuel cell waste truck to fleet	United Kingdom	Low emission vehicle	TRL 7
Cluster 2: Circular business models for Land-based transport	**Expak** offers pool distribution to allows companies to ship their products	USA	Pool distribution	TRL 8
	MAN's Truck & Bus Deposit Return Scheme	European Union	Remanufacturing / Reuse	TRL 9
	NS Dutch Railways - on track to develop fully circular trains by 2030	The Netherlands	Refurbishment / Recycling	TRL 8-9
Cluster 3: End of life circular strategies.	**Renault** creates a consortium to recycle EV batteries	France	Recycle	TRL 7
	Transition-One retrofit the thermal car to EV	France	Product life extension	TRL 7
	TIER e-scooters recovers parts and batteries through CE	European Union	Refurbishment / Recycling / Leasing	TRL 8-9
	Michelin initiates a project for recycling end-of-life tyres into new tyres	France, Spain	Remanufacturing / Reuse	TRL 7

Section 1: Why Ireland needs to unlock Circular Innovation for its Road and Rail Systems

The road and rail transportation sector in Ireland plays a crucial role in the country's infrastructure and economy and provides vital mobility and transportation services to millions of citizens and businesses. The critical importance of the sector to many other industries that depend on it, such as for transportation of goods, means that there is even greater urgency that our road and rail systems address the considerable environmental and climate challenges we face. A circular economy offers a solution to many of these problems and a path towards sustainable development and a net-zero carbon economy for Ireland's transportation sector.

The transportation sector in Ireland is responsible for a substantial portion of the country's greenhouse gas (GHG) emissions, with transport accounting for 20% of total GHG emissions in 2019 (DECC, 2021). These emissions contribute to climate change and air pollution, particularly in urban areas where the majority of Ireland's population lives and works. The Irish government has set ambitious targets for reducing GHG emissions from transport, aiming for a 51% reduction by 2030 (Oireachtas, 2021). These targets can only be met with a transition to low-carbon alternatives such as electric vehicles and biofuels. However, such clean fuel innovations alone are insufficient in transitioning us from a linear to a circular economy.[2] It is critical that a wholesale circular economy approach is adopted across the sector to help accelerate Ireland's green and sustainable transition, whilst creating novel business opportunities, technologies and innovations in the process.

> **The circular economy is a waste-minimizing, resource-maximizing approach to economic development that keeps materials and products in use for as long as possible (CIRCULÉIRE, 2021).**

In the transportation sector, this means reducing GHG emissions, promoting the use of renewable energy, and improving the efficiency of vehicles. For example, by using recycled materials in vehicle production, manufacturers can reduce their demand for virgin resources and lower the carbon footprint of their products. The circular economy also prioritizes remanufacturing and repair, extending the life of vehicles and components – such as EV batteries, and creating new jobs in the repair and maintenance sector.

[2] As is noted later in this guide, the CRMs needed for EV batteries can pose considerable environmental and environmental challenges. For instance, CRMs like lithium and cobalt are incredibly resource and carbon intensive to mine, particularly when virgin materials are used. Meanwhile limited recycling infrastructure means it can be difficult to effectively recover and reuse these hazardous materials.

In the rail sector, circular economy principles can be applied to enhance the sustainability and efficiency of rail transportation. This can be done through the development of more eco-friendly and efficient trains, as well as optimizing rail infrastructure to minimize energy consumption and waste. Using renewable energy sources like wind and solar power to power trains and rail infrastructure can help reduce GHG emissions and increase energy efficiency. Meanwhile, there are opportunities to reduce waste and GHG emissions by ensuring end-of-life considerations are kept in mind in the design phase of new trains, considering the use of environmentally friendly materials and processes to minimize waste, but also looking at how larger vehicles, components and parts can be made more durable, repairable and recyclable.

It's not just the businesses directly operating in the road and rail transportation sectors who could seize the economic and environmental benefits of a circular economy. The dependence of other sectors on the road and rail transportation sector for the transportation of people and goods also highlights the importance of the sector to the Irish economy. The agricultural, manufacturing, and tourism sectors, among others, all rely on the road and rail networks to transport goods and people, and the efficient functioning of these networks is essential for the success of these sectors. The road and rail transportation sector also provides critical connectivity between Ireland's cities and towns, facilitating economic development and promoting business growth and investment. It plays a critical role in maintaining commercial activity in Ireland's rural economy. The sector provides essential transportation services to rural communities, connecting them to the rest of the country and providing access to goods, services, and markets.

Ireland’s Land-based Transportation Sector

Ireland's road and rail transportation sector is a critical pillar of the nation's infrastructure and economy, providing essential mobility services to millions of people and businesses. The sector is an important contributor to economic growth, employment, and competitiveness, and is a key driver of the Irish economy. The freight and logistics industry for instance, is the largest employer within the goods transportation industry in Ireland – and employs some 103,000 people, contributing an estimated €6.5bn to the economy (CSO, 2021). The rail transportation sector is also important, providing essential transportation services for passengers and goods and contributing to the economic development of the country.

Meanwhile, the sector is responsible for the transportation of over 70% of all goods in Ireland, including food, fuel, and other essential products. This sector is also critical for the movement of people, with millions of passengers relying on the road and rail networks to travel to work, school, and other destinations. Irish road transport accounted for 159.4 million tonnes of freight in 2019 (IGEES, 2020). As e-commerce continues to expand, the transportation of goods is becoming increasingly atomized, resulting in more commuters and goods moving in and out of Ireland. While our currently linear transport systems mean that all this is not

without environmental issues, this growth in transportation is framed as an important engine the economy, leading to more economic growth and development. However, rail transport (which is considered a more sustainable transport option) has lagged behind, with a drop of 32.9% in overall tonnage in 2019. To support the transition to a more sustainable and efficient transportation system, key Government Strategies, such as the Rail Freight Strategy 2040 (see more below) are looking to increase Ireland's overall share of rail freight in the years ahead by expanding and electrifying Ireland's railway network.

Investing in and supporting the transition to a net-zero circular economy for Ireland's transportation sector will likely have multiplier effects, creating benefits that are far-reaching for businesses in other key industries who depend on the sector for the transportation of their people, goods and services. In short, the adoption of circular approaches by the sector could help reduce the scope 3 GHG emissions across multiple sectors related to their transportation, logistics and supply chains.

What do we mean by Circular Land-based Transportation?

A circular economy is one in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life (Ellen MacArthur Foundation, 2015a). A circular economy is restorative and regenerative by design and maintains the embedded value and utility of products, components, and materials, whilst distinguishing between technical and biological cycles (Schwab, 2016).

Current mobility trends do not favour a high-performing, low-cost system, as they continue to result in increased congestion, environmental depletion, and economic losses (Ellen MacArthur Foundation, 2015b). According to the Ellen MacArthur Foundation, a circular mobility system is characterised by three main features: (i) An accessible, affordable, and effective mobility system, (ii) A multi-modal mobility structure that incorporates public transportation in combination with on-demand cars as a flexible last-mile solution, (iii) Electric-powered, shared, and automated transportation (Ellen MacArthur Foundation, 2017). The table below outlines some of the ways that such circular principles are being applied to different aspects of the Land-based Transportation Sector (Béguerie, 2019):

	Preserve natural capital	Optimize natural resources	Reinforce system efficiency
Procurement	Equipment recycling level/total equipment required for rolling stock.	Removal of fossil fuel use	Biomass, hydrogen refuelling station network, Electric rail and train systems
Manufacturing	Eco-design of rolling stock to facilitate dismantling and recovery (e.g., using of bolts as opposed	Obligation on manufacturers to reduce HGV emissions by 30% by 2030; The need to	New rules on HGV aerodynamics; Increased weights and volumes (e.g., mega trucks); platooning;

	to welding); Repair; Refurbishment & Remanufacturing	adopt railway transport as a more sustainable and efficient mode of transport for heavy freight.	New circular/sustainable rules on railway freight transport
Utilization	Anticipatory maintenance; Ecological driving training	Equipment use level; transport levels/use; load level/utilization; CO_2/km levels; no-load levels	Digital platforms to reduce transport without load and service interruption level (waiting time, traffic jams, climatic conditions, accidents)
Recycling	Equipment recycling level	Real utilization rate/ optimal equipment usage	Blockchain tracking of recycling efficiency.

Table 1. Adapted from (Béguerie, 2019)

Why do we need a circular economy for Ireland's Land-based Transportation?

> *Road transport alone accounts for seventy-five percent of the emissions from the transportation sector and its impact is expected to grow to have the number of cars right now doubled by the year 2050 (Ellen MacArthur Foundation, 2020)*

In car-dominated Europe, structural waste is rampant and spans land-utilisation to car and resource utilisation. The car industry accounts for 15% of the average European household's expenditure. 92% of the time, European cars are parked — often on scarce inner-city land. On average, only 1.5 of the car's five seats are occupied when it is in operation. The deadweight-to-weight ratio frequently exceeds 12:1. Only a third of total petroleum energy is converted into kinetic energy, and only a small portion of that energy is used to carry humans. Up to 50% of inner-city territory is dedicated to mobility (roads and parking spaces). Even during rush hour, however, cars only cover 10% of the typical European road. The economic costs of this congestion are significant. In places like Stuttgart and Paris, the cost of congestion surpasses 2% of GDP (Ellen MacArthur, 2016).

Furthermore, waste and GHG emissions resulting from the end state of used cars can end up decaying in junkyards and carparks. End-of-Life Vehicles (ELVs) generate between 8 and 9 million tonnes of waste in the European Union (EU) annually (EPA, 2021). Although over 75% of the overall vehicle parts are recyclable, the rest is not. Components like batteries and old tyres end up contributing to landfills which release GHGs and other toxic pollutants to the soil, water to the dumping site – with negative impacts on biodiversity (Ellen MacArthur, 2016).

Circular economy approaches have an important role to play in overcoming the negative impacts of our currently linear transportation systems. Circular economy principles of reducing waste, using renewable rather than non-renewable energy

sources, and improving the efficiency of vehicles and infrastructure can lead to significant reductions in GHG emissions. For example, by using renewable energy sources to power trains and rail infrastructure, businesses can reduce their dependence on fossil fuels and lower their carbon footprint. Additionally, by promoting remanufacturing and repair, businesses can extend the life of vehicles and components, reducing the need for new products to be manufactured, and further lowering their GHG emissions. Implementing circular economy principles in the transportation sector can also lead to cost savings, as businesses can reduce their energy costs and material expenses by optimizing their operations and making more efficient use of resources (Kumar Dey al., 2022). In addition to emissions reduction, programmes like car sharing, public transportation, and active modes of transportation can promote sustainable development by fostering a sense of community and social structure. Additionally, a circular economy can promote the sustainable production of goods and services, leading to a boost in economic performance and local GDP.

In the rail sector, circular economy strategies such as recycling and reusing rail components like rail, ballast, sleepers, and wires, can significantly reduce CO2 emissions while maintaining commercial revenue. Examples include the recycling and reuse of rail components and the digitalization of assets for greater efficiency. The success of these strategies is exemplified by TRAFIKVERKET's "Design, Bid, Build" sleeper procurement process, which achieved a 26% reduction in CO2 emissions and a 14% cost reduction (UIC, 2021). Following the success of this example, new railway projects with a budget over 5 million EUR in Sweden are now required to reduce CO2 emissions by 18% compared to traditional production methods. Digitalization in the rail sector enables the efficient management and reuse of assets through internal circular economy apps such as the SURPLUS app – an internal stock market app developed by Network Rail which facilitates the internal redistribution of assets internally within the company (UIC, 2021). By reusing unwanted or underutilised items within the rail network, this approach reduces the need for new assets and minimizes waste sent to landfill.

