ACWG
ALL COMPANY WORKING GROUP

The Regulators' Alliance for Progressing Infrastructure Development (RAPID) is a partnership between the three water regulators Ofwat, Environment Agency and Drinking Water Inspectorate, formed in 2019 to help accelerate the development of new water infrastructure and design future regulatory frameworks. RAPID was set up to identify and address issues relevant to the development of joint infrastructure projects and to analyse the feasibility of nationally strategic supply schemes. These Strategic Resource Options (SROs) are being developed by different water companies in partnership and are following RAPID's gated process to identify strategic water resource solutions to help meet the water needs of the future. The gated process relates to the funding of investigations and development of SROs from April 2020 until March 2024.

The All Company Working Group (ACWG) was set up to ensure that water companies with SROs were using a consistent approach where possible. The ACWG has commissioned a number of studies to identify where consistencies need to be made and how approaches can be aligned between different companies and SROs. A review of the approaches adopted across the SROs identified key areas in which consistency was needed, including cost, water quality, environmental assessments, deployable output, carbon and the design of schemes. The output reports from these studies are available for review on the WRSE website in the document library, and have been adopted by SROs and also by companies for their draft water resource management plans and the regional water resource planning groups.

In 2020, the Environment Agency published the first National Framework for Water Resources to transform how we plan future water supplies; requiring water companies and other large water users to collaborate across boundaries and develop plans that consider their region's water needs. These regional water resources plans should then fit together to provide a joined up national solution. There are five regional groups which together include all the water companies operating in England. Each regional group is producing a strategic water resources plan to assess the future need for water and identify the set of options that present the best value to customers, society and the environment to secure long-term resilience. In addition to the ACWG consistency reports, there are also regional planning related reports available to review on the WRSE website, including the reconciliation of regional plans reports (for both the emerging and draft regional plans) and a materiality paper regarding data changes through the gated process.

Any queries relating to the ACWG reports can be directed to contact@wrse.org.uk.

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ACWG Carbon Ambition

SRO low capital carbon alternatives

December 2022

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All Company Working Group (ACWG)

ACWG Carbon Ambition

SRO low capital carbon alternatives

December 2022

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Contents

Executive summary

The All Company Working Group (ACWG) commissioned Mott MacDonald to develop a methodology that identifies key capital carbon hotspots (and chemicals) for typical Strategic Resource Options (SRO) types and that assesses potential decarbonisation opportunities through building clever or building efficiently measures. This means alternative material or technology choices or construction practices.

It was agreed that build-nothing and build-less options in the PAS 2080 carbon reduction hierarchy (i.e. how to optimise resources through alternative design practices) are site specific and will have been considered through the earlier stages of the delivery process, as part of regional planning and design development stages. **The scope of this report focuses on capital carbon and chemicals (as well as replacement of membranes over time, for the case of desalination and wastewater reuse).**

The focus of the assessment is to model four typical SRO option types: Reservoirs, Pipeline transfers, Desalination, Wastewater reuse. To identify the decarbonisation potential of each SRO type, the following activities have been undertaken.

1. Complete a carbon estimate to identify carbon hotspots
2. Review with suppliers and technical experts mitigation opportunities for the each carbon hotspot
3. Estimate the level of reductions possible in three scenarios: worst case, middle case, and best case. Varying levels of decarbonisation are presented depending on when the schemes are delivered within the three time horizons being considered by WRSE (2025-2040, 2040-2060, 2060-2100).
4. The findings are presented in a Red/Amber/Green (RAG) scale (0-25% = red, 26%-75% = amber, 75%+ = green).

This summary shows the results assuming a ‘middle case’ is adopted. For all SROs, this requires proactive engagement with the supply chain, as many of the mitigation measures are outside the direct control of the Water Companies (e.g. the capital carbon within the materials being procured).

Reservoirs

For a reservoir SRO, carbon hotspot assessments identified earthworks as the primary source of emissions, accounting for over 90% of the capital carbon. These emissions are primarily due to diesel-powered construction plant on-site (16% of emissions), and quarrying/ HGV transport of imported material (41% and 36% of emissions respectively). For this reason, alternative fuels for construction plant have been investigated to understand the potential impact on reservoir SRO carbon emissions.

Four alternative fuels have been investigated: battery electric, hybrid electric vehicles, hydrotreated vegetable oil (HVO), and hydrogen. HVO and hydrogen provide the best opportunities for carbon savings, although both face constraints in today’s markets. For HVO, while it is used in construction plant, the supply of this fuel within the UK is a limiting factor. For hydrogen, both the vehicles and the supply of green and blue hydrogen need to advance.

Table 1-1 shows the summary of the recommended ‘middle case’ scenario.

Table 1-1: Service Reservoir SRO, Middle Case Summary

Time of construction	% capital carbon savings	Assumptions	Actions needed
2025-2040	62%	• 50% diesel-electric hybrid vehicles • 50% HVO vehicles	• Engage with the supply chain to ensure diesel-electric hybrid plant are used on site along with HVO powered plant • Discussion with suppliers of HVO could take place in the 5 years prior to construction to secure supply for the duration of construction
2040-2060	96%	• Hydrogen adopted across 100% of construction plant	• Engage with the supply chain to ensure hydrogen powered plant are used on site along with hydrogen powered HGVs for transport of materials to/from site
2060-2100	96%	• Hydrogen adopted across 100% of construction plant	• Engage with supply chain to confirm green hydrogen sourced from 100% renewables or blue hydrogen is available.

Notes: “Baseline” in this case is defined as a do nothing approach, whereby the reservoir is constructed with conventional plant used today (diesel).
*Note, these represent ‘well to wheel’ emissions, critically assuming that hydrogen used is Green hydrogen with 0 emissions.

Transfer Pipelines

For a transfer SRO, carbon hotspot assessments for medium diameter (DN800) and large diameter (1400/1800) identified the pipeline material as the primary source of emissions, accounting for over 70% of the capital carbon. These emissions are due to the burning of fossil fuels to provide the very high temperatures required in the iron and steel making process, process emissions associated with using carbon as a chemical reductant, and indirect emissions from electricity consumption.

Transportation, excavation, backfilling, and imported backfill are also a large source of emissions for the transfer SROs, accounting for an additional ~25% and ~10% of the capital carbon impact for the medium and large diameter examples. These emissions are primarily due to diesel-powered construction plant on-site, and quarrying/ transport of imported material.

Five alternative pipe materials have been investigated for medium diameter pipework, and three alternative pipe materials have been investigated for large diameter pipework. Plastic based pipe materials have lower carbon emissions than steel or ductile iron. However, all pipe materials are expected to reduce in embodied carbon as time progresses, due to substitutes in feedstocks, improvements in the manufacturing process, and lower carbon plant being used to produce aggregates and install pipelines.

Table 1-2 shows the summary of the recommended ‘middle case’ scenario for pipe transfers. While carbon savings are achieved simply by switching materials (as evidenced by reading down a column), Water Companies who have asset standards which specify a given pipe material can see carbon savings for a given pipe material by manufacturing process improvements and installation improvements (evidenced by reading across a row).

Table 1-2: Transfer pipeline SRO, Middle Case Summary

Diameter	*Pipeline option* –*	*2025-2040*	*2040-2060*	*2060-2100*	*Assumptions*
		*(% Reduction Against Baseline**)*			
Medium (up to DN800).	DI**	7%	39%	48%	• Increased deployment of stove flue or top gas recycling in most Blast Furnace-Basic Oxygen Furnace (BF-BOF) sites
	Steel	25%	60%	66%	• Rebuild of plants with advanced steel production technology

Diameter	***Pipeline option* –***	***2025-2040***	***2040-2060***	***2060-2100***	***Assumptions***
		*(% Reduction Against Baseline**)*			
					• Carbon intensity of imported material assumed to reduce with the adoption of low-carbon construction plant (reducing quarrying emissions)
	HPPE	24%	59%	77%	• Continued use of fossil fuel-based plastics
	MO-PVC	51%	82%	90%	• Heat and power required for refining and plastics production are supplied by 100% renewables
	GRP	53%	89%	94%	• Carbon intensity of imported material assumed to reduce with the adoption of low-carbon construction plant (reducing quarrying emissions)
Large (DN 1200 / 1400)	Steel**	9%	25%	36%	As above
	DI	-3%	20%	32%	As above
	GRP	71%	84%	91%	As above

Notes: *Carbon emissions include material capital carbon and installation capital carbon (includes variation in trench widths and backfill)
**"Baseline" in this case is defined as a do nothing approach, whereby the pipeline is constructed with conventional plant used today. For medium pipe diameters this is using DI which is considered typical for this pipe size. For large diameters this is using steel.
*** Bedding and surround are included in the pipeline options relevant to each type of material. The quantities of bedding are incorporated in the carbon models used for pipelines

Similar to the reservoir SROs, Water Companies can engage with the supply chain to promote lower carbon construction and haulage plant to reduce installation emissions. Pertaining to pipe materials, Water Companies can investigate whether standards can be modified to allow for lower carbon pipe materials. Communication of this 'change in standards' to pipe suppliers, could stimulate suppliers to invest in reducing embodied carbon so as to not lose out on market share.

Desalination and Reuse SROs

Desalination and water reuse SROs share common process technologies, equipment, consumables and ancillary asset components, resulting in similar carbon hotspots and decarbonisation opportunities. Both have been therefore analysed together. While the carbon hotspot analysis and decarbonisation opportunities focus on capital carbon emissions (for the construction of assets as well as emissions associated with membrane replacements), operational emissions from power consumption for these two SROs are important to understand. Utilising the government's projection of grid electricity decarbonisation, **if the first year of operation of either of these SROs is delayed until 2040, it would result in a 50-55% reduction in whole life carbon compared with operation beginning in 2025.**

Returning to capital carbon, the largest hotspots are buildings, tanks and foundations accounting for over 60% of capital carbon emissions. Pipelines also contribute 9% of capital carbon, and replacement of membranes and consumption of chemicals are also likely to contribute a large proportion to whole life emissions however it is recognised that more research is required to better understand the emissions from chemical manufacturing processes and associated emissions from complex supply chains in this sector.