The adoption of circular rail and road transportation approaches can also support commercial operators – including in other industries – to reduce their scope 3 GHG emissions by promoting more sustainable and efficient transportation systems. By supporting businesses in reducing their scope 3 GHG emissions, the circular economy can help to promote a more sustainable and low-carbon future for Irish industry more generally.

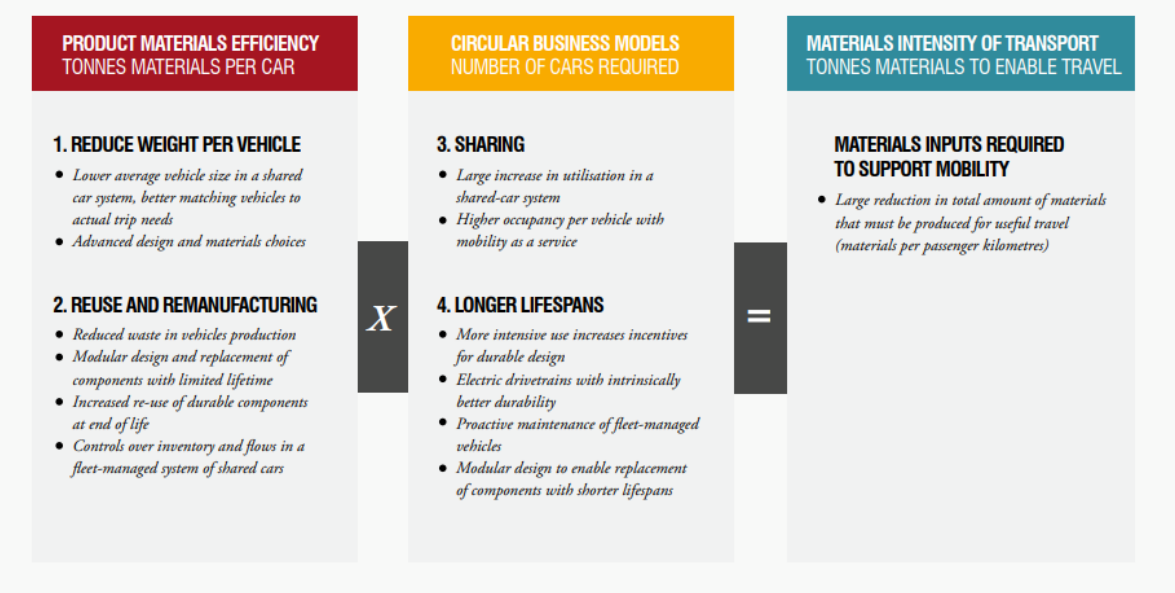

Figure 1: A summary for circular economy strategies that can sharply reduce the material requirements of mobility (Enkvist and Klevnäs, 2020)

Policies and Government Support

At the EU level, various policies and strategies aim to minimise the worst effects of our linear transportation systems. The European Union regulation 2019/1242 of June 20, 2019, obliges vehicle manufacturers to reduce the CO_2 emissions of new heavy goods vehicles by 15% by 2025 and by 30% by 2030, generating estimated fuel cost savings of €5,000 and €11,000 per vehicle per year respectively[3] (Council of European Union, 2019). Meanwhile, in response to the negative impacts of ELVs, the EU ELVs Directive (2000/53/EC) sets out circular measures to promote the reuse, recycling and recovery of ELVs and requires each Member State to meet the targets of 95% reuse and recovery of ELVs, with a minimum of 85% reuse and recycling (EPA, 2021).

Nationally there are several government-led plans, strategies and initiatives that are (either directly or indirectly) driving circular economy outcomes in the transport sector by reducing waste and promoting the use of sustainable and efficient modes of transportation. These include:

Climate Action Plan 2021

The Plan sets specific targets for the transport industry in Ireland. Some of these targets include:

1. Increasing the number of electric vehicles on the road to at least 936,000 by 2030. Below we will unpack how the adoption of EVs is not circular in and of itself, and must therefore be aligned with circular principles and objectives.

[3] The objectives in the regulation are expressed in percentage emission reductions compared to the EU average over the July 1 2019-June 30 2020 reference period.

2. Reducing greenhouse gas emissions from the transport sector by at least 50% by 2030 compared to the 2005 levels.
3. Increasing the use of public transportation, cycling, and walking as modes of transportation.
4. Encouraging the uptake of sustainable fuels, such as biofuels and hydrogen, in the transport sector.
5. Improving the energy efficiency of the transport sector through the implementation of energy-efficient technologies and the use of renewable energy sources.

Waste Action Plan for a Circular Economy (WAPCE)

The Waste Action Plan for a Circular Economy is Ireland's roadmap for waste planning and management. This Plan shifts focus away from waste disposal and looks instead to how we can preserve resources by creating a circular economy (DECC, 2019). In transportation and mobility sectors, Ireland uses the Extended Producer Responsibility (EPR) model for dealing with a number of waste streams and has developed six Producer Responsibility Initiatives (PRIs) for packaging, batteries, waste Electrical and Electronic Equipment (WEEE), end of Life Vehicles (ELVs), tyres and farm plastics (DECC, 2021).

Circular Economy and Miscellaneous Provisions Act 2022

Ireland's Circular Economy Act is expected to support circular economy outcomes in the transportation sector by implementing broad measures that encourage the adoption of circular principles in the sector. The Act places the Circular Economy Strategy on a statutory footing for the first time. Some of the indirect ways that the act is expected to support circular economy outcomes in the transportation sector include:

1. Supporting the increased use of recycled or reused materials in the Irish market - which is applicable to batteries from electric vehicles and other components from conventional vehicles.
2. Fostering the development of a circular economy by reducing waste and promoting the reuse of materials and components, including by highlighting the requirement to streamline end-of-waste and by-product mechanisms (as a way to build up Ireland's secondary materials market).
3. Encouraging the development of new business models and initiatives that support the circular economy for Irish industry.

Whole of Government Circular Economy Strategy 2022 – 2023

Ireland's Whole of Government Circular Economy Strategy 2022-2023 provides a framework for the development of a circular economy in Ireland, with a focus on supporting the transition to a low-carbon, resource-efficient, and sustainable

economy. The Strategy outlines preliminary actions for inclusion in Transportation Sectors' Circular Economy Roadmap, such as:

1. Increased use of telecommuting, as well as of local and regional hubs
2. Prioritising resource efficient personal mobility, e.g. walking and cycling
3. Expanding public transport capacity and promoting shared mobility schemes
4. Efficient end-of-life vehicle waste management schemes

Project Ireland 2040: National Planning Framework

Project Ireland 2040 is the government's long-term overarching strategy to make Ireland a better country for all and to build a more resilient and sustainable future. The strategy ensures the alignment of investment plans with the stated National Strategic Objectives for 2040 in a considered, cohesive and defined manner (Department of Housing, 2021). The plan is aimed at investing in electric trains to replace the old locomotives. Further, there is emphasis on the switch electric vehicles even when it comes to HFVs thereby reducing the carbon footprint as well as contributing to economic growth by saving on heavy fuel costs.

Irish Government's 2018-2027 National Development Plan

The Plan includes a focus on sustainable infrastructure, which complements circular economy outcomes for the road and rail transport sectors. It prioritizes investments in public transportation, which could encourage the use of active and sustainable modes of transportation, such as cycling and walking. Additionally, the plan includes funding for research and innovation in sustainable transport technologies, which could drive the adoption of circular economy strategies in the road and rail sectors. The plan's focus on sustainable growth and development aligns with the principles of circular economy and may provide a foundation for the transformation of the transport sector towards a more sustainable and efficient system.

Rail Freight Strategy 2040

The strategy aims to increase the share of freight moved by rail, which could help to reduce emissions and congestion associated with road transportation. By providing a more efficient and cost-effective alternative to road transport, rail freight can help to reduce the environmental impact of logistics activities, particularly for long-distance and heavy loads. Additionally, the strategy prioritizes the use of more sustainable and circular materials in the rail sector, such as recycled or reclaimed materials for track construction and maintenance. This approach can help to reduce the demand for new materials and minimize waste in the rail sector. The strategy also supports the use of digital technologies and smart logistics solutions, which can enable more efficient and transparent tracking of goods throughout the supply chain. This can help to optimize the use of resources, reduce waste and improve the sustainability of logistics activities.

Department of Transport Smarter Travel Policy

The policy provides reliable public transport options to reduce the need and dependency on cars (Department of Transportation, 2009). This will be done by adopting public and non-motorised systems of transport especially when it comes to neighbourhood and in city travel. This will contribute to the reduction of carbon emissions and adoption of environmental and fuel-efficient modes of transport like public transport for freight and long-distance passenger travel.

Regional transport strategies for metropolitan areas:

Transport Strategy for the Greater Dublin Area 2022-2042

The strategy provides a framework for the planning and delivery of transport infrastructure and services through investing in sustainable and efficient land-based transport systems in the Greater Dublin Area (GDA) over the next two decades. It also provides a transport planning policy to frame the role of other agencies involved in land use planning, and environmental protection (National Transport Authority, 2021).

Cork Metropolitan Area Transport Strategy (CMATS) 2040

A key principle for CMATS is to reduce dependency on the private car within the CMA, while increasing the appeal of sustainable transport options. A fundamental principle of the Strategy is to support the future growth of the CMA through the establishment of an efficient, sustainable transport network (National Transport Authority, 2019).

Purpose of this Guide

CIRCULÉIRE's Circular Road and Rail Good Practice Sectoral Guide is intended for those involved in the Road and Rail Transportation sector, from heavy-goods vehicles manufacturers to logistics and transportation businesses, as well as policy makers and key decisionmakers. It aims to provide industry stakeholders with an overview of industry-led circular innovations that are shaping the land-based transportation in other parts of the world, and to highlight the opportunities to circularize the sector here in Ireland. It does this by providing an overview of good circular economy practices from the mobility sector with a major focus on road and rail transport to inspire, increase knowledge & awareness and encourage replication and adaptation of good practices from across Europe to the Irish context.

For policymakers, it aims to draw attention to some of the key policy strategies which are helping to advance circular economy in the transportation and mobility sector in other jurisdictions. It is part of a series of reports produced by Ireland's National Platform for Circular Manufacturing targeted at Irish industry players in sectors deemed strategically important to supporting Ireland's transition to a circular economy.

In this guide, we primarily focus on the following clusters which are driving circular innovations in the transportation industry:

1. Clean Fuels and Multi-Modality.
2. Circular business models for Land-based transport
3. End-of-life and product life extension strategies

Methods

The report is based on information gathered using the following methods. An initial two-part scoping desktop review was conducted on:

1. The literature on circular economy in Land-based Transportation sectors
2. Policies and public sector-led initiatives aimed at supporting Land-based Transportation

The findings of desktop review were used to refine our Sectoral Guide objectives and were used to develop key criteria to select our case studies, using purposeful sampling, and to develop our analytical framework. Key circular economy databases were identified and used to identify a long list of circular innovations in the road and rail sectors. In the final stage of our research, we identified and selected case studies based on the following criteria:

Circularity of the project / initiative	To enable comparative analysis of the processes enabling different kinds of innovation, projects were selected which explicitly presented themselves as a circular innovation, appeared to pursue one or more circular economy strategies, and which illustrated circularity under one or more of the following dimensions: **1. Clean Fuels and Multi-Modality.** **2. Circular business models in Road transportation and Mobility sector.** **3. End-of-life and product life extension strategies**
Type of innovation and circular economy strategies employed	The case studies have been selected on the basis that they demonstrate a diversity of one or more of the following types of innovation. They are defined as the following: • **Process innovation** is the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software (Eurostat Statistics Explained, 2022a). • **Technological innovations** comprise new products and processes and significant technological changes of products and processes(OECD, 2013). This may include digitally enabled solutions, such as BIM or Material Passports. • **Product innovation** is the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. It involves significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics(Eurostat Statistics Explained, 2022b).