Table 1.3 shows the summary of the recommended 'middle case' scenario for the desalination and reuse options.

Table 1.3: Desalination and Reuse SRO

Item	*Scenario*	*Construction before 2025*	*2025-2040*	*2040-2060*
		(% Reduction Against Baseline)		
Operational Carbon	Starts operation 2025 (This is the baseline case)	0%	-	-
	Starts operation on or after 2040	-	50-55% (against whole life carbon)	
Desal and Reuse Capital Carbon	Worst case	11%	19%	21%
	Mid case	11%	29%	35%
	Best case	25%	46%	61%

Notes: "Baseline" in this case is defined as a do nothing approach, whereby the desal plant is constructed with conventional plant used today, and put into operation in 2025. Operational carbon savings are shown against the whole life carbon of the project. Capital carbon savings are shown relative to the baseline capital carbon (emissions arising from power are omitted). Note: capital carbon also includes membrane replacements and chemical consumption over a 60 year operating lifespan.

While operational carbon emissions are simply a function of electrical grid factor decarbonising with time, capital carbon reductions arise from a multitude of sources. Some reductions may be harder than others, for example reducing emissions from tanks compared with buildings.

The largest emissions savings would arise from a operating the SROs further into the future when grid electricity has further decarbonised. The decision of when these schemes are delivered, however, will be driven by other priorities – such as availability of water, resilience, etc. Therefore, aside from delaying delivery of these SROs or having direct renewable energy (ie, embedded generation sources with private wire), Water Companies can focus efforts on reducing capital carbon.

Following the current industry pace, and with a good level of supply chain engagement, the middle case can be used as a likely trajectory for both desalination and reuse plants Achieving the 'middle case' in capital carbon would require:

- **Concrete**: Optimising current practice and technology, including fly ash from stockpiles and widespread adoption of mixes that use limestone powder, calcined clay, and/or volcanic ash as SCMs
- **Concrete long term**: Engage with supply chain to also adopt AACMs based on calcined clays or volcanic ash
- **Reinforcement Steel**: Maintain current levels of rebar recycling. Engage with supply chain to increase deployment of stove flue or top gas recycling in most BF-BOF sites. Rebuild of plants with advanced steel production technology
- **Membranes**: Work with and challenge suppliers to develop longer lasting composite plastic membranes.

If outperformance of the 'middle case' is desired progressing towards the best case, acceleration in any of the capital carbon hotspots (concrete, steel, buildings, or membranes) could be targeted. The greatest leverage point would be to accelerate decarbonisation of concrete, which would require close engagement with the supply chain to promote lower concrete alternatives as noted in the discussion section above.

It is important for water companies to have a more strategic engagement with chemicals suppliers, through Water UK or other industry bodies to better understand the manufacturing processes, global supply chain logistics as well as the potential to swap chemicals with lower carbon alternatives for any of the desal or reuse options. UKWIR has done a research project over the years on chemicals and greenhouse gas emissions however the sector's understanding needs to significantly improve.

Glossary / Abbreviations

Abbreviation	*Description*
AAM / AACM	alkali-activated materials / alkali-activated cementitious materials
ACWG	All Company Working Group (Mott MacDonald)
A1 to A5	Related to ‘cradle to gate’. A1 to A5 refers to the life cycle assessment stages, specifically A1 to A3 which is cradle to gate and encompasses producing a product, plus A4 and A5 which is the transportation of the product to site and the use of the product in construction.
Asset	A physical entity forming part of infrastructure that has potential or actual value to an organization and its stakeholders (PAS2080:2016)
Baseline	A scenario for what carbon emissions would have been in the absence of planned measures aiming to reduce emissions (PAS2080:2016)
BFRP	Basalt Fibre-Reinforced Polymer
Biofuel	Fuel derived from biomass
BF-BOF	Blast furnace-Basic oxygen furnace
Capital carbon	Greenhouse gas emissions that can be associated with the creation, refurbishment and end of life treatment of an asset (PAS2080:2016)
Carbon capture and storage (CCS) technology	Technologies associated with the direct capture carbon dioxide at its emission source, its transport and isolation (usually involving underground storage)
Carbon dioxide equivalent (CO2e)	Unit for comparing the radiative forcing of a greenhouse gas to carbon dioxide (PAS2080:2016)
Carbon hotspot	Elements of an SRO that are responsible for a significant proportion of emissions
Carbon management	The assessment, removal and reduction of GHG emissions during the delivery of new, or the management of existing, infrastructure assets and programmes (PAS2080:2016)
Carbon reduction	The process of minimising GHG emissions in the development of new infrastructure assets and programmes of work or the refurbishment of existing assets (PAS2080:2016)
Carbon sequestration	The process of capturing and storing atmospheric carbon dioxide
Cradle to gate	Refers to life cycle assessment stages A1 to A3, which encompasses the ecological impact of production of product.
DI	Ductile Iron
DN	Nominal diameter (e.g., DN800 = 800 nominal diameter)
EAF	Electric arc furnace: an industrial method for melting steel / iron using electricity
Emissions factor	The amount of greenhouse gases emitted, expressed as CO2e and relative to a unit of activity (PAS2080:2016)
GGBS	ground granulated blast-furnace slag
GFRP / GRP	Glass Fibre Reinforced Polymer / Glass reinforced polymer
GHG emissions	Greenhouse gas emissions – the total mass of GHGs released to the atmosphere over a specific period of time (PAS2080:2016)
Greenhouse gases (GHG)	Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth’s surface, the atmosphere, and clouds (PAS2080:2016)

HGV	Heavy Goods Vehicle
HPPE	High Performance Polyethylene
HVO	Hydrotreated Vegetable Oil – a lower carbon diesel fuel alternative
Hydrogen	Grey hydrogen: produced though Steam Methane Reforming. Blue hydrogen: same as grey hydrogen but with carbon capture and storage. Green hydrogen: produced using renewable electricity to split water using hydrolysis
MO-PVC	Molecularly Oriented- Polyvinylchloride
Operational carbon	Greenhouse gas emissions associated with the operation of infrastructure required to enable it to operate and deliver its service (PAS2080:2016)
PAS2080	Publicly Available Specification (PAS) developed from a preliminary draft prepared by a Technical Authoring Team from Mott Macdonald and Arup on carbon management in infrastructure
Product / Material supplier	An organization which extracts, manufactures, or produces materials or products for incorporation into works to construct, build or maintain an asset (PAS2080:2016)
RAG	Red, Amber, Green scale
RO	Reverse osmosis
SCM	Supplementary cementitious materials
SDR	Standard dimension ratio. Relates to the pipe wall thickness to the outside pipe diameter for plastic pipes.
Scope 1, 2, 3	Defined by the GHG accounting protocol, Scope 1 refers to emissions directly within a company's control, typically emissions from fuel combustion and process emissions. Scope 2 refers to indirect emissions from the generation of electricity used by the reporting company. Scope 3 refers to all other emissions outside the control of the company, notably embodied carbon of products purchased.
SRO	Strategic Resource Option
Tank to wheel	Emissions arising from burning the fuel in a vehicle (e.g. the Scope 1 emissions).
UF	Ultra-filtration
Well to wheel	Emissions arising from producing the fuel, transporting it to the vehicle, and burning it in the vehicle (e.g. Scope 1 and Scope 3 emissions)
Whole-life cycle carbon emissions	Sum of GHG emissions from all stages of the life cycle of a product or asset and within the specified system boundaries of the product or asset (PAS2080:2016)
WRSE	(Water Resources South East) - An alliance of the six water companies that cover the South East region of England

1 Introduction

The All Company Working Group (ACWG) identified that for the Strategic Resource Options (SRO) Gate 2 submissions it would not be realistic to have detailed cost and carbon estimates of the impacts of different mitigation options. This would be particularly challenging for capital (embodied) carbon and chemicals where not all companies have done detailed assessments or carbon data (especially for chemicals) is not very accurate in the industry.

The ACWG commissioned Mott MacDonald to develop a methodology that identifies key capital carbon hotspots (and chemicals) for typical SRO option types and that assesses potential decarbonisation opportunities through building clever or building efficiently measures. This means alternative material or technology choices or construction practices. It was agreed that build-nothing and build-less options in the PAS 2080 carbon reduction hierarchy (i.e. how to optimise resources through alternative design practices) are site specific and will have been considered through the earlier stages of the delivery process, as part of regional planning and design development stages.

The scope of the analysis focuses on capital carbon and chemicals (as well as replacement of membranes over time, for the case of desalination and wastewater reuse)

The focus of the assessment is to model four typical SRO option types. These are:

- Reservoirs
- Pipeline transfers
- Desalination
- Wastewater reuse

Each option model reflects typical asset sizes to illustrate the decarbonisation opportunities. Each company will have to tailor the models as part of their own detailed assessments to reflect their own projects and asset information.

2 Methodology

To estimate the decarbonisation potential of each SRO type, the following activities have been undertaken.

Task 1 - For each SRO option type (Reservoirs, Transfers, Desalination, Water Reuse), carbon hotspots have been identified by performing analysis on existing SRO carbon estimates. This analysis has been limited to one SRO project for each of the four SRO option types.

Task 2 – Having identified major carbon hotspots for each SRO option type, mitigation opportunities have been investigated through liaison with relevant technical experts and suppliers. This has informed an understanding of:

1. Current and future carbon reduction technologies/ techniques
2. Potential carbon reductions
3. Likely timescales

A range of potential scenarios have been developed for each technology within the three time horizons being considered by WRSE (2025-2040, 2040-2060, 2060-2100). These scenarios have been provided to address uncertainties associated with the viability of future technologies, their commercial readiness, and dependencies on sector-wide carbon transitions.

Task 3 – To estimate the potential carbon reduction for each SRO option type, analysis has been performed to model the various scenarios developed within task 2 and apply these to the underpinning carbon data within each carbon hotspot. From this, a Red/Amber/Green (RAG) scale has been produced for each technology/technique, based on its potential to reduce the carbon emissions of each SRO option type.

It is important to note that these analyses focussed on key hotspot contributors based on Gate 1 and 2 assessments; for reservoirs and transfer pipelines, this was largely dominated capital carbon emissions, whereas desal and reuse were found to have a broader mix of capital and operational contributors.

For reference, Scope 1 and 2 emissions refer to those in the direct control of the companies and designers delivering a project, with Scope 3 emissions being those outside of this direct control. In this report, Scope 1, 2 and 3 emissions are presented from the point of view of the asset owner.

3 Reservoirs

3.1 Carbon Hotspots

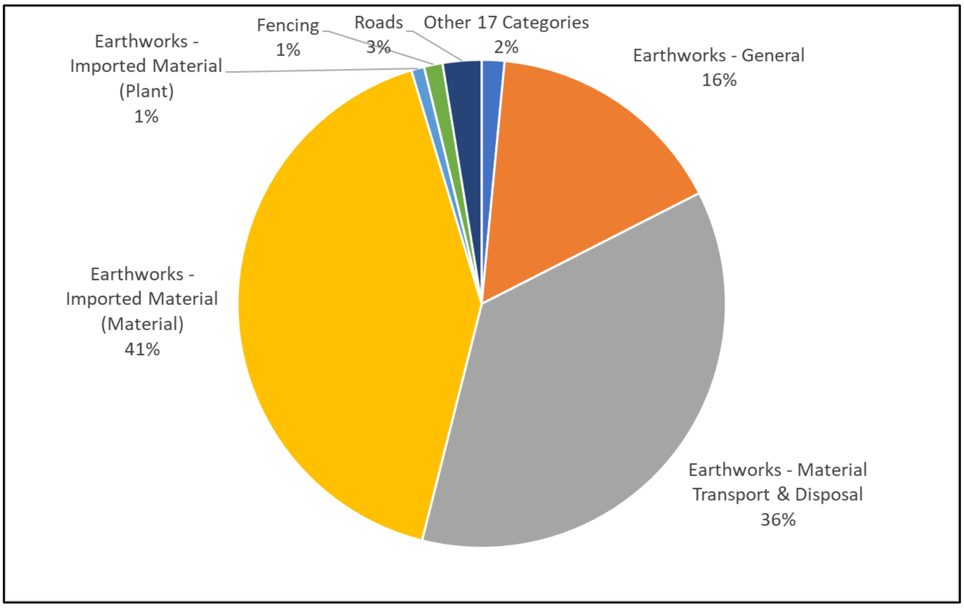
As summarised in Figure 3-1, hotspot analysis performed on existing carbon estimates for a reservoir SRO identified earthworks as the primary source of emissions, accounting for over 90% of the capital carbon impact for this SRO. The hotspot analysis and all carbon assessments in this section cover:

- Construction of the public water supply reservoir, including earthworks and haulage associated with on-site movements of earthworks and import/export of material on to site.
- Civil structures within the reservoir footprint, including draw-off towers, roads etc…

The assessment excludes major upstream and downstream infrastructure, such as raw water transfer pipelines, or water treatment works. It also excludes operational carbon.

These emissions are primarily due to diesel-powered construction plant on-site (16% of emissions), and quarrying/ HGV transport of imported material (41% and 36% of emissions respectively). For this reason, alternative fuels for construction plant have been investigated to understand the potential impact on reservoir SRO carbon emissions.

Figure 3-1: Reservoir SRO Capital Carbon Hotspots



3.2 Low Carbon Alternatives

The following alternative fuels have been investigated, to reduce the emissions associated with construction plant operating with diesel.

Battery Electric – Electrification of construction plant could deliver a large reduction in emissions when compared to diesel plant. The carbon emissions from electric plant are highly dependent on the carbon intensity of the energy grid, which is anticipated to fall to near zero over the period to 2050. However, this technology is currently limited to small plant (<5 tonnes)[1], and is likely to be unsuitable for the large construction plant associated with reservoir construction. It is therefore not considered further.

Hybrid – This technology reduces vehicle emissions by improving fuel efficiency and can deliver a moderate reduction in emissions. Diesel/ electric hybrid plant are widely available on the UK market at present, including for larger sized plant (up to ~21 tonnes)[1]. Future uses of this technology in conjunction with Hydrotreated Vegetable Oil (HVO) may deliver further carbon reductions.

Hydrotreated Vegetable Oil (HVO) – HVO is a biodiesel alternative which could deliver a large reduction in emissions when compared to mineral diesel. Currently the UK's supply of HVO is underdeveloped. Although construction plant technologies operating with HVO are available, the risk of a secure supply of HVO may limit its applicability nationwide.

Hydrogen – The use of hydrogen presents the opportunity to move to zero-emissions plant when considering 'tank to wheel' emissions. These are emissions associated with the combustion of fuels to power construction plant and do not consider the 'well to tank' emissions associated with producing the fuels themselves. This is particularly important for hydrogen as the 'well to tank' emissions are largely dependent on how the hydrogen is produced. At present, hydrogen is mainly produced though Steam Methane Reforming (grey hydrogen), however future production of hydrogen utilising this process plus carbon capture and storage (blue hydrogen) or producing hydrogen using electrolysis with renewable energy (green hydrogen) has the potential to reduce 'well to tank' carbon emissions from construction plant. Discussions with plant manufacturers (JCB and Komatsu) indicate that prototype large excavators (21T and 35T) and dozers are being developed and potentially available in the next 2 years. However, the nationwide applicability of fully hydrogen run construction plant in the UK will depend on how fast the hydrogen market will develop and be commercially viable.

A summary table of the above technologies is provided below:

Table 3-1: Insert Table Caption - Update fields via ribbon

Fuel Type	Vehicle Type	'Well to wheel' Carbon Savings[1]	Availability
Diesel	Conventional	0%[1]	Industry standard
Diesel	Hybrid	20%	Widely used up to 21 tonnes
HVO	Conventional	92%	HVO only available in limited supply. Vehicles available.
HVO	Hybrid	94%	
Green hydrogen	Hydrogen powered	100%[2]	Green hydrogen not currently available on the market. Vehicles not currently available.

Notes: 1-Carbon reduction refers to 'well to wheel' carbon emission savings, compared to a conventional diesel vehicle.
2-Assuming 100% renewable electricity is used.

Table 3-1 and engagement with construction plant suppliers has indicated that hydrogen is likely to offer the lowest carbon solution when considering the type and size of plant required for reservoir construction. Of particular note is that any form of hydrogen is unlikely to offer significant 'well to wheel' carbon reductions until:

1. Carbon Capture & Storage is developed, allowing the production of blue hydrogen, or green hydrogen from renewable energy is available on the market
2. Infrastructure is developed to distribute these fuels
3. Construction plant and HGVs are commercially available to run on hydrogen.

[1] From current discussions with plant manufacturer Komatsu

3.3 Scenarios

The decarbonisation potential of reservoir SROs is largely dependent on the transition to alternative fuel sources. Three scenarios have been developed to model the transition to alternative fuels over the three time horizons considered by WRSE. This results in nine different variants: for examples for the worst case scenario, there are three different delivery alternatives depending on whether the 8 year construction period occurs in the next 20 years, 40 years, or beyond 40 years from now. Table 3-2 provides a summary of the scenarios considered.

Results are presented in Figure 3.2, and show that savings in capital carbon emissions are driven by improvements in the earthworks, materials transport, and imported material categories. This is due to a reduction in 'tank to wheel' emissions, which are direct emissions from the plant and haulage vehicles themselves (Scope 1 emissions). Detailed discussion of the results is provided in the next section.

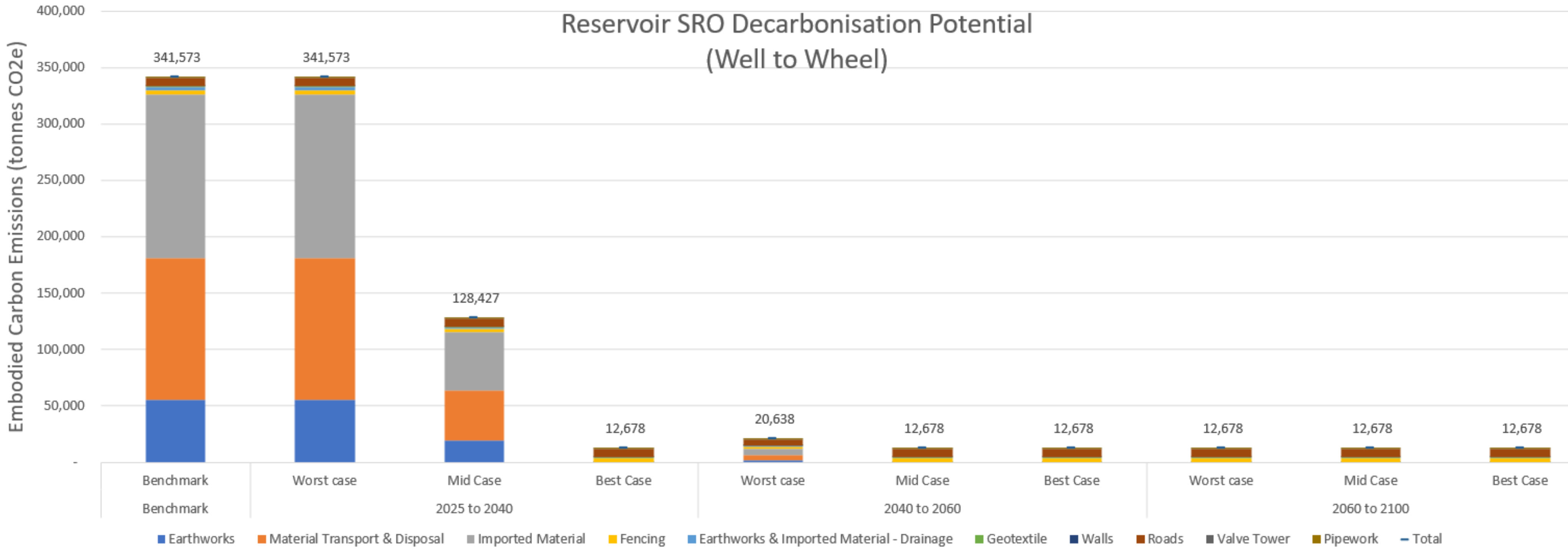
3.4 Scenarios & Decarbonisation Potential