	• **Business model innovation** relates to innovations in a company's value proposition, creation and delivery, and in value generation. Circular business model innovation could involve developing a completely new business model or introducing a business model that is new to the company, even if it is considered fairly common in other companies or sectors (European Environment Agency, 2021). • **System innovation** can be characterised as a horizontal approach to innovation directed at problems that are systemic in nature, such as transitioning towards low-carbon energy systems or low-carbon transport systems, involving longer-term private and public sector actors' engagement and collaboration around the issue. Some defining characteristics of system innovations we focus on in this guide include i) a process of co-evolution between the different elements and actors in socio-technical systems. ii) Transitions or transformations which occur at multiples level (i.e. an 'area' where there is space for radical innovation, experimentation and learning); and iii) Changes in consumer practices and markets (including market building through regional and industry cluster-based approaches) (Adapted from: OECD, 2016).
Impact of the project/ initiative (proven or high-potential)	"Circularity" in and of itself does not guarantee positive social, economic, and environmental performance (i.e., sustainability) (Blum et al., 2020). For this reason, we shortlisted case studies on the basis that they overtly self-identified as circular innovations and have demonstrated efforts to create impact against different social, economic and environmental impact indicators. Particular consideration was given to ensure projects and initiatives profiled demonstrated positive performance (proven or high-potential if scaled) against material waste and carbon emission reductions. That said, while we targeted examples of potential or established good practices, the aim of the case studies was not to evaluate projects or organisations - since even less 'successful' cases can provide important insights about current barriers to implementing or scaling circular innovations.
Technological Readiness Levels (TRLs) of the Initiative	To gather information on both emergent / cutting-edge innovations and more established, 'market ready' circular transportation innovations, we aimed to select case studies that were judged to range from TRL 6 – 9 based on publicly available data about the innovations. This enabled us to gather insights about the opportunities and challenges (such as regulatory, scaling and replication challenges) from circular transportation innovations at different stages of maturity.

Geographic variety	In order to analyse the processes associated with supporting circular transportation innovations in different socio-economic and policy contexts, and in the context of different market and sectoral conditions, we aimed to select cases from a variety of regions (with a particular focus on European regions). Particular attention has been given to spotlight good practices originating or operating in other regions, nonetheless, the Guide also endeavours to highlight good practice examples of circular innovations within Ireland, where identified.

The public sector examples profiled in section 3 were identified – based on a policy landscaping exercise – and used as a basis for determining and benchmarking the range of systems levers that are being used by key decisionmakers to facilitate the development of enabling market conditions and innovation ecosystems for circular road and rail. Comparative analysis was undertaken to understand processes and approaches that have been adopted in these regions, and the insights gathered around the opportunities and gaps were used to inform the recommendations presented in section 3 about how the Road and Rail Sector can be supported to transition to a circular economy in the Irish context.

Structure of the Guide

This Guide is structured as follows:

- Section 2 builds on desk research and summarises circular economy good practices arising in land-based transportation sector in Europe and internationally.
- Section 3 draws on the lessons learnt from other contexts that have made good progress in advancing circularity in the sector and offers some recommendations about what's needed to advance a circular economy for the road and rail sectors here in Ireland.

Section 2: Circular Economy innovations in the Land-based Transport sector

This section showcases case studies from Ireland and around the world that highlight how circular innovations are shaping the land-based transportation sector, with a particular focus on road and rail transport and mobility. The case studies are grouped into three clusters: 1) Clean fuels and multi-modality, 2) Circular business models for land-based transport, and 3) End-of-life and product life extension strategies. These case studies cover the complete life cycle of processes in the road transport sector and emphasize their economic, environmental, and social impacts. A more detailed description of each cluster and its role in advancing the circular economy for the road transport and mobility sector in Ireland and Europe can be found on the following pages. Table 2.1 below provides an overview of the case studies focused on.

Table 2.1 Overview of the case studies

Cluster	Case study name (include project/website links)	Region covered	What are the top 3 CE Strategies?	What is the TRL of the initiative?
Cluster 1: Clean Fuels and Multi-Modality	**Savonlinja** fuels their buses with Neste Renewable Diesel	Savonlinja, Finland	Valorisation of organic waste material	TRL 8
	Alke electric zero emission vehicles for logistics	Italy	Low emission vehicle; Product Life Extension	TRL 9
	Aberdeen City Council adds UK's first hydrogen fuel cell waste truck to fleet	United Kingdom	Low emission vehicle	TRL 7
Cluster 2: Circular business models for Land-based transport	**Expak** offers pool distribution to allows companies to ship their products	USA	Pool distribution	TRL 8
	MAN's Truck & Bus Deposit Return Scheme	European Union	Remanufacturing / Reuse	TRL 9
	NS Dutch Railways - on track to develop fully circular trains by 2030	The Netherlands	Refurbishment / Recycling	TRL 8-9
Cluster 3: End of life circular strategies.	**Renault** creates a consortium to recycle EV batteries	France	Recycle	TRL 7
	Transition-One retrofit the thermal car to EV	France	Product life extension	TRL 7

	TIER e-scooters recovers parts and batteries through CE	European Union	Refurbishment / Recycling / Leasing	TRL 8-9
	Michelin initiates a project for recycling end-of-life tyres into new tyres	France, Spain	Remanufacturing / Reuse	TRL 7

Cluster 1: Clean Fuels and Multi-Modality

Road transport accounts for 96% of GHG emissions and generates air pollutants that harm both human health and the environment (EEA, 2020). The associated noise, accidents, and congestion also affect quality of life, discourages active travel, and cost hundreds of millions of euros each year. Meanwhile diesel trains contribute to greenhouse gas (GHG) emissions and air pollution, although the exact amount depends on factors such as the age of the train, how it is operated, and the specific type of fuel used. According to the US Environmental Protection Agency (EPA), diesel locomotives emit nitrogen oxides (NOx), particulate matter (PM), sulphur dioxide (SO2), and other harmful pollutants that can harm human health and the environment. Despite this, diesel trains are estimated to emit around 20% less CO2 per passenger mile than gasoline-powered cars, but twice as much CO2 per passenger mile as electric trains powered by renewable energy sources (BBC, 2019). It's worth noting that there are efforts underway to reduce the environmental impacts of diesel trains, such as by retrofitting or replacing older trains with cleaner technologies or transitioning to electrified train networks.

Promoting cleaner, safer, and more sustainable mobility is crucial for climate policy, and it also presents an opportunity to enhance our health, well-being, and social connections, and to address the needs of our expanding urban centres and rural communities (Government of Ireland, 2021).

One emerging policy area with potentially significant impacts is the growing interest in clean fuels. Reducing Ireland's dependence on foreign energy sources while promoting domestically produced renewable fuels such as biodiesel and hydrogen, alongside a shift to sustainable travel modes and vehicle fleet electrification, could have major effects on rural communities, the environment, and transportation systems and infrastructure.

In this cluster, we profile the following key examples of circular innovations that are looking to apply circular economy approaches to the challenges around the sector's current reliance on fossil fuels:

- Savonlinja uses Neste Renewable Diesel to power their buses.
- Alke has developed electric zero-emission circular vehicles for logistics.
- Aberdeen City Council's introduction of the UK's first hydrogen fuel cell waste truck to its municipal fleet.

Case Study 1: Savonlinja fuels their buses with Neste Renewable Diesel

Website: www.neste.com/releases-and-news/transportation/savonlinja-and-neste-launch-low-emission-green-travel-service-bus-passengers
Partner(s) involved: Neste
CE Strategies used: Valorisation of organic waste material
Type of CE innovation: Material innovations
Region(s): Savonlinja, Finland
TRL: 8

What circular challenge / opportunity is the case study trying to address?
Transportation is responsible for a large percentage of greenhouse gas (GHG) emissions in Ireland, with road transport accounting for over 70% of these emissions (EEA, 2022). Meanwhile, fuel has become a critical aspect of strategic decision-making and financial performance for companies with large vehicle fleets and logistics networks – both for its price volatility and high carbon cost. In a circular innovation that is helping to overcome such linear risks, Finnish bus service provider Savonlinja has teamed up with Neste to use biofuel made entirely from waste and residues to reduce greenhouse gas emissions in the transportation sector (Circulary, 2019).

Background of the initiative
Savonlinja has introduced a Green Journey surcharge on top of its normal bus ticket price in collaboration with Neste (Circulary, 2019). This surcharge is available to all long-distance passengers through the mobile app "Linjalla" and the Savonlinja online store. Customers can choose the amount of the surcharge, which will be used to reduce greenhouse gas emissions by fuelling the buses with Neste MY Renewable Diesel™ (Lipponen, 2019). This fuel is made from 100% waste fats, residues, and vegetable oils and is classified as Hydrotreated Vegetable Oil (HVO) (Neste, 2020).

Impact and maturity of the initiative
The use of Neste MY Renewable Diesel can help users reduce their greenhouse gas emissions by up to 90% over the fuel's lifecycle compared to conventional fossil diesel (Circulary, 2019). This reduction is equivalent to removing three million passenger cars from the roads for a year, more than the number of cars in London, UK. Savonlinja plans to double the amount of money collected through the Green Journey surcharge and use these funds to cut down greenhouse gas emissions by refuelling with Neste MY Renewable Diesel (Lipponen, 2019).

Case Study 2: Alke offers electric zero emission vehicles for logistics

Website: www.alke.com/electric-car-recharge-solar-panels
Partner(s) involved: -
CE Strategies used: Low emission vehicle
Type of CE innovation: Product innovation
Region(s): Italy
TRL: 9

What circular challenge / opportunity is the case study trying to address?

Greenhouse gas emissions from heavy goods and heavy-duty vehicles (HGVs and HDVs)— trucks, buses and coaches — have increased in the European Union almost every year since 2014. These vehicles are currently responsible for about a quarter of total road transport emissions in the EU (EEA, 2022). In Ireland, some 159.4 million tonnes of freight were transported via road in 2019, which represented about 6% of the total freight (IGEES, 2020). At the end of 2020 there were 377,890 commercial goods vehicles in Ireland. Of this amount, 39,922 were heavy goods vehicles (HGVs) (AIB, 2022).

Light Commercial Vehicles (LCVs) represent the majority of the commercial vehicle fleet in the EU but are responsible for around 10% of the total GHG emissions from road transport (EEA, 2022). With a 5.7% increase in commercial vehicle registrations in 2019, electric LCVs offer a promising solution for reducing CO2 emissions during vehicles' use phase (acea, 2020). Alke has developed zero-emission electric vehicles suitable for different types of freight transportation, from business logistics to last mile delivery.

Background of the initiative

When entering low emission zones, which are often located in historic city centres with shops, open-air markets, and bars, vehicles in transit release high amounts of exhaust gases that can affect people nearby. Alke Electric Light Commercial Vehicles provide pollution-free logistics in these zones, as well as indoor spaces.

Alke offers various configurations suitable for logistics, with load capacities up to 1,630 kg and towing capacities up to 4,500 kg (2,000 kg if type-approved). Thanks to their compact dimensions, these nimble mini-vans can easily move in small warehouses and on small roads in cities. The most popular configuration, equipped with lithium batteries, has a maximum range of 150 km and short recharging times.