Table 3-2: Summary of Scenarios

Scenario	Timeframe	Proportion of Fuels used Within Construction Plant			Comments
		Diesel	HVO	Green Hydrogen*	
Worst Case	2025	100%	-	-	• Continued supply limitations for HVO • Continued use of diesel plant
	2040	-	70% (+hybrid)	30%	• Transition to biofuels to hydrogen • Enhancements in biofuel technology, such as HVO/ electric hybrids
	2060	-	-	100%	• Hydrogen adopted across 100% of construction plant
Mid Case	2025	50% (+hybrid)	50%	-	• Easing of supply limitations and increased use of HVO • Continued use of diesel-hybrid plant to supplement supply due to some limitations of HVO supply
	2040	-	-	100%	• Hydrogen adopted across 100% of construction plant
	2060	-	-	100%	
Best Case	2025	-	-	100%	• Hydrogen adopted across 100% of construction plant
	2040	-	-	100%	
	2060	-	-	100%	

Notes: *Green hydrogen has been assumed here instead of blue hydrogen since the Carbon Capture Utilisation and Storage (CCUS) technologies are not certain when will be commercially available. Blue hydrogen can be assumed to have zero emissions.

Figure 3.2: Summary of Decarbonisation Potential (Well to Wheel)



3.5 Discussion

3.5.1 Scenario 1 – Worst Case

This scenario considers a slow hydrogen transition, whereby green hydrogen is adopted across all construction plant in the 2060-2100 time horizon. In this slow transition, the supply issues noted for HVO are assumed to remain the same, leading to a continued use of diesel within the immediate future (2025-2040), with a transition to hydrogen and biofuels such as HVO post-2040. In this scenario it is also assumed that the use of hybrid construction plant is widespread post 2040, and that this technology can be applied to HVO-powered construction plant.

As seen in Figure 3.2, the continued use of diesel plant does not provide a reduction in Reservoir SRO emissions if construction occurs from 2025-2040. Between 2040-2060, the Reservoir SRO emissions fall dramatically (by 96% against the baseline) due to the use of both hybrid-HVO plant and hydrogen plant used in earthworks and imported material. This is due to the low carbon intensity of HVO and zero emissions from Hydrogen. Between 2060-2100, the assumed widespread use of hydrogen eliminates all emissions associated with earthworks due to zero-emissions produced by burning hydrogen to power construction plant. This reduces the Reservoir SRO emissions by 96% against the baseline.

In comparison to the decarbonisation of HGV's discussed in Ofwat's guidance on long-term delivery strategies[2], this scenario aligns to Ofwat's 'slower technology scenario', with low-emission HGV's/fleets to only become standard by 2040. The analysis in this report has been driven by how the market is likely to respond to the three key time frames of WRSE regional planning options and therefore they are slightly offset from the 2030, 2035 and 2040 timeframes quoted in Ofwat's guidance.

3.5.2 Scenario 2 – Middle Case

This scenario considers a moderate hydrogen transition, whereby hydrogen is adopted across all construction plant in the 2040-2060 time horizon. In this moderate transition, between 2024-2040, the supply issues noted for HVO are assumed to ease, such that HVO can be utilised across half of all construction plant, with the use of diesel-electric hybrid construction plant to address the gap in supply.

As seen in Figure 3.2, the continued use of diesel to supplement the gap in HVO availability limits the SRO emissions reduction potential to 562% against the baseline between 2025-2040. Between 2040-2100, the assumed widespread use of hydrogen eliminates all emissions associated with earthworks due to zero-emissions produced by utilising hydrogen powered construction plant. This reduces the Reservoir SRO emissions by 96% against the baseline.

This scenario can again be mapped against Ofwat's guidance on long-term delivery strategies[2], falling somewhere in between their faster and slower technology scenarios for HGV's. Low-emission plant (hydrogen) is not expected by 2030 in this middle-case scenario, but a HVO hybrid is said to be in place as an interim.

3.5.3 Scenario 3 – Best Case

This scenario considers a rapid hydrogen transition, whereby hydrogen is adopted across all construction plant in the 2025-2040 time horizon. In this rapid transition, the widespread availability of hydrogen would eliminate all emissions associated with earthworks due to zero-emissions produced by utilising hydrogen powered construction plant. This reduces the Reservoir SRO emissions by 96% against the baseline. Note that this reduction considers the 'well to wheel' emissions to power the construction plant.

[2] *PR24 and beyond: Final guidance on long-term delivery strategies.* Ofwat. April 2022. Available: https://www.ofwat.gov.uk/wp-content/uploads/2022/04/PR24-and-beyond-Final-guidance-on-long-term-delivery-strategies_Pr24.pdf

Ofwat's guidance on long-term delivery strategies[2] predicts a 'faster technology scenario' to adopt low-emission HGVs by 2030, aligning to the best-case scenario discussed above seeing the widespread adaptation of hydrogen by 2030.

3.6 RAG Scale

A red/amber/green (RAG) scale has been produced of the overall capital emission savings as a summary (Table 3-3). The RAG scale can be broken down as follows:

- A 0-25% reduction against the baseline emissions is red
- A 26-75% reduction against the baseline emissions is amber
- A 75+% reduction against the baseline is green

Table 3-3: RAG scale for reservoir SROs

	% Reduction in total capital emissions		
Scenario	**2025-2040**	**2040-2060**	**2060-2100**
Worst Case	0%	94%	96%
Mid Case	62%	96%	96%
Best Case	96%	96%	96%

Notes: "Baseline" in this case is defined as a do nothing approach, whereby the reservoir is constructed with conventional plant used today.
*Note, these represent 'well to wheel' emissions, critically assuming that hydrogen used is Green or Blue hydrogen with 0 emissions

3.7 Recommendations for Gate 2 Application

When applying this analysis at the Gate 2 stage, the 'middle case' can be used as a guideline for the likely trajectory of future reservoir emissions, assuming a proactive level of targeted engagement with the supply chain. The analysis behind the middle case is based on the current industry pace, and would require the following:

- **If construction occurs before 2040 (e.g. 2032) convention diesel plant and conventional HGVs should not be used**. The water companies can engage with the supply chain to ensure diesel-electric hybrid plant are used on site along with HVO powered plant. To overcome current supply constraints, discussion with suppliers of HVO could take place in the 5 years prior to construction to secure supply for the duration of construction, for example committing to ordering specific volumes from the market in advance.
- **If construction occurs after 2040, hydrogen should be pursued as a first priority**. This is subject to green or blue hydrogen being readily available, which might require discussion and agreements with the supply chain years in advance to stimulate investment. It is expected that by this time hydrogen powered construction plant and HGVs will be available, but ongoing discussions with contractors may be required to ensure the plant is available at the same time as the fuel source is.

It is recognised that not all of the above actions are within the direct control of the Water Companies, and that markets need to change and shift. However, with industry often found waiting for demand to spur on investment in new technologies, large projects such as the reservoirs could be the catalyst needed to stimulate industry.

If outperformance of the ‘middle case’ is desired, a greater proportion of HVO could be used instead of diesel-electric hybrid, or greater stimulation of the hydrogen supply chain could take place to displace diesel-electric hybrid or HVO.

4 Transfer Pipelines

4.1 Carbon Hotspots

Two transfer SRO examples have been selected for analysis to understand the hotspots and decarbonisation potential across a range of transfer SRO sizes.

- A DN800 example has been selected to assess the decarbonisation potential of medium diameter transfer SROs. This is the upper limit of pipeline diameters where a large range of alternative pipe materials are available.
- A DN1400/1800 example has been selected to assess the decarbonisation potential of large diameter transfer SROs. Due to material properties, the range of pipeline materials available above DN800 are significantly limited.

Table 4-1 summarises the key baseline asset assumptions for both transfer SRO examples, with Figure 4-1 and Figure 4-2 summarising the hotspots within the medium and large diameter transfer SROs respectively.

Table 4-1: Transfer SRO Baseline Assumptions

Baseline Asset Assumption	DN800 SRO	DN1400/1800 SRO
Pipeline material	Ductile Iron	Steel
Pipeline length	21.5km	24km (DN1800) & 70km (DN1400)
Construction technique	Open cut	Open cut
Length of construction in road	15km	1km (DN1800) / 5km (DN1400)
Bedding in road	Imported bed only	Imported bed, surround and trench backfill
Road % of excavated material removed	38%	100%
Length of construction in Field	6.5km	23km (DN1800) / 65km (DN1400)
Bedding in field	Imported bed only	Imported bed and surround only
Field % of excavated material removed	38%	11%

The scope of the analysis includes:

- The transfer pipeline, covering A1-A5 emissions covering embodied carbon within the pipe materials and associated construction effort of installing the pipelines.
- Ancillary items, such as, valves, thrust restraints and washouts
- Crossings
- Allowance for kiosks and buildings

Notably, operational carbon is excluded.