The Electric Light Commercial Vehicles are designed to be durable, with a long lifespan and the ability to be repaired and maintained over time (Alkè, 2022). This contributes to the circular economy by reducing the need for new vehicles and the associated resource consumption and waste generation.

Impact and maturity of the initiative

Alke's electric vans release no emissions that affect customers at bars and outdoor markets. The vehicles' compact size makes parking easy and allows other vehicles to pass while parked. Alkè electric vehicles also reduce noise pollution and maintenance costs when compared to traditional combustion

engines. Alke Electric Light Commercial Vehicles can be considered part of the circular economy because they use recycled materials, are designed to be long-lasting, and their LCV batteries can be repurposed for stationary energy storage after their use in vehicles. However, the limitations of this circular solution include the limited recycling infrastructure for lithium batteries, the potential environmental impact of battery production, and the fact that the vehicles still require energy from the grid (which can rely on coal-powered and non-renewable energy) to charge.

Case Study 3: Aberdeen City Council adds UK's first hydrogen fuel cell waste truck to its fleet

Website: www.circularonline.co.uk/news/aberdeen-city-council-adds-uks-first-hydrogen-fuel-cell-waste-truck-to-fleet/
Partner(s) involved: Geesinknorba
CE Strategies used: Low emission vehicle
Type of CE innovation: System innovation
Region(s): United Kingdom
TRL: 9

What circular challenge / opportunity is the case study trying to address?

Aberdeen City Council has taken an important step towards reducing the GHG emissions of heavy-duty vehicles, which account for a significant proportion of all transport emissions. Between 1990 and 2016, CO2 emissions from HDVs increased by 25%, and future trends show that without additional actions to curb CO2 emissions, the share of road transport CO2 emissions for which the HDV sector is responsible is set to increase from 27% in 2016 to 32% in 2030. In response, Aberdeen City Council has partnered with Hyzon Motors to introduce the UK's first hydrogen-fuelled waste collection vehicles, replacing petrol vehicles with alternative fuelled ones.

Background of the initiative

While typical waste trucks are powered by diesel and petrol, the new waste truck will use green hydrogen from existing refuelling infrastructure in Aberdeen (Moore, 2022). The new vehicle will initially cover wheeled bins in various locations before moving on to mixed recycling and bulk bins on other routes.
The UK's first hydrogen-fuelled waste collection truck was revealed in Aberdeen, in a move that continues to accelerate the city's thriving hydrogen economy. The truck will start collecting waste and recycling around the city from early March 2022 and will be the first hydrogen-powered waste truck to become operational in the UK. It will initially cover wheeled bins in a number of specified neighbourhoods before moving to mixed recycling and bulk bins on other routes (Transport & Logistics, 2022).
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Impact and maturity of the initiative

Aberdeen's hydrogen-powered waste collection trucks are estimated to save over 25kg CO2e/litre across a year, based on a diesel truck on similar routes. Hydrogen fuel cell waste trucks can be considered one part of the wider shift to a circular economy because they use green hydrogen produced from renewable energy sources, such as wind and solar power, to power the trucks. By doing so, they reduce the reliance on fossil fuels and lower greenhouse gas emissions associated with traditional waste collection vehicles. Not only does this innovation contribute to reducing emissions, but it will also collect data to enable further rollouts of hydrogen-fuelled waste trucks in the future. Meanwhile,

Ireland has initiated its own first zero-emissions bus in cork. This bus uses biomethane which can be used interchangeably with conventional fossil-fuel natural gas, meaning it can be added to the existing gas grid (MaREI, 2022).

Cluster 2: Circular business models for Land-based transport

These are initiatives organized by logistics companies and retailers to which concerns the activities related reducing the emission associated with transportation processes of products. In addition, It highlights the activities related to products, components and materials returning into the value chain and reintroduce them to the original processing and manufacturing cycle. A company may implement this program in collaboration with end-of-life logistics and material processing firms (CircularEconomy Practitioner Guide, 2018). The following cases covering the circular logistics/distribution processes layer:

- Expak offers pool distribution to allows companies to ship their products.
- MAN's Truck & Bus Deposit Return Scheme.
- NS Dutch Railways - ensures circular economy principles are embedded at trains' EoL.

Case Study 4: Expak offers pool distribution to allows companies to ship their products

Website: www.expaklogistics.com/what-is-pool-distribution/
Partner(s) involved: B2B Customers
CE Strategies used: Pool distribution
Type of CE innovation: Business model innovation
Region(s): USA
TRL: 8

What circular challenge / opportunity is the case study trying to address?

While nearly three-quarters of the world's cargo is carried by ocean-going ships, road vehicles like trucks and vans make up the majority, 65%, of freight's emissions (Greene, 2023). Road freight, can emit more than 100 times as much CO_2 as ships to carry the same amount of freight the same distance (*Ibid.*). Meanwhile, growing consumer demand for e-commerce and home delivery explains why 80% of the global increase in diesel consumption can be attributed to trucks (*Ibid.)* It is against this urgent backdrop, that road freight transport providers must identify low-carbon and sustainable, circular strategies to critically reduce the carbon footprint of this growing sector.

Here, Expak's shared truckload shipping circular solution is enabling more efficient use of space on trucks, by allowing companies to ship their products along with other orders in a single truck. This enables businesses meet their freight needs in a more resource efficient manner.

Background of the initiative

In Expak, the pool distribution involves consolidating multiple shipments from a single shipper at one point of origin — typically the shipper's distribution centre. The approach is similar to a Less-Than-Truckload shipping option that allows companies to pay only for the portion of the trailer they use rather than the entire truck. The remaining space is filled with goods from other companies heading to the same area. The load as a whole will be going toward a specific geographic region, with multiple delivery points within that region for individual shipments. Shipments are consolidated and loaded onto a truck to make maximum usage of the space. Next, it goes to a pool point facility (also known as a regional terminal) or distribution centre, instead of directly to the final destination. The pool shipment will then be offloaded, scanned, and organised by where the freight is headed. Shipments are then reloaded onto smaller, local delivery trucks or vans for their final mile delivery (Expak, 2021).

Impact and maturity of the initiative

Expak Logistics' pooled distribution model demonstrates circular impacts for B2B road freight customers across all 50 US States in several ways (Expak, 2022):

- Resource optimization: Multiple shippers can share a vehicle, optimizing the use of resources like fuel, labour, and time, reducing the number of vehicles needed and minimizing resources for transport.

- Reduced waste and emissions: Consolidated shipments reduce packaging materials and fuel, minimizing waste and emissions, and reducing traffic congestion.
- Increased efficiency: Reducing empty miles traveled by delivery vehicles increases fuel efficiency and reduces carbon footprint.
- Increased asset utilization: Pooling shipments allows better use of transportation assets, increasing asset lifespan, and reducing the need for new assets.
- Reduced costs: Sharing transportation costs among multiple shippers reduces overall transportation costs, encouraging sustainable practices.

Case Study 5: MAN's Truck & Bus Deposit Return Scheme

Website: https://www.mantruckandbus.com/en/innovation/recycling-is-the-starting-point-for-new-products.html
Partner(s) involved: -
CE Strategies used: Take back scheme, Remanufacturing; Reuse
Type of CE innovation: Process innovation; Business model innovation
Region(s): European Union
TRL: 9

What circular challenge / opportunity is the case study trying to address?

The shortages of metals and their supply challenges in Europe, the rise in global demand for raw materials has created extraordinary price volatility (Hagelüken et al., 2016). For the automotive and heavy-duty and off-road (HDOR) vehicle industries, the added costs associated with these linear risk are increasing by several million euros from one year to the next (Piazza, 2015). With 270 million light vehicles (passenger cars and light commercial vehicles) and 20 million HDOR vehicles in use in Europe (ICCT, 2017), the automotive and HDOR sectors are two industrial giants in Europe which represents 6.5% of the EU gross domestic product (ACEA, 2016). Being able to forestall shortages and secure supplies of raw materials is of the utmost importance for manufacturers. In this context, MAN Truck & Bus established a take back scheme for used engines and 55 other product groups to be remanufactured and sold to customers at a competitive price (MAN Truck & Bus, 2022).

Background of the initiative

Under its MAN Genuine parts ecoline scheme, MAN Truck & Bus recovers used engines and products through its sales network, and reusable parts are then professionally remanufactured. Through the remanufacturing process, the parts are completely disassembled, down to its individual constituent components, and inspected against engineering specifications for reuse. Those components that are within remanufacturing guidelines are thoroughly cleaned and undergo additive manufacturing processes to bring them back to original, if not better, engineering specifications and tolerances, but with a much lower price tag. Approximately 3,900 remanufactured products are currently offered under this initiative – from turbochargers, differentials, coolant pumps and alternators to cylinder heads (MAN Truck & Bus, 2022).

Impact and maturity of the initiative

In terms of quality, the remanufactured product is just as good as a new one because it is assembled and tested in the same way as a new product. What is more, the price is only 70% of that of a new product and the delivery time is shorter. Besides the customer, the environment also benefits from where remanufacturing uses about 80% less energy compared to what is required to make a new product (MAN Truck & Bus, 2022). In 2021 alone, 1440 engines were remanufactured. Remanufacturing not only extends the service life of components and thus of our products. A study certified by the TÜV Nord

technical inspection authority also found that the remanufacturing of an ecoline MAN cylinder head emits 85% less CO_2 than the production of a new cylinder head of the same design (MAN Truck and Bus, 2021). Furthermore, the process saves on methane emissions, energy consumption, and raw materials such as cast materials. Beside this scheme which aims to close MAN's material loops, the company is looking to embed circularity in its business in the following ways: i) optimizing the lifetime of products and components; ii) improving product usage and utilization and iii) promoting innovative business models.

Case Study 6: NS Dutch Railways – on track to develop fully circular trains by 2030

Website: www.ns.nl/en/about-ns/sustainability/circular-enterprise
Partner(s) involved: -
CE Strategies used: Remanufacturing; Reuse
Type of CE innovation: Process innovation; Business model innovation
Region(s): The Netherlands
TRL: 8-9

What circular challenge / opportunity is the case study trying to address?

Shifting towards circular trains is a big challenge since trains are very complex products, bound by a wide range of very strict operational and safety regulations. Trains also have a long product lifetime, which means that it is difficult to process the train in a fully circular manner at the end of life. Additionally, the train market is very conservative owing to the strict safety regulations, which makes it difficult to realize change (OUDHEUSDEN, 2020). The Dutch Railways (Nederlandse Spoorwegen, NS), the national rail operator for the Netherlands, has an ambitious plan to achieve fully circular trains and operations by 2030.

Background of the initiative

The Dutch Railways (Nederlandse Spoorwegen, NS) has taken several steps to embed circular economy principles into its business model and end-of-life of its trains in a holistic manner (NS, 2021). Some of these steps are:

1. Circular Procurement: NS aims to make all procurement circular by 2030 by reusing, refurbishing, or recycling products and services purchased, which has already been applied to train maintenance and refurbishment contracts.
2. Refurbishment and Reuse: NS has a refurbishment programme for its older trains, which extends their lifespan, makes them more energy-efficient, and comfortable for passengers.
3. Recycling: At end-of-life, NS aims to recycle as many train components as possible, with a target to recycle 95% of its trains by 2025, and already recycles large amounts of steel and copper from old trains.
4. Sustainable Energy: All of NS's trains are powered by wind energy, and the company is exploring the use of hydrogen fuel cells for its trains in the future to use more renewable energy sources.
5. Circular Business Model: NS is exploring circular business models, where old trains can be taken back, refurbished and reused for as many components as possible, and the remaining parts are recycled, to reduce waste and lower environmental impact.