As summarised in Figure 4-1 and Figure 4-2, hotspot analysis performed on existing carbon estimates for both example transfer SROs identified the pipeline material as the primary source of emissions, accounting for ~70% of the capital carbon impact for both SROs. These emissions are due to the burning of fossil fuels to provide the very high temperatures required in the iron and steel making process, process emissions associated with using carbon as a chemical reductant, and indirect emissions from electricity consumption.

Hotspot analysis has also identified the transportation, excavation, backfilling, and imported backfill as a large source of emissions for the transfer SRO, accounting for an additional ~25% and ~10% of the capital carbon impact for the DN800 and DN1400/DN1800 SRO examples. These emissions are primarily due to diesel-powered construction plant on-site, and quarrying/ transport of imported material.

As both of these activities account for over 80% of carbon emissions for both transfer SRO examples, alternative pipeline materials and their decarbonisation potential have been investigated, along with investigating the potential of alternative fuels for construction plant (previously discussed in Section 3).

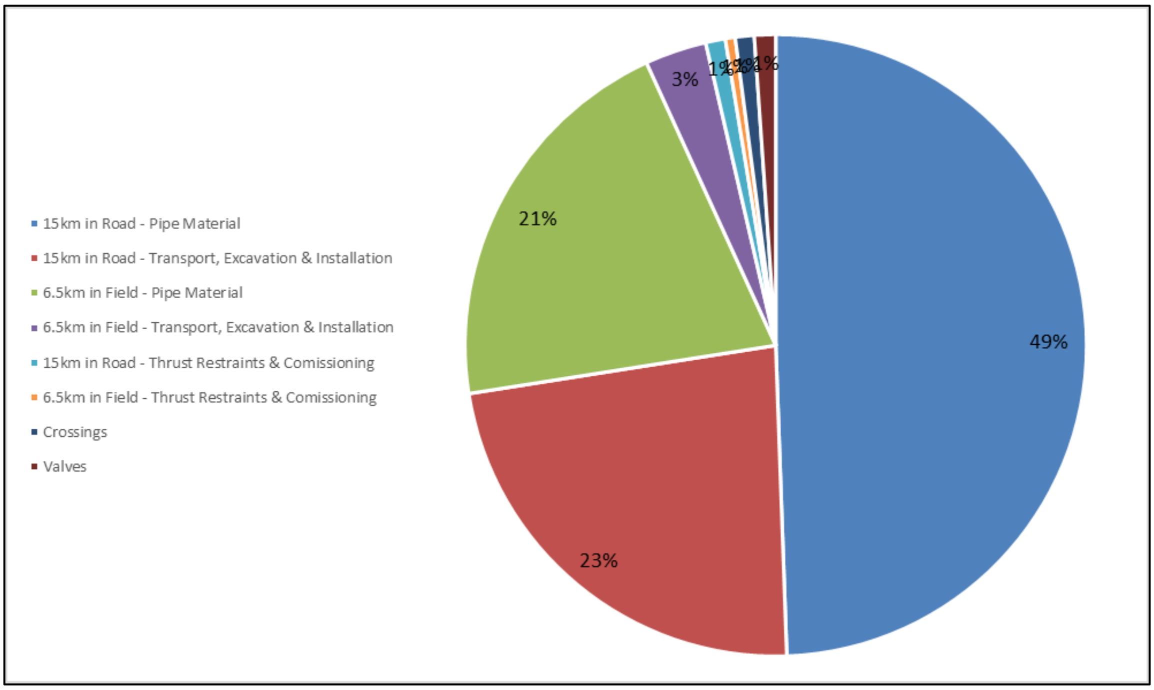


Figure 4-1: DN800 SRO Carbon Hotspots

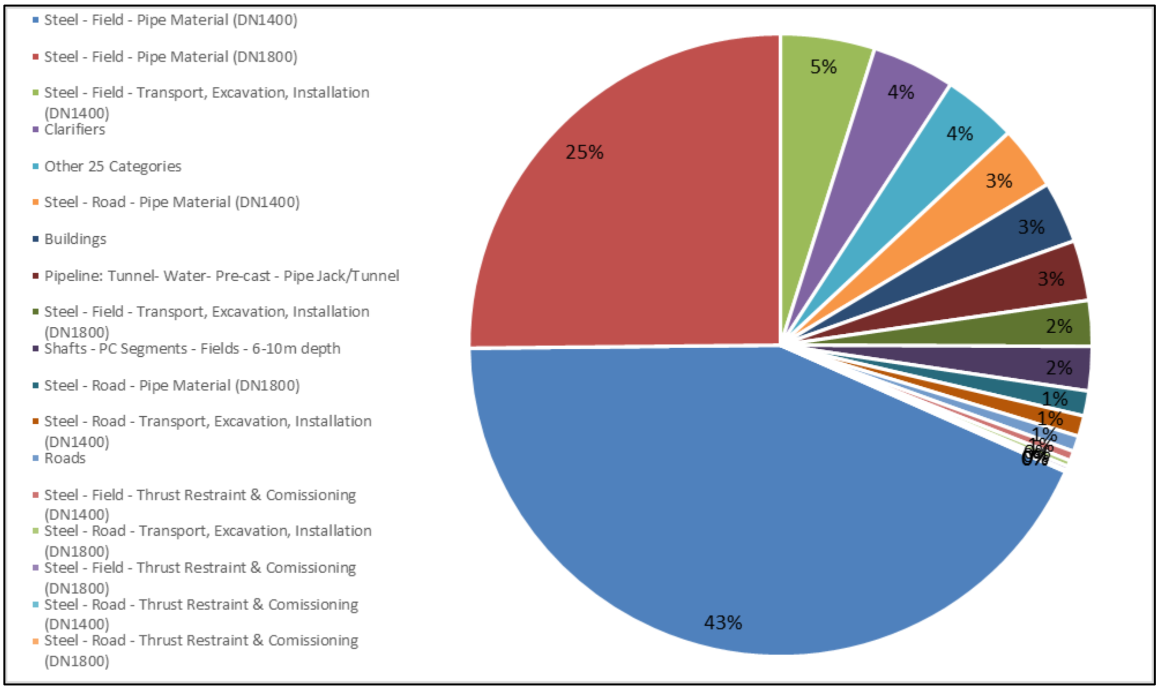


Figure 4-2: DN1400 / DN1800 Transfer SRO Carbon Hotspots

4.2 Low Carbon Alternatives

4.2.1 Pipeline Materials

As noted in Section 4.1, the pipeline material accounts for ~70% of capital carbon emissions for both transfer SROs assessed. Due to this, the following alternative pipeline materials have been investigated, to understand the current level of carbon reduction achievable if these materials were selected instead of ductile iron (shown in Figure 4-3). Further investigation and discussions with pipe manufacturers have also provided insight into how ductile iron, and alternative pipeline materials may decarbonise in the future.

Of note, asset lifespans and maintenance requirements are assumed to be the same among all pipe materials. At the time of writing the design lifespans of pipe material (e.g. between a steel pipe or HPPE pipe) are not considered to vary significantly, while the actual asset life of an installed pipeline varies with other aspects of installation (bedding/surround/size/location etc).

Similarly, different pipelines may require different backfilling requirements. As stated in Table 4-2 a variation of pipe bedding material has been allowed for between pipe types. Two types of backfill are considered: imported Type 1 or as-dug material, with proportions of imported fill varying based on pipe type, bedding, and location (in road or in field).

Ductile Iron (DI)– A conventional pipeline material, commercially available in the UK for a wide range of diameters up to ~2000mm. As noted with Section 4.1, the burning of fossil fuels and process emissions associated with iron and steel production result in a relatively high carbon intensity of ductile iron. This, in addition to the wall thicknesses required for transfer SRO applications (21mm), results in the highest carbon emissions per metre for a DN800 pipeline.

Steel – As with ductile iron, steel is also conventional pipeline material, commercially available in the UK for a wide range of diameters up to ~2000mm. Due to the additional stages required to produce steel from iron, steel is more carbon intensive than iron. However, due to its improved material properties compared to ductile iron, steel pipes can deliver the same performance with significantly smaller wall thicknesses (6.5mm – 8mm). This results in the carbon emissions of steel pipe being <u>~36% less</u> than ductile iron (per metre). Future decarbonisation of ductile iron and steel largely depend on the uptake of decarbonising technologies within the industry, as discussed in the following section.

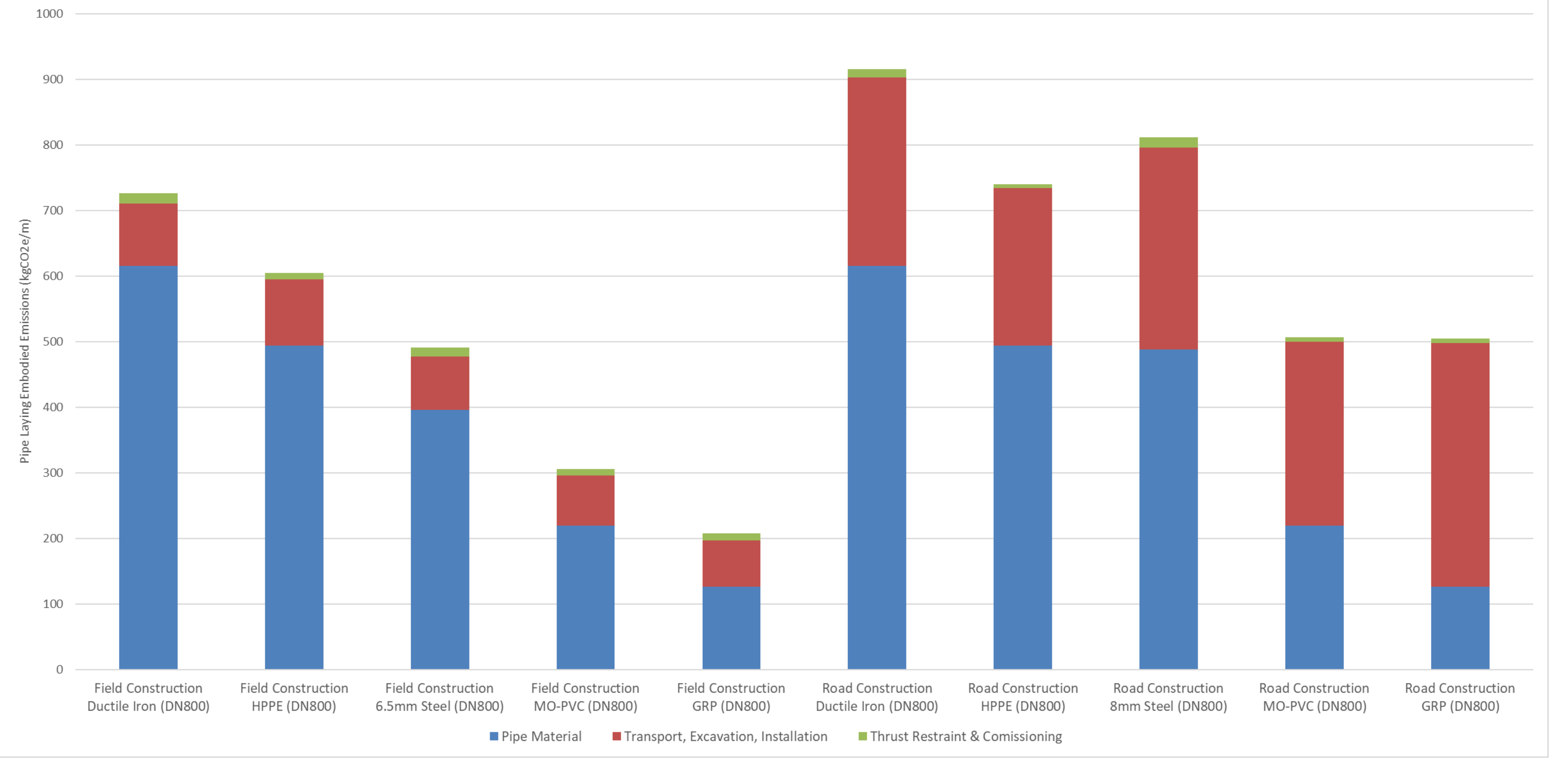
High Performance Polyethylene (HPPE) – A conventional pipeline material, commercially available in the UK. Assuming SDR11 pipework is required, HPPE is typically only supplied in diameters up to DN800 for water supply applications, which would make it unsuitable for larger transfer schemes. HPPE has a significantly lower carbon intensity than ductile iron (per unit volume). However, due to its material properties, HPPE requires a substantially higher wall thickness (73mm at DN800) when compared to all other materials considered, resulting in a <u>~20% reduction</u> in carbon emissions when compared to ductile iron (per metre). Polyethylene is originally derived from hydrocarbons (natural gas and crude oil), which requires process electricity and heat for production. Future decarbonisation of this material, in addition to other plastic pipe materials (GRP and MO-PVC noted below) will largely depend on the uptake of decarbonising technologies within the industry, as discussed in the following section.

Glass Reinforced Polymer (GRP) – Has been used historically within the UK, however, uncertainties surrounding maintenance and repairs have resulted GRP becoming an uncommon pipeline material choice and excluded in some company asset standards. GRP pipes are commercially available in the UK for a wide range of diameters up to ~2000mm. As with HPPE, GRP has a significantly lower carbon intensity than ductile iron (per unit volume). However, unlike HPPE, the material properties allow thinner wall thicknesses when compared to ductile iron (15mm at DN800), this results in the carbon emissions of GRP pipe being <u>~40% lower</u> than ductile iron.

Molecularly Oriented- Polyvinylchloride (MO-PVC)– Well established in European markets, with increasing popularity in the UK. MO-PVC pipes are commercially available within the UK, however, they are only available in diameters up to ~1200mm, making them unsuitable for larger transfer schemes. As with GRP, MO-PVC has a significantly lower carbon intensity (per unit volume) than ductile iron, and due to the material properties, allows a thinner wall thickness when compared to ductile iron (17.4mm at DN800), this results in the lowest carbon emissions per metre of pipe, being 64% lower than ductile iron.

Pipe material is typically selected based on anticipated loadings, material cost, ground conditions, operating pressures, and the strength of the combined pipe material and trench. When considering the suitability of the above pipe materials for transfer SRO applications, all materials can offer a solution for the DN800 example, whereas only ductile iron, steel and GRP are able to offer a solution for larger diameters.

Figure 4-3: Pipe Laying Emissions of Alternative Pipe Materials



Note: Asset lifespan does not vary between pipe material. Backfilling bedding class (included in the red bars above) varies between pipe material as listed in Table 4-2.

4.2.2 Construction Plant and Imported Material

As noted in Section 4.1, construction effort (including imported material) accounts for ~25% and ~10% of carbon emissions for the DN800 and DN1400/DN1800 transfer SROs. Decarbonising construction plant could offer a significant reduction in carbon emissions resulting from pipe laying activities (haulage, excavation, laying, backfill). In addition, low emissions construction plant is also assumed to lower the carbon intensity of imported backfill, as the carbon intensity of quarrying and transport also reduces.

Alternative low carbon fuels for construction plant has been discussed previously within Section 3.2, and for all transfer SRO scenarios noted in the following section, the decarbonisation of construction plant has been assumed to follow the middle case scenario summarised in Section 3.3.

4.2.3 Additional Items, Ancillaries & Commissioning

As seen in Figure 4-1, the remaining 5% of emissions are associated with ancillaries, thrust restraints and commissioning. Due to the low emissions these items contribute to the transfer SRO, these items have been excluded from analysis.

As seen in Figure 4-2, the remaining 20% of emissions is largely associated with a water treatment aspect of the transfer SRO, rather than the transfer pipeline itself. As the focus of this analysis is on the transfer pipeline itself, these items have been excluded from analysis.

4.3 Scenarios

The decarbonisation potential of transfer SRO pipework is largely dependent on the decarbonisation of the iron, steel, and plastics industries, and the transition to alternative fuel sources for construction plant.

Supplier engagement[3] and a literature review have been undertaken to understand the potential decarbonisation of the pipeline materials noted within Section 4.2.1. The carbon emissions for iron, steel, and plastic-based pipes are a result of the relatively carbon-intensive production processes.

The iron and steelmaking process requires significantly high temperatures, which is mainly provided by the burning of fossil fuels. This, in conjunction with the use of carbon as a chemical reductant, and indirect emissions from electricity consumption comprises the main sources of emissions for these materials. The potential to decarbonise these materials largely depends on the industry's uptake of carbon reduction technologies, such as:

- Energy efficiency and heat recovery
- Electrification or decarbonisation of heat
- Fuel and feedstock availability
- Carbon capture

Plastics are currently produced through refining crude oil and natural gas feedstocks. Extracting, flaring, venting, transporting and fugitive emissions resulting from the extraction of these feedstocks which are a significant source of emissions in the production process. This, in conjunction with the heat required for the refining process comprises the main sources of emissions for this material. The potential to decarbonise these materials largely depends on the industry's uptake of carbon reduction technologies, such as:

- Alternative feedstocks (such as bio-based plastics)
- Electrification or decarbonisation of heat

A range of scenarios have been developed to model the decarbonisation of the materials industries over the three time horizons considered by WRSE. The impact this has on transfer SRO carbon emissions is shown in the next section for a medium diameter (DN800) and large diameter (DN1800) transfer SRO[4].

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[3] Peak Pipe Systems (HPPE pipe supplier) and Amiblu (GRP pipe supplier)

[4] A validated carbon model including trench dimensions and backfill requirements for GRP is currently unavailable, the carbon emissions from GRP for the large diameter example presented within Figure 4-5, Figure 4-7, and Figure 4-9, therefore assume similar trench conditions to steel

It is important to note that the analysis of the large diameter pipelines (Figure 4-5, Figure 4-7, and Figure 4-9) can be applied to an entire transfer project, whereas Figure 4-4, Figure 4-6, and Figure 4-8 are only to be applied to the pipeline install.