Impact and maturity of the initiative

While NS still has a way to go in becoming fully circular, these circular economy interventions have helped the company reduce its environmental impact, save money, and position itself as a leader in sustainable transportation. Other key impacts include:

1. Reduced Carbon Footprint: NS's use of renewable energy sources, such as wind power, has helped the company significantly reduce its carbon footprint. According to NS, the company's trains emit 75% less CO2 per passenger kilometres than cars.
2. Waste Reduction: NS's focus on circular procurement, refurbishment and reuse, and recycling has helped the company reduce waste. By keeping materials in circulation, the company is saving 11.7 million kilos of waste (KPMG, 2022)
3. Extended Product Lifespan: NS focuses on effective maintenance and timely repairs to extend the service life of its trains, and upgrades 20-year-old train components in its double-decker trains, reintegrating 85% of them in the upgraded trains, while removing valuable components for reuse before decommissioning trains. This approach has resulted in a 99% new lease of life for each VIRM2/3 train, and has earned NS the 2021 Circular Award, while reducing overall environmental impacts of train production (NS, 2021).
4. Cost Savings: According to the company, NS's refurbishment programme has been more cost-effective than buying new trains, and the company has saved money by recycling old train components.
5. Job Creation: NS's circular economy interventions have created new job opportunities in the Netherlands. For example, NS has established a circular train maintenance centre in the city of Maastricht, which has created jobs for local residents.
6. Leadership in Sustainable Transportation: NS's circular economy interventions have positioned the company as a leader in sustainable transportation. NS has won several awards for its sustainability efforts, including the European Railway Award for Sustainable Mobility in 2020.

Overall, NS's circular economy interventions have had several economic impacts, including cost savings, new revenue streams, job creation, improved brand reputation, and increased competitiveness within the sector.

Cluster 3: End of life circular strategies

The end of life circular strategies includes the checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing (Len and Arditi, 2011). Furthermore, it includes processes of reducing a product all the way back to its basic materials, reprocessing those materials, and using them to make new products, components or materials (Ellen MacArthur Foundation, 2020).

This cluster highlights several case studies which demonstrate a range of circular innovations that are emerging in downstream processes, end-of-use measures such as recycling, upcycling and reuse. These are viewed as prominent approaches which can close material loops and retain the material quality of textiles for as long as possible. This includes the development and large-scale adoption of innovative sorting and recycling technologies separating fibres without reducing their inherent material quality. In this context, various technologies have reached the proof-of-concept stage and now need to be brought to the mass market in order to foster wide-spread adoption. Specifically, the circular innovations profiled here are:

- Renault creates a consortium to recycle EV batteries.
- TIER e-scooters recovers parts and batteries through CE.
- Michelin initiates a project for recycling end-of-life tyres into new tyres.

Case Study 7: Groupe Renault joins a strategic consortium for closed loop recycling of EV batteries

Website: www.solvay.com/en/press-release/groupe-renault-veolia-solvay-join-forces-to-recycle-end-life-ev-battery-metals
Partner(s) involved: Veolia, Solvay
CE Strategies used: Recycling
Type of CE innovation: Process innovation
Region(s): France
TRL: 7

What circular challenge / opportunity is the case study trying to address?

By 2030, the number of electric vehicles on the road worldwide is expected to rise to 100 million, from 10 million today (Ellen MacArthur Foundation, 2021). Ensuring access to responsibly sourced secondary raw materials to keep up with this growth is a strategic challenge for Europe. Groupe Renault, Veolia and Solvay have started a new collaboration which has the goal of preserving and circulating valuable Critical Raw Materials (CRMs) for important battery metals such as cobalt, nickel and lithium in the electric vehicle battery value chain, while reducing the carbon emissions associated with virgin raw material extraction (solvay, 2021).

Background of the initiative

In September 2020, Veolia and Solvay entered a Joint Operation Agreement to begin a demonstration phase of their strategic collaboration in a demonstration phase to enable the circular economy of EV battery metals in Europe through closed-loop recycling, and are in the setting up a pre-industrial demo plant in France (WEKA Industrie Medien, 2022). The consortium was then joined by Groupe Renault in March 2021, a key player in the EV market with a long-standing involvement in the circular economy and in the life cycle of EV batteries (Solvay, 2021).

The consortium partners each leverage their respective expertise at different steps of the value chain – from collection of end-of-life electric vehicle batteries, to dismantling, metal extraction, and purification – and by enhancing existing mechanical and hydrometallurgical battery recycling processes (WEKA Industrie Medien, 2022). Through Solvay and Veolia's joint innovative technology, strategic metals that were previously recovered in a form only suitable for metallurgical applications will be extracted and purified into high-purity metals ready to be reused in new batteries, thereby reducing the environmental footprint of future EV batteries through this closed loop (solvay, 2021).

Impact and maturity of the initiative

Closed loop recycling initiatives for EV CRMs, like the one being developed by this consortium are an important tool in addressing some of the linear challenges associated with EVs. For once, energy use (and associated CO2 emissions and other emissions to air) and water use are typically much lower for secondary CRMs than for primary CRMs (EC, 2018). The consortium plan help

customers reduce the total cost of battery pack by 30% to 50% compared to first life batteries and to generate revenue for the recycler of $40/kWh.
(Niese et al., 2020). Meanwhile, this closed loop recycling initiative enables
For an automotive OEM like Groupe Renault, recycling allows the company to keep used batteries and reclaim these materials, rather than selling them into the stationary storage supply chain.

Case Study 8: Transition-One retrofit the thermal car into EV

Website: www.transition-one.fr/
Partner(s) involved: -
CE Strategies used: Product life extension
Type of CE innovation: ICT innovation
Region(s): France
TRL: 7-8

What circular challenge / opportunity is the case study trying to address?

To tackle the environmental challenges posed by aging internal combustion engine vehicles and rising emissions, countries across Europe, like France, are banning their sale from 2040 and incentivizing the purchase of electric vehicles (e.g. through purchase subsidies, tax exemptions, low-emission zones, free parking, and access to charging infrastructure).

There is an inherent circular limitation with such approaches, in that the production of new car parts and components can contribute significantly to greenhouse gas emissions and other environmental impacts. Retrofitting existing vehicles can help to reduce these impacts by extending the lifespan of the vehicle and reducing the need for new materials and production processes. Here, Transition-One's solution presents an opportunity to transition more fully towards a more circular economy, reducing waste and pollution by repurposing and electrifying existing vehicles.

Background of the initiative

Transition-One offers a fast and effective solution to convert petrol and diesel cars into electric vehicles in just four hours. With a range of 100-200km and a maximum speed of 110kph, the conversion only takes place under the car's bonnet and costs roughly $8,500. Following official approval from the French government, the company received authorization this year and updated the incentive conversation bonus, making the process more affordable for customers (EDF, 2022). Transition-One currently offers conversions for popular hatchbacks in the French market, such as the Renault Twingo, Volkswagen Polo, Fiat 500, and the PSA/Toyota C1/107/Aygo triplets (Transition-One, 2022).

Impact and maturity of the initiative

Transition-One's circular business model has enabled the company to retrofit over 1,000 vehicles. The company has generated over €6 million in revenue since its founding in 2017, and raised over €1.5 million in seed funding from investors. Additionally, the company has created over 50 jobs in France, demonstrating the potential for circular business models to not only provide environmental benefits but also be profitable and create jobs. Meanwhile the solution boasts considerable impacts too, including the following:

i) Environmental benefits:

- 66% reduction in CO2 emissions by converting a gas-powered car to electric (ADEME, 2021).

- Conservation of natural resources by reusing the body and chassis of existing cars.
- Reduction in waste and associated environmental impacts by keeping vehicles in productive use for longer.

ii) Economic benefits:

- Lower cost compared to purchasing a new electric car, estimated at €9,500 by Transition-One (along with an estimated cost savings of up to €1,000 per year for drivers)
- Potential increase in resale value of up to 10% due to increased demand and environmental benefits (Cox Automotive).

Case Study 9: TIER e-scooters recovers parts and batteries through CE

Website: https://about.tier.app/tier-and-northvolt-start-partnership/
Partner(s) involved: TIER, Northvolt
CE Strategies used: Refurbishment; Recycling; Leasing
Type of CE innovation: Process innovation; Business model innovation
Region(s): European Union
TRL: 8

What circular challenge / opportunity is the case study trying to address?

As the global shift toward electrification continues to accelerate, micro-mobility solutions, like e-scooter sharing are following suit.[4] While seen as an important tool in decarbonising transportation, by shifting away from fossil fuels, the mining of raw materials for batteries and battery manufacturing processes is a carbon intensive process which accounts for the majority of greenhouse gases an e-scooter or an e-vehicle is responsible for over its lifetime, Meanwhile, there are several linear challenges associated with e-scooters and e-scooter batteries, including their short battery lifespan and limited recycling infrastructure to effectively recover and reuse hazardous CRMs like lithium and cobalt when they reach end-of-life. Northvolt, to Micro-mobility provider, TIER, and Swedish battery-manufacturer, Northvolt, entered into partnership to improve sustainability of e-scooter batteries, reduce raw material needs and lower associated emissions, and return the valuable materials contained within them back into the supply chain (Northvolt, 2021).

Background of the initiative

In 2021, TIER, Europe's leading e-scooter operator, partnered with Northvolt, a European supplier of sustainable, high-quality battery cells and systems, to treat end-of-life batteries as a valuable resource which can be recovered and recycled to provide secondary raw materials for future batteries (TIER Mobility, 2021). The

[4] The global micro-mobility market is estimated to register 31.9 million vehicles by 2025, up from 20.5 million in 2020 at a compound annual growth rate (CAGR) of 9.2% (Tan, 2021)

pilot project, including the distribution of batteries for 5000 e-scooters, was rolled out throughout 2021(Billington, 2021).
The partnership with Northvolt follows TIER's recent introduction of user-swappable batteries, which allow riders to charge batteries themselves at charging stations in exchange for free rides. This year TIER will set up 4,500 charging stations within local businesses across Europe, creating a green energy network which the company hopes can transform urban transport and help to electrify cities (TIER Mobility, 2021). Tier has expanded its strategic partnerships with other second-life enablers to improve and scale the circularity of its e-scooters and batteries internationally. The company also partnered with Nunam, a German-Indian impact-driven start-up company advocating for a green power supply in rural India. In February 2021, TIER and Berlin startup Vertical Values entered into a partnership to extend the lifespan of batteries by repairing and upcycling lithium batteries across European markets. In June 2022, TIER Mobility stepped up its commitment to recycle all elements of lithium-ion batteries in key markets across Europe with an agreement with Remondis, one of the world's largest recycling providers (TIER, 2022). Importantly, batteries are only sent for recycling if they cannot be repaired or be reused. TIER already provides a second-life solution for lithium-ion batteries through its partnership with Vertical Values (*Ibid.)*.

Impact and maturity of the initiative

Partnership's like the one between TIER Mobility and Northvolt will help the micro-mobility provider to reduce CO2 emissions in production cycles with battery replacement and recycling by 56% to 81% (TIER Mobility, 2021). Meanwhile, TIER's ongoing commitment to resource conservation and goal to embed circularity in its end-of-life management of the lithium-ion batteries through further international strategic partnerships means that more than 160,000 e-scooters, e-bikes and e-mopeds the company currently operates in 16 European countries will now achieve improved circularity outcomes.