Table 4-2: Summary of Pipeline Materials and Scenarios

Scenario	Material Industry	Decarbonisation of Pipe Material	Pipe Material	Pipe Trench Information
Worst Case	Iron & Steel I[5]	• Existing trends in energy efficiency and decarbonisation continue • Major options including stove flue gas recycling and steam or power plant upgrades	Ductile Iron	• Open Cut • Minimal use of imported backfill material for pipe surround due to material strength, as dug material for rest of backfill
			Steel	• Open Cut • Imported pipe surround for field installation and full trench for road installation
	Plastics[6]	• Continued use of fossil fuel-based plastics • Improved recycling of plastic	HPPE SDR11	• Open Cut • No requirement for imported backfill in road or field
			GRP	• Open Cut • Imported pipe surround for field installation and full trench for road installation
			MO-PVC	• Open Cut • Imported pipe surround for field installation and full trench for road installation
Middle Case	Iron & Steel[4]	• Increased deployment of stove flue or top gas recycling in most Blast Furnace-Basic Oxygen Furnace (BF-BOF) sites • Rebuild of plants with advanced steel production technology	Ductile Iron	• No alternative installation techniques considered due to pipe installation requirements • No alternative trench properties due to design limitations governing trench properties • Carbon intensity of imported material assumed to reduce with the adoption of low-carbon construction plant (reducing quarrying emissions)
			Steel	As above
	Plastics[5]	• Continued use of fossil fuel-based plastics • Heat and power required for refining and plastics production are supplied by 100% renewables	HPPE	As above
			GRP	As above
			MO-PVC	As above
Best Case	Iron & Steel[4]	• Half of existing BF-BOF sites have been rebuilt using advanced technologies and integrated carbon capture • The other half of existing sites have been retrofitted with carbon capture	Ductile Iron	As above
			Steel	As above
	Plastics[5]	• Use of bio-based plastics	HPPE	As above
			GRP	As above

[5] Scenarios obtained from the Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050, commissioned by the DECC and BIS in 2015. Analysis assumes that the carbon intensity of iron and steel products would reduce by a similar percentage as the industry as a whole

[6] Scenarios based on the academic paper ''Strategies to reduce the global carbon footprint of plastics' Analysis assumes that the carbon intensity of plastic products would reduce by a similar percentage as the industry as a whole

Scenario	Material Industry	Decarbonisation of Pipe Material	Pipe Material	Pipe Trench Information
		• Heat and power required for refining and plastics production are supplied by 100% renewables	MO-PVC	As above

4.4 Decarbonisation Potential

4.4.1 Analysis Results (Worst Case)

Figure 4-4: Decarbonisation of Pipeline Materials Medium Diameter (Worst Case)

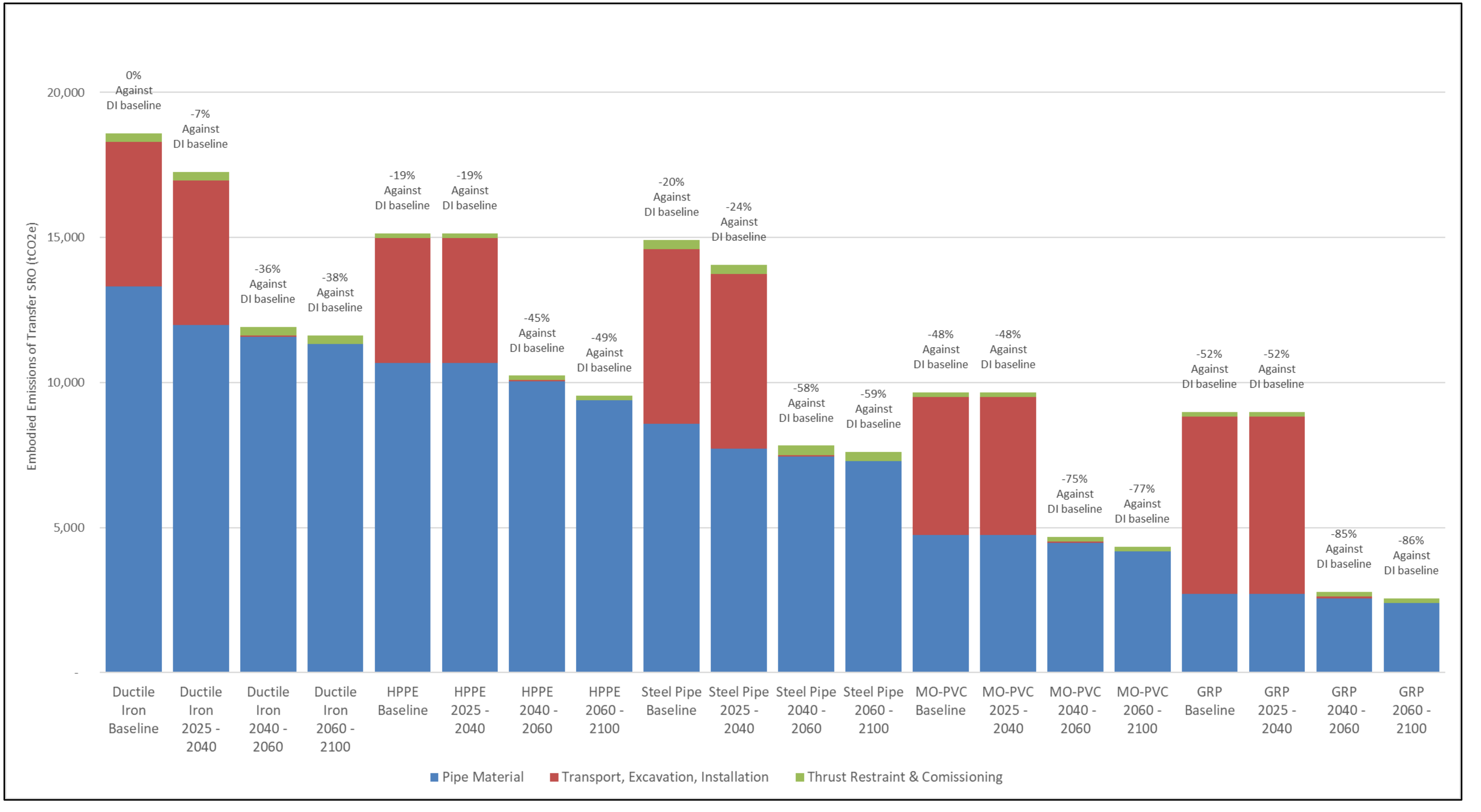

Table 4-3: Worst Case Emissions Summary (DN800 SRO)

SRO	Baseline Material	Baseline Pipe Material Emissions (tCO2e)	Baseline Plant Emissions (tCO2e)	Year	Pipe Material	Pipe Material Emissions (tCO2e) & Reduction vs Baseline (%)	Plant Emissions (tCO2e) & Reduction vs Baseline (%)
DN800	Ductile Iron	13,320	4,970	Today	Ductile Iron	13,320 (0%)	4,970 (0%)
					HPPE	10,680 (-20%)	4,300 (-13%)
					Steel	8,560 (-36%)	6,020 (+21%)
					MO-PVC	4,750 (-64%)	4,740 (-5%)
					GRP	2,720 (-80%)	6,100 (+23%)
				2025-2040	Ductile Iron	11,990 (-10%)	4,970 (0%)
					HPPE	10,680 (-20%)	4,300 (-13%)
					Steel	7,710 (-42%)	6,020 (+21%)
					MO-PVC	4,750 (-64%)	4,740 (-5%)
					GRP	2,720 (-80%)	6,100 (+23%)
				2040-2060	Ductile Iron	11,570 (-13%)	50 (-99%)
					HPPE	10,040 (-25%)	40 (-99%)
					Steel	7,440 (-44%)	60 (-99%)
					MO-PVC	4,470 (-66%)	50 (-99%)
					GRP	2,560 (-81%)	60 (-99%)
				2060-2100	Ductile Iron	11,320 (-15%)	(-100%)
					HPPE	9,400 (-29%)	(-100%)
					Steel	7,280 (-45%)	(-100%)
					MO-PVC	4,180 (-69%)	(-100%)
					GRP	2,390 (-82%)	(-100%)

Notes: Reduction percentages are shown against the baseline emissions for that component of the pipeline. E.g. A plant emissions % reduction (right column) is comparing the new plant emissions (right column) against the baseline plant emissions (fourth column).
‘Pipe material emissions’ refer to the emissions solely for the pipe material. ‘Plant emissions’ refers to all other emissions associated with installation of the pipe, including excavation, imported fill, and installation.

Figure 4-5: Decarbonisation of Pipeline Materials Large Diameter (Worst Case)