Case Study 10: Michelin's BlackCycle project for recycling end-of-life tyres into new tyres

Website: www.michelin.com/en/press-releases/blackcycle-a-major-european-project-for-recycling-end-of-life-tyres-into-new-tyres/
Partner(s) involved: Multiple
CE Strategies used: Remanufacturing; Reuse
Type of CE innovation: System innovation
Region(s): France, Spain, Germany, Greece, and Switzerland
TRL: 7

What circular challenge / opportunity is the case study trying to address?
Currently, 1.6 billion new tyres are sold worldwide each year, representing more than 26 million tonnes, and just as many fall into the category of end-of-life tyres (ELT) providing a large and partially untapped potential for material recovery. Today's ELT treatment processes are not circular and do not result in many raw materials that can be reused in the tyre industry. Furthermore, as there is not enough solution to valorise materials from ELT in the EU, more than half of EU end-of-life and second-hand tyres are exported to far-off countries (MICHELIN, 2020). Together with seven industrial partners, five Research & Technological Organizations (RTOs) and an innovation cluster spanning five EU countries, leading global tyre manufacturer, Michelin, ,launched the BlackCycle project to enable a massive circular economy of tyres by designing world-first processes to produce new tyres from ELTs (BlackCycle, 2020).

Background of the initiative
The BlackCycle project aims to enable a massive circular economy of tyres. This European project - funded with a budget of about 12 M€ from Horizon 2020 - helps design world-first processes to make new tyres from end-of-life tyres (BlackCycle, 2020). The project aims at creating, developing, and optimising a full value chain form ELT feedstock to Secondary Raw Materials (SRMs), with no waste of resources in any part of the chain and a specific attention for the environmental impact (BlackCycle, 2021). These SRMs will be used to develop new ranges of passenger car and truck tyres, which will be sold commercially in European and global markets.
The BlackCycle project is based on a unique European public-private partnership that gathers all the necessary competencies along the circular value chain to ensure its success. The project demonstrates the technical, environmental, and economic viability of world-first circular processes. The consortium will develop specific solutions to produce sustainable raw materials for tyres: ELT collection and feedstock selection, oil refining and valorisation, furnace process optimisation, and sustainable tyre performance assessment (MICHELIN, 2020).

Impact and maturity of the initiative
The project is expected to achieve considerable circular and sustainability outcomes in Europe. As early as 5-6 years after the project, close to 1 out of every 2 European ELTs is expected to be incorporated into the only virtuous

cycle of this magnitude amongst all industrial sectors for the recovery of end-of-life products (BlackCycle, 2021).
Compared to a single-use tyre, a retreaded tyre allows saving of 70% natural resource extraction (ore, oil), 29% of land use, 24% CO_2 emissions, 21% air pollution and 19% water consumption (Michelin, 2017). As a result, the BlackCycle value chain has a lower carbon footprint, emitting 0.93 kg CO2/kg tyres less and a lower using of fossil resources, using 0.89 kg fossil/kg ELT less products (BlackCycle, 2021).
Additionally, by offering an economically and environmentally viable alternative, BlackCycle will reduce the export of end of life tyres. By relocating end-of-life tyre management and transformation within the EU, BlackCycle is expected to create sustainable jobs inside the EU (*Ibid.).* Previous analysis by Michelin has found that a retreaded tyre supports 4.3 times as many jobs as a non-retreadable imported tyre (Michelin, 2017).

Section 3: What's needed to circularize Ireland's Road and Rail sectors?

As has been highlighted in the sections above, sustainable and circular transport transformation is critical to addressing climate change and to facilitating a flow of people and goods that is safe, affordable, and future-proofed for Irish society. The 10 case studies highlighted in this guide have been purposefully selected to spotlight a wide range of innovation strategies relevant to the circular economy in the transportation sector, including circular design, procurement and regulations, low-emission fuels, circular business model developments, and various end-of-life strategies. They range in maturity and technological readiness level from early-stage pilots (with Technology Readiness Levels 7) like the Aberdeen City Council project and Renault, to more mature, fully commercialised circular transportation innovations and systems like Alke and NS Dutch Railways (TRL 8 or 9).

Based on the author's analysis of the case studies, below we present some of the main lessons learned regarding what's needed to pilot and scale circular transportation system innovations in the road and rail sectors. We discuss some of the major roadblocks to creating an effective ecosystem that supports and sustains circularity. Following that, we present two regional examples that have been recognised as pioneers in promoting circular transportation networks. Finally, we conclude with five key recommendations aimed at advancing circularity in Ireland's transportation sector, based on our cross-comparative examination of these regional examples and the wider literature.

Key enablers/lessons learnt from the case studies and wider literature

Importantly, when selecting the case studies, consideration was given to the industry profile of the rail and road sectors in Ireland. For instance, automotive manufacturing on the island of Ireland is limited, with only a small number of companies involved in the production of vehicles or vehicle parts. Ireland is consequently a net importer of both new and used vehicles. This contextual reality is an important consideration when looking at future opportunities to circularise the sector here in Ireland. The reality that this sector remains at a smaller scale compared with other EU countries, like Germany and France, and is at the end of longer international distribution chain (often at a remove from OEMs), has a considerable bearing on the kinds of circular strategies that will best respond to the market needs and reality here. Nonetheless, drawing on the case studies highlights several key cross-cutting lessons that could help promote the transition to a circular transportation industry if applied in the Irish context.

All the case studies profiled in this Guide have sought to anticipate and address linear risks facing the transportation sector (such as understanding the scarcity and resource intensity of sourcing virgin raw materials, such as CRMs). Others are looking to circular business models as a means innovate and raise revenue in a way that is unlike typical linear businesses, such as by extending the lifespan of existing

products (e.g. Transition-One's retrofitting of existing cars into electric vehicles, MAN Truck & Bus's remanufacturing of used engines and products).

Among the most important cross-cutting lessons from the case studies are the following:

1. **Collaborations and Partnerships:** A feature across most of the case studies is that they featured strategic partnerships between different organizations to implement circular innovations in the transport sector, leveraging different partners' expertise and capabilities at different points along the value chain. For instance, Savonlinja partnered with Neste to use biofuel made entirely from waste and residues to reduce greenhouse gas emissions. Key examples case studied for this Guide demonstrate that collaborations and partnerships between companies, government agencies, and other stakeholders can play a critical role in creating an enabling environment for circular innovations in the transport sector. It was in this context that Aberdeen City Council partnered with Hyzon Motors to introduce the UK's first hydrogen-fuelled waste collection vehicles. The BlackCycle project involves a public-private consortia whose partners have essential competencies all along the circular value chain to ensure its success. Meanwhile other cases involved multiple partners working together to address the circular challenges associated with their respective circular products or processes. In the case of Groupe Renault, Veolia, and Solvay, the consortium brings together expertise in collection, dismantling, and metal extraction. Meanwhile TIER Mobility has leveraged strategic partnerships to improve the sustainability and circularity of its e-scooters and batteries, and accordingly has partnered with Northvolt, Nunam, and Remondis. Collaboration among stakeholders with different expertise, interests, competencies and capabilities is essential in addressing the complex challenges of circularity in the transportation sector.

2. **Supportive Policy, Regulatory and R&I Frameworks:** Most of the case studies were implemented in regions that have supportive policy, regulatory and R&D investment frameworks that encourage circular innovation in the transport sector. For example, the introduction of low-emission zones in some cities is driving the demand for low-emission vehicles. Policies that support the development of renewable energy sources are enabling the use of green hydrogen to power transport vehicles. These policy and regulatory frameworks provide additional incentives and guidance for industry to transition to circular models. In general, supportive national R&D investment frameworks can play a critical role in driving circular economy innovation and adoption too. They can provide the necessary resources, expertise and public sector buy-in needed to de-risk, develop and test circular economy solutions, as well as create incentives for businesses and organizations to adopt circular practices. The case study examples of Savonlinja and Alke have benefited from supportive national R&D investments to fund their businesses. For example, cleantech company Neste previously received government support for its sustainable renewable fuels

research and development efforts. While Alke has collaborated with the Italian National Research Council to develop and test aspects of their circular business. Elsewhere EU funding, like Horizon 2020 and Horizon Europe – has helped initiate a number of large-scale circular transportation projects. For instance, BlackCycle project's unique public-private collaboration to bring together various actors along the ELT value chain was made possible thanks to a 12M € EU grant fund.

3. **Business model innovation:** Several of the cases highlight the importance of new business models that help unlock innovative circular transportation approaches. In the case of Transition-One, retrofitting combustion engine cars into electric vehicles has been an effective business model innovation that allows the company to generate revenue by effectively tapping into a consumer group who might ordinarily be locked out of the EV market due to their high cost. This approach fundamentally recognises that a significant amount of emissions are generated at the manufacturing stage (it is estimated that 6.0 tCO2e is generated by an internal combustion engine per vehicle during the manufacturing stage (IEA, 2021)). This allows for a circular approach to be applied to extending the productive life and use of previously fossil-fuel powered cars, while helping to reduce the vehicle's total lifetime emissions at the use phase. Moreover, by adopting a frugal innovation approach, Transition-One has been able to reduce the production and operational costs associated with manufacturing new EVs, and in so doing, has identified a key market segment. Retrofitting helps to significantly reduce the costs associated with brand-new EVs, making it easier for more consumers to access more affordable Evs. Such business model innovations will be needed to support a just transition, ensuring no consumers get left behind. Elsewhere, Expak's shared truckload shipping solution enables businesses to use resources more efficiently by consolidating multiple shipments from different companies. In this way, Expak can reduce its carbon emissions whilst lowering its operational costs. MAN Truck & Bus's take-back scheme and remanufacturing of used engines and other parts also represents a novel revenue stream that serves to reduce the company's need for virgin materials and components. Meanwhile, the TIER Mobility case study involves a business model innovation through its introduction of user-swappable batteries, which allows riders to charge batteries themselves at charging stations in exchange for free rides. The company also has a cost-sharing model that enables local businesses to set up charging stations, creating a decentralised green energy network that transforms urban transport and helps electrify cities. Additionally, TIER Mobility partners with second-life enablers to expand the reach of its repair and upcycling services of lithium batteries across European markets. This focus on business model innovation enables TIER Mobility to scale and improve the circularity of its e-scooters and batteries, while also creating new revenue streams and value for customers. Finally, Dutch Railway operator, NS, highlights the value of integrating circularity in the business model in a holistic way. It has done this by developing circular business model strategies, while also

implementing circular procurement, refurbishment and reuse programmes, generating new revenue streams from activities like recycling end-of-life train components.

4. **Material, Product and Process Innovations:** Several of the case studies illustrate a variety types of circular transport innovations happening at the material, product and process levels. The Savonlinja case study involves valorization of organic waste material to create biofuel, the Alke case study involves the development of low-emission electric vehicles for logistics, while the Aberdeen City Council case study involves the use of hydrogen-fuelled waste collection vehicles. All three case studies involve process innovations to enable circularity in their respective value chains. In the case of Groupe Renault, Veolia, and Solvay, the joint innovative technology enables the extraction and purification of strategic metals from end-of-life EV batteries, reducing the environmental footprint of future batteries through closed-loop recycling. TIER Mobility and Northvolt aim to treat end-of-life batteries as a valuable resource that can be recovered and recycled to provide secondary raw materials for future batteries. Michelin's BlackCycle project has developed world-first processes to make high-performing retreaded tires from end-of-life tires which reduces many of the negative environmental impacts of single-life tyres (e.g. saving of 70% natural resource extraction (ore, oil), 29% of land use, 24% CO_2 emissions, 21% air pollution and 19% water consumption (Michelin, 2017).) Such innovations require considerable R&I investment and support both by industry and government.

5. **Importance of Digital Technologies and Data-sharing to boost industry-led circular innovation:** Transition-One's retrofitting solution relies on innovative ICT approaches to convert combustion engine vehicles into electric vehicles quickly and effectively. The use of technology in this way enables circular approaches to transportation that are more efficient, cost-effective, and sustainable. Meanwhile, technology can also help to improve collaboration and data-sharing across circular stakeholders and supply chains. For example, in the case of Expak, the pool distribution method relies on digital technologies to optimise how shipments can be combined from a single shipper at a single origin location. The company has developed web-based, client-facing tool utilized to create, label, and track shipments, update shipment statuses, view customizable analytics and reporting, manage and audit invoices and more. Meanwhile, Expak Logistics' ExpakConnect is a complete Electronic Data Interchange (EDI) solution, allowing to connect effortlessly carrier, client, 3PL and/or other required systems together over the entire logistics chain (Expak, 2022). Such examples highlight the role that Key Enabling Technologies (KET) can play in boosting the circular innovation and digital transformation of the road transport sector. KET are Information and Communication Technologies (ICT) associated with high Research and Development (R&D) intensity, rapid innovation cycles, high capital expenditure, and highly skilled employment (Romero-Gazquez, 2021). KET are considered a key instrument for boosting the

innovation and digital transformation in most of European industries, traditional sectors and society (Ortega-Gras et al. 2021).

Key barriers in the transition process of Land based Transportation circular economy

Several cross-cutting challenges have been identified which pose a significant barrier to transitioning from a linear to circular economy for the transportation sector and industry. These include:

Market barriers

- Cars have long been regarded as a status symbol, with buyers driven by conspicuous consumption to buy new, large vehicles. Privately held cars are only effectively used at 1.5% of their seat and time capacity (WEF, 2021). Consequently, this results in prevailing problematic use patterns and outcomes, such as avoidable pollution, inefficient use of vehicles and energy, traffic congestion and unmet demands for parking.
- Linear costs are not properly accounted for in the current market, which can make it difficult for circular transportation business models to compete with traditional (linear) market incumbents. For example, CO2 emissions are not yet properly priced into the cost of mobility. Expanding schemes such as fleet emissions credit markets to include lifecycle carbon emissions, non-circular resource consumption and capacity factors could significantly benefit circular business models (WEF, 2020).
- The capital-intensive nature of vehicle development and manufacturing processes encourages the automotive industry to sustain linear business models that treat cars as a product, rather than a service. This curtails opportunities to adopt and invest in circular products and services e.g. car or ride-sharing (WEF, 2021). For new service-focused business models to compete, a new service-focused system would have to be optimized and achieve significant scale.
- The benefits of investing in circularity can be diffuse and not easily captured by any single entity to capture through current business models (WEF, 2020). For instance, improved design for recyclability benefits end-of-life vehicle values, not sales margins. Consequently the current market system does sufficiently incentivise industry to invest in circularity.
- While examples like Renault show the real potential and value of value chain collaboration with larger consortia, for the most part, the competitive industry landscape can inhibit circular innovation and processes by slowing down sharing of information and data (which makes it difficult to access good data needed for integrated sustainable mobility systems and vehicle lifecycle management). Moreover, a lack of incentives for pre-competitive collaboration can slow down adoption of scalable technologies, such as traceability technologies like digital product passports, which are needed to facilitate effective lifecycle management and reverse logistics of vehicles and their constituent parts across the supply chain.

Regulatory and policy barriers

- Current policies, regulations and legislation don't go far enough in incentivizing holistic circular outcomes. For example, regulatory CO2 performance metrics only cover tailpipe emissions and fail to take a lifecycle perspective into account (WEF, 2021). While end-of-life legislation focuses on recycling but lacks specific quality requirements, which in turn disincentivizes the need to design for high-value recycling and product life extension (*Ibid.)*.
- Metrics and factors used to influence transport sector regulations and policy decisions are often incomplete and neglect a variety of important broader environmental considerations. In the case of car use, for instance, regulations ought to holistically regard life-cycle CO2 per passenger km instead of just exhaust emissions to effectively incentivize the reduction of all CO2 along a car's life cycle (WEF, 2020). Such an approach would promote the circular benefits of product life extension, remanufacturing and retrofitting strategies for vehicles. Meanwhile, transport infrastructure must similarly adopt a more holistic, lifecycle approach that extends beyond calculating the associated air quality, CO2 emissions, noise, water pollution impacts of moving people and resources from point A to B, and which considers also the underlying impact and lifecycle of construction and renovation activities. This is particularly important given the high volumes of material used, and high proportion of emissions that occur during material production in transportation infrastructure construction (UIC, 2021).
- Elsewhere, regulations can have unintended consequences. OEMs and suppliers are forced to comply with a multitude of regulations when designing and planning new vehicles. These well-meaning regulations can pose an obstacle to circularity; for instance, by complicating the use of reused and remanufactured parts in the production of new vehicles (WEF, 2020).
- Policymakers can lack the capabilities and confidence required to shift into the more directional, active role needed to support and accelerate the transport sector's circular transition. Such transition – or 'mission-oriented innovation' - management calls for a culture of experimentation and risk-taking (Mazzucato, 2018), and a degree of cross-sectoral stewardship that is new and unfamiliar to many public sector officials. For instance, strengthening our national rail freight capacity and ensuring rail assets and networks are designed in a way that supports circular and sustainable outcomes, and which shifts from diesel to renewable energy systems, requires that public sector and industry leaders adopt an integrated approach to embed circularity holistically in procurement and strategic planning. The highly complex nature of the transportation sector also requires collaboration among stakeholders to access distributed expertise, competencies and capabilities along the value chain. In the rail example, this relies on 'coordination and cooperation between rail infrastructure managers,

better overall management of the rail network, and the deployment of new technologies such as digital coupling and automation' (EC, 2021).

Building an environment for circular economy in Ireland's Transport sector

Below are some key examples from across Europe which underscore the value strong leadership and effective public-private cooperation and collaboration to catalyse circular transportation:

France:

France has implemented several steps in its approach to supporting a circular economy for its transportation and mobility sectors that aims to foster and scale industry innovation, including by: **i) Encouraging Circular and Sustainable Transport Startups:** France has a thriving startup ecosystem focused on sustainable transport solutions. The French government has implemented policies to support these startups, such as providing funding and regulatory support. This approach aims to foster innovation and scaling up of sustainable transport solutions; **ii) Promoting Research and Development:** France has a strong focus on research and development in the transportation and mobility sectors. The government has invested heavily in research and development of new technologies and solutions, such as electric vehicles, hydrogen fuel cells, and new mobility services. **iii) Earmarking Dedicated Funding and Support for Circular Innovation:** France has implemented policies to provide funding and support for innovation in the transportation and mobility sectors. For example, the Transition Ecologique et Énergétique pour le Climat (TEEC) Fund: The TEEC fund is a government initiative that finances green investments in the energy and transport sectors, including sustainable and circular transportation. The strategy aims to reduce the sector's emissions by 28% by 2030 compared to 2015, and focuses on achieving this through five key levers: 1) decarbonizing the energy consumed by vehicles and adapting the associated infrastructures; 2) improving the energy performance of vehicles; 3) control of demand growth (for passenger and freight transport); 4) modal shift (for passenger and freight transport) towards the most energy-efficient and low-emitting modes; 5) optimize vehicle use (for passenger and freight transport) (MTES, 2020). Elsewhere, the French recovery and resilience plan (RRP) provides for large-scale investments in the green transition such as sustainable transport and the circular economy. One of the largest measures in the RRP finances is the reconstruction and modernisation of the railway network, in particular local railway and freight lines. In addition to directing funding towards stimulating industry-led transportation innovation, the electrification of vehicles and scaling up of mass public transit systems were both accelerated with financial support from the instrument (EC, 2023). **iv) Creating a Network of Innovation Hubs:** France has established a network of innovation hubs that focus on sustainable transport solutions. These hubs bring together industry experts, researchers, and entrepreneurs to collaborate and develop new solutions.; **v) Encouraging Public-Private Partnerships:** France has implemented policies to

encourage public-private partnerships in the transportation and mobility sectors. These partnerships bring together government agencies, industry, and academia to collaborate on research and development of new sustainable transportation solutions.

Germany:

Germany's goal of cutting greenhouse gas (GHG) emissions by 40% by 2020 and 95% by 2050 (compared to 1990 levels) is an important anchor for its national sustainable and circular transport efforts. To support this goal, the German government has implemented several initiatives to support the sustainable transition in the road and rail sectors, with some priority given to how this can be achieved through circular adoption. Key examples include: i) **National Platform for Future of Mobility:** The German government has set up a National Platform for Future of Mobility, which aims to bring together stakeholders from industry, science, and civil society to develop and implement strategies for sustainable and innovative mobility (NPM, 2022). The platform has identified the circular economy as a key thematic priority and is developing a roadmap to support the transition to a circular economy in the transport sector. ii) **Electric Mobility promotion and battery recycling:** Germany's goal is to have seven to ten million EVs on the road by 2030, however, this poses an immense linear challenge to recover and reuse CRMs from EV batteries (CIE, 2021). The Circular Economy Initiative Deutschland's Traction Batteries working group has developed a common vision for the Circular Economy for traction batteries in 2030. This vision has been created along five key dimensions of regulatory framework, material streams, technical development, value networks and in-company implementation. Through its work on three pilot profiles, the Traction Batteries working group identified key issues and outlined possible steps for practical implementation to accelerate the transformation process. By developing recommendations for policy makers, business and academia and creating a schedule for their implementation, the Circular Economy Initiative Deutschland has created a pathway forward for achieving its vision. iv) **Circular Rail:** German railway industry operators are working with others across Europe as part of the Europe's Rail (EU-Rail) technology initiative - a Horizon Europe programme (running from 2021 to 2027). With the goal of speeding up the shift from road to rail, the initiative supports a wide range of mobility-focused innovations. To achieve this goal, the major players in Europe's rail industry are pooling their respective areas of expertise. German company, Knorr-Bremse, one of the world's leading manufacturers of braking systems and a leading supplier of safety-critical sub-systems for rail and commercial is a founding member. The project is covering the Sustainable and green rail systems with decarbonization of Diesel trains, noise and vibration reduction, energy savings, circular economy, resource consumption, resilience to climate change (Knorr-Bremse, 2022).

These are just a few examples of the policies, programmes, and initiatives that the German government and frontrunner companies are pursuing to support the circular economy in the road and rail sectors.

Five key recommendations to advance Ireland's Circular Land Based Transportation Sector

Having outlined the key enablers and barrier to catalysing circular transportation innovation, below we present some of the key recommendations for advancing the sector's circular transition:

1. **Ensure all transportation and mobility policies adopts an integrated approach to circularity and lifecycle thinking**

To achieve meaningful emissions reductions and create a sustainable transport system, policy must ensure that circularity and lifecycle thinking, and sustainable development goals, are made a mainstream priority in a way that reflects the 'whole-of-government' circular economy approach espoused by the Government. In various Irish policy plans and strategies, such as Project 2040, the Government has highlighted road-transport electrification as a key strategy in decarbonising Ireland's transport sector.[5] The shift from petrol and diesel cars to electric vehicles will make a big impact on our emissions and will considerably improve our air quality. However, several of these same strategies and plans ignore many of the linear challenges associated with EVs already acknowledged in this guide.[6] Simply swapping linear consumption patterns of combustion engine vehicles with electric vehicles is not enough to fully address the issues of climate change and resource scarcity. As we have noted, the mining of raw materials for batteries and battery manufacturing processes is a carbon-intensive process which has other hidden costs. Most lithium, for instance, is obtained through hard rock mining or underground brine reservoirs, which often rely on energy from fossil fuels, producing significant CO2 emissions.[7] Adding to all this is the reality that the huge quantities of the CRMs we need to power our EVs are sourced from countries where questions about deplorable working conditions, human rights violations and child labour abound. Policy and regulation must adopt a more holistic approach to sustainability and circularity that considers the entire lifecycle of vehicles (including EVs), from production to end-of-life. To keep pace with increasing number of vehicles anticipated in the coming years, actions must be taken now to rapidly scale up Ireland's repair, recycling and reuse infrastructure for

[5] Project Ireland 2040, for instance, sets a target of having 500,000 Electric Vehicles (EVs) on the road by 2030.

[6] For instance, the author's review of the Electric Vehicle Policy Pathway Working Group Report 2021 finds that it only mentions battery recycling once in the report, and without any specific recommendations, actions or targets. Accessed: cde9b7e9-1557-4c2f-9876-651ffc79974a.pdf (www.gov.ie)

[7] For every tonne of lithium mined from hard rock, 15 tonnes of CO2 are emitted (MIT Climate Portal, 2022). Sourcing battery materials such as lithium, cobalt, and nickel is a laborious process that requires water from areas where it may already be scarce, often leaving behind toxic waste and contaminants.

EVs and EV batteries, ensuring mechanisms are in place to recover valuable materials such as lithium and cobalt at their End-of-Life.

2. **Strategic planning for future circular transportation infrastructure (e.g. EV charging stations and large-scale public transportation roads must integrate circular and sustainability principles in decision-making processes**

Circular procurement and integration of circular design principles can play a role in ensuring that future charging stations and transport infrastructure projects are designed to be modular and scalable, that they use secondary raw materials wherever possible, can be easily upgraded and expanded over time - to reduce the likelihood of obsolescence, while ultimately reducing primary resource extraction and waste. Moreover, when looking at assessing the environmental cost of transport infrastructure projects, it is key that beyond working out the associated air quality, CO2 emissions, noise, water pollution impacts of moving people and resources from point A to B, attention is given to working out the underlying impact and lifecycle of construction and renovation activities for transport infrastructure. This is particularly important given the high volumes of material used, and high proportion of emissions that occur during material production in infrastructure construction (UIC, 2021). Proposals included in regional transport strategies and planning decisions upheld by planning authorities - like An Bord Pleanála - must similarly demonstrate that they adhere to national Climate Action Plans (indeed, a failure for An Bord Pleanála to consider the requirements outlined in the 2021 Climate Action Plan and Low Carbon Development Act 2015 in its decision to approve planning for the 18km N6 Galway Ring Road infrastructure project has seen the project stalled.) This underscores the need for transport policymakers and planners to recognise and actively promote the need to shift from linear transport solutions towards mass public transport and sustainable transport modes, and to consider statutory circular economy and climate action obligations linked to reducing the transport sector's carbon emissions.

3. **Look to meaningfully align sustainable, circular transportation policies with just and fair transition outcomes**

Policymakers must endeavour to apply the resource or waste hierarchy priority order (EPA, 2021, p. p. 5) to EV and sustainable transportation policy approaches. Accordingly, reasonable efforts should be made to promote proven retrofitting schemes – like French government-backed Transition-One scheme – above scrappage schemes for combustion engine vehicles. Such models can be an effective way to extend the lifespan of existing vehicles, reducing the need for virgin materials and production processes associated with brand new vehicles. Since a significant proportion of a vehicle's embodied carbon is generated in the manufacturing phase, retrofitting can in turn reduce emissions and preserve natural resources by optimizing these vehicles' productive use. Meanwhile, efforts should be made to adapt elements of policies and legislation already implemented in other EU member countries that promote circular transportation alongside just

and fair transition outcomes. A key example is Italy's RETROFIT National Decree which aims to simultaneously lower the economic barriers to EV access while growing jobs in the repair economy, by stimulating the market for "converting conventional vehicles with combustion engines into retrofitted electric cars, efficient, zero emissions and zero fuel consumption" (INTERREG, 2018). The novelty of this legislation is that it encourages and accelerates the process of reducing CO2 emissions in the national territory, converting vehicles with combustion engines into EVs, in line with the Rules of the road and the following Regulations UN10, UN85, UN100 e UN101 of the United Nations Economic Commission for Europe (*Ibid.)* Moreover, the scheme has proven an effective mechanism to stimulate public-private investment in circular transportation, whilst benefitting people that cannot afford to buy a new EV but that wish to convert their conventional vehicles into EVs; as well as stimulating innovation and economic activity for craftsmen and SMEs of car-repair sectors; as well as specialized automobile repair shops. Importantly such approaches might be particularly well suited to the contextual reality of Ireland's road transport industry. As an island economy at the end of along distribution chain, automotive OEMs are not typically located on the island. This makes certified repair training schemes (such as the CIRCULEIRE-supported Circular Economy Skills Initiative, which ought to establish more repair and reuse specialists in the white goods sector) an interesting model to adapt for the automotive industry.

4. **Incentivise positive behaviour change and continue to increase infrastructure investments needed for the public and businesses to adopt more active, low-carbon and sustainable modes of transport and circular consumption.**

Mass transit systems are more efficient in terms of energy use and emissions per passenger, reducing congestion, air pollution, and greenhouse gas emissions. Meanwhile, active travel is emission-free, reduces the demand for car travel, and promotes physical activity, which in turn reduces the need for new vehicle production and associated environmental impacts while creating more sustainable and equitable transportation systems. A 2021 study by MaREI estimates the average vehicle occupancy of private cars in Ireland at 1.5 persons per journey (O'Riordan et al., 2021, p. 10). For private citizens, the shift towards a circular economy transportation sector thus requires that mass transit and active travel are invested in and promoted over individual car journeys. Ride-sharing and sharing economy models can also play a role in increasing the efficiency and average occupancy of private car journeys – particularly in rural areas where reliable public transport coverage can be lacking. Finally, in tandem with ongoing efforts to invest in and expand Ireland's rail freight network, businesses must be supported and incentivised to transition to rail freight and be made aware of the sustainability and economic benefits of doing so. In addition to GHG reductions, investments (both public and private) in more sustainable transport infrastructure solutions can deliver environmental, social and economic benefits. These can include improved local air quality and reduced traffic congestion. Effective and well-designed public

awareness campaigns, and proven behaviourally informed policy interventions can all help encourage citizens and businesses to adopt more circular, sustainable, low-carbon modes of transports and consumption patterns.

5. **Promote cross-sectoral collaboration and experimentation to advance Ireland's circular transportation system**

Circular innovation advances for the transport sector will require a high degree of risk-taking and experimentation, cross-sectoral collaboration between a broad coalition of stakeholders, and some trial and error. International best practices such as the Dutch deep demonstrator project, 'De Circulaire Weg' programme ('The Circular Way') offer interesting examples of how public-private experimentation can be used to advance learning and practice in support of this goal. De Circulaire Weg is a deep demonstrator programme which is initiating several demo pilots each aimed at answering key questions about the opportunities, barriers and practical implications of rolling Product Service Systems for large-scale transport infrastructure projects (which the programme refers to as 'IaaS' i.e. Infrastructure as a Service). The programme is structured around eight 'test projects' or pilot infrastructure-as-a-service contracts for road sections, bridges, viaducts, verges or the road lighting solutions (De Circulaire Weg, 2021) taking place in the municipalities of Amerfoort, Amsterdam Zuidoost (district) and Utrecht and the provinces of Noord-Brabant, Noord-Holland and Overijssel. Each of these pilots are designed to gather practical insights into specific questions related to the future implementation of IaaS, such as when IaaS is an appropriate contract mechanism, how to include the right incentives to promote circularity, and what specific consideration for setting up contracts and partnership agreements. (Check out CIRCULEIRE's Circular Construction and Built Environment Sectoral Guide for a full write-up of the De Circulaire Weg case study). Integrating such R&I methodologies into future large-scale circular transport demonstrator projects, and using this as an means to test out and eventually scale-up effective circular business models and solutions presents a significant opportunity for government, industry, academia and others to collaborate around advancing circular transportation systems, processes and solutions.

Annex I: Key Stakeholders

The drive for a circular economy in transportation in Ireland is supported by:

- **The Private Sector**: they are a major stakeholder in implementing a circular economy as they form the are the largest consumers of the sector. In road infrastructure, the public-private partnership (PPP) model has been practically the exclusive vehicle for private investment. Several countries (e.g., Portugal, Spain, Italy, France) entrusted large shares of their motorway network to the private sector through PPP (concessions) and relied heavily on PPPs to create new connections (Makovšek, 2019). Ireland has an existing track record in the design/manufacturing of key components linked both directly and indirectly to the auto sector where this industry has a revenue of around 2.3 bn$ in 2018 (Statista, 2021). Aligning with this revenue, several vehicle parts and accessories manufacture put extra investment in the research and development. For instance, Autotech giant Valeo is to invest €44m in a major research, development and innovation (RD&I) centre in Tuam, Co Galway (IRISH TECH NEWS, 2019). In addition, Jaguar Land Rover is expanding rapidly at its new facility in Shannon, which includes an advanced R&D workshop for its vehicles (Reporter, 2018).
- **Public sector**: There is a clear opportunity for the circular economy to drive policy and public service innovation. At a basic level, the Circular Economy Package demands innovation and the appropriate allocation of resources. The revised National Development Plan, which is made up of different public sectors coming together to come up with, will provide the financial supports to deliver much of the necessary infrastructure over the next decade. EU funding will also be sought to underpin many of the measures involved.

Specific Organisations

- **Environmental Protection Agency (EPA)**: the agency launched the Circular Economy Programme, which was devised to support the Government's circular economy policy agenda. It will incorporate the previous National Waste Prevention Programme and will be the driving force for Ireland's move to a circular economy for the transportation sector through providing clean and competitive solutions for all transport modes. With focus on safe resilient transport and smart mobility services for passengers and goods (Environment Protection Agency, 2021).
- **Freight Transport Association Ireland (FTA)**: is a multimodal representative trade association for the freight, distribution, Passenger, and logistics sector. Due to the nature of the association, the FTA supports, shapes and stands up for efficient and sustainable logistics, putting them at the forefront to the adaptation and leading in the circular economy within the country. They have come up with a foundation established for 3 years dubbed, Alternative Fuels

Working Group which is eyed at improving fuel usage, efficiency, and the environmental impacts of the same (Freight Transport Association, 2022).

- **The National Transport Authority (NTA)**: is a statutory non-commercial body, which operates under the aegis of the Department of Transport. Established in 2009, the NTA is responsible for developing and implementing strategies to provide high-quality, accessible, sustainable transport across Ireland. Some of their roles include; (i) maintenance and management of stations and other assigned infrastructure, (ii) creation of new infrastructure projects like the introduction of cycling and pedestrian infrastructure, (iii) research and data collection in regards to the transport sector.
- **Transport Infrastructure Ireland (TII)**: purpose is to provide sustainable transport infrastructure and services, delivering a better quality of life, supporting economic growth and respecting the environment. Some of the projects that the organisation has spearheaded include (i) the upgrade of the Green Line Infrastructure corridor, (ii) The extension of the Sandyford Depot, (iii) the redevelopment of the Red Cow Transport hub.
- **Iarnród Éireann:** Irish Rail is committed to implement specific circular economy strategies to grow the rail freight which will focus on the commercial, environmental and economic value that rail freight can provide in the years ahead, and the company will develop a new freight business plan through 2021 in partnership with key Industry and Government stakeholders (Iarnród Éireann, 2020). Some of their roles include materials management for Cork Line relaying, reduction in single use plastics, targeting 80% of traction and utility electricity from renewable sources with greater consideration of Scope 3 emissions in the rail value chain (Iarnród Éireann, 2022).

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