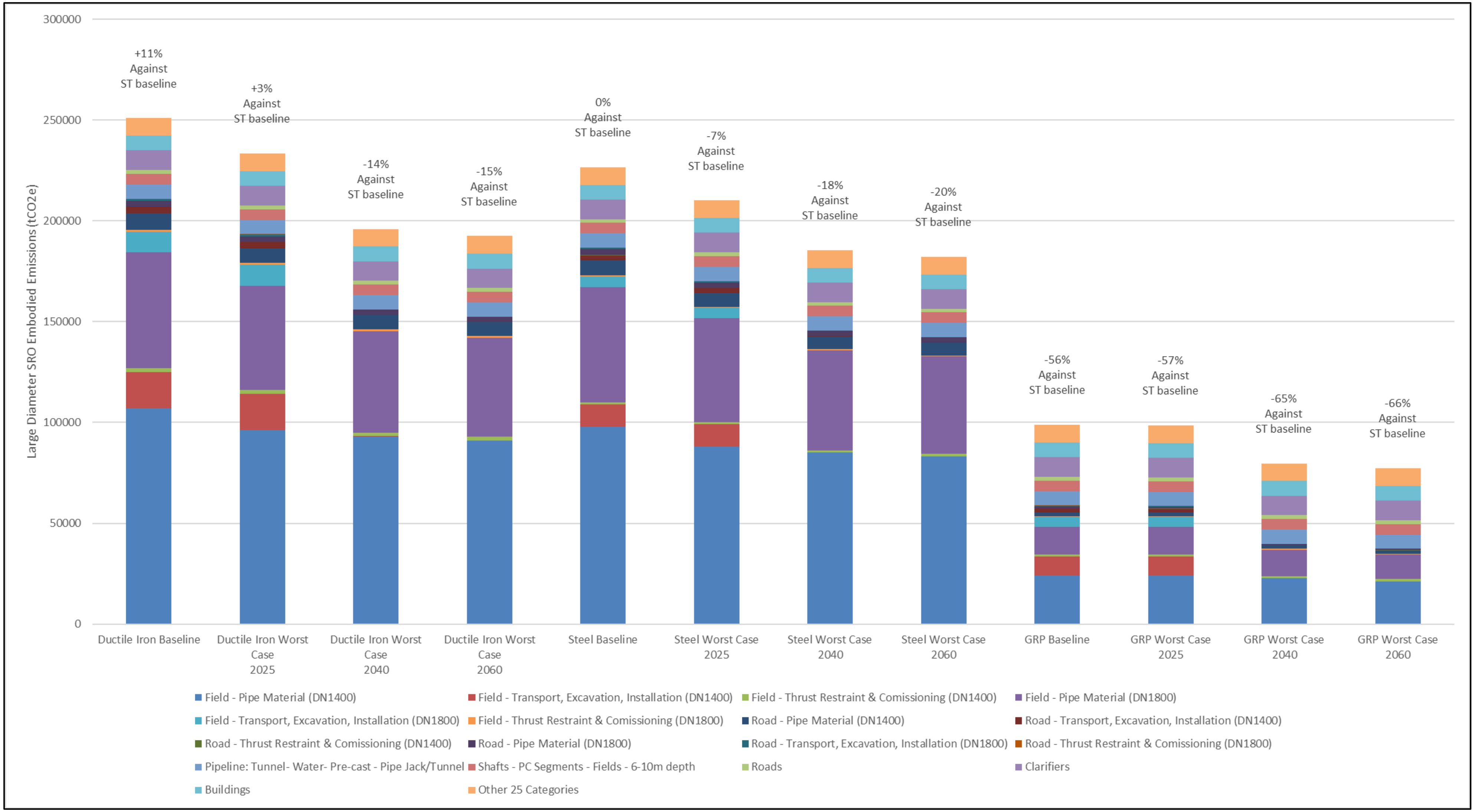

Table 4-4: Worst Case Emissions Summary (DN1400/ 1800 SRO)

SRO	Baseline Material	Baseline Pipe Material Emissions (tCO2e)	Baseline Plant Emissions (tCO2e)	Year	Pipe Material	Pipe Emissions (tCO2e) & Reduction vs Baseline (%)	Plant Emissions (tCO2e) & Reduction vs Baseline (%)
DN1400 / DN1800	Steel	165,320	19,620	Today	Steel	165,320 (0%)	19,620 (0%)
					Ductile Iron	175,850 (+6%)	32,130 (+64%)
					GRP	40,440 (-76%)	16,590 (-15%)
				2025-2040	Steel	148,790 (-10%)	19,620 (0%)
					Ductile Iron	158,270 (-4%)	32,130 (+64%)
					GRP	40,180 (-76%)	16,590 (-15%)
				2040-2060	Steel	143,570 (-13%)	200 (-99%)
					Ductile Iron	152,710 (-8%)	320 (-98%)
					GRP	37,830 (-77%)	170 (-99%)
				2060-2100	Steel	140,520 (-15%)	(-100%)
					Ductile Iron	149,470 (-10%)	(-100%)
					GRP	35,510 (-79%)	(-100%)

Notes: Reduction percentages are shown against the baseline emissions for that component of the pipeline. E.g. A plant emissions % reduction (right column) is comparing the new plant emissions (right column) against the baseline plant emissions (fourth column).
'Pipe material emissions' refer to the emissions solely for the pipe material. 'Plant emissions' refers to all other emissions associated with installation of the pipe, including excavation, imported fill, and installation.

4.4.2 Analysis Results (Middle Case)

Figure 4-6: Decarbonisation of Pipeline Materials Medium Diameter (Middle Case)

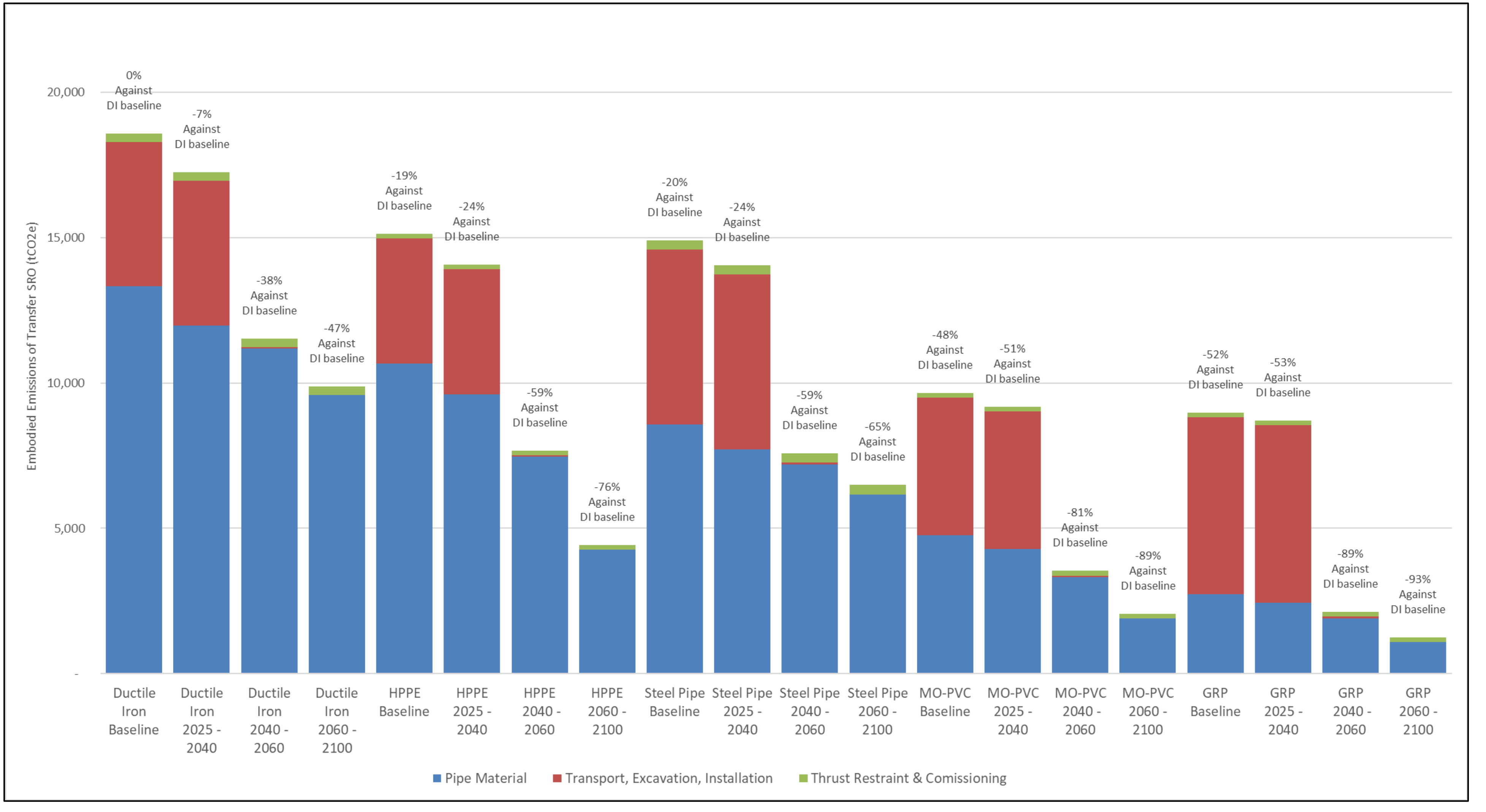

Table 4-5: Middle Case Emissions Summary (DN800 SRO)

SRO	Baseline Material	Baseline Pipe Material Emissions (tCO2e)	Baseline Plant Emissions (tCO2e)	Year	Pipe Material	Pipe Material Emissions (tCO2e) & Reduction vs Baseline (%)	Plant Emissions (tCO2e) & Reduction vs Baseline (%)
DN800	Ductile Iron	13,320	4,970	Today	Ductile Iron	13,320 (0%)	4,970 (0%)
					HPPE	10,680 (-20%)	4,300 (-13%)
					Steel	8,560 (-36%)	6,020 (+21%)
					MO-PVC	4,750 (-64%)	4,740 (-5%)
					GRP	2,720 (-80%)	6,100 (+23%)
				2025-2040	Ductile Iron	11,990 (-10%)	4,970 (0%)
					HPPE	9,610 (-28%)	4,300 (-13%)
					Steel	7,710 (-42%)	6,020 (+21%)
					MO-PVC	4,280 (-68%)	4,740 (-5%)
					GRP	2,450 (-82%)	6,100 (+23%)
				2040-2060	Ductile Iron	11,190 (-16%)	50 (-99%)
					HPPE	7,480 (-44%)	40 (-99%)
					Steel	7,190 (-46%)	60 (-99%)
					MO-PVC	3,330 (-75%)	50 (-99%)
					GRP	1,900 (-86%)	60 (-99%)
				2060-2100	Ductile Iron	9,590 (-28%)	(-100%)
					HPPE	4,270 (-68%)	(-100%)
					Steel	6,170 (-54%)	(-100%)
					MO-PVC	1,900 (-86%)	(-100%)
					GRP	1,090 (-92%)	(-100%)

Notes: Reduction percentages are shown against the baseline emissions for that component of the pipeline. E.g. A plant emissions % reduction (right column) is comparing the new plant emissions (right column) against the baseline plant emissions (fourth column).
'Pipe material emissions' refer to the emissions solely for the pipe material. 'Plant emissions' refers to all other emissions associated with installation of the pipe, including excavation, imported fill, and installation.

Figure 4-7: Decarbonisation of Pipeline Materials Large Diameter (Middle Case)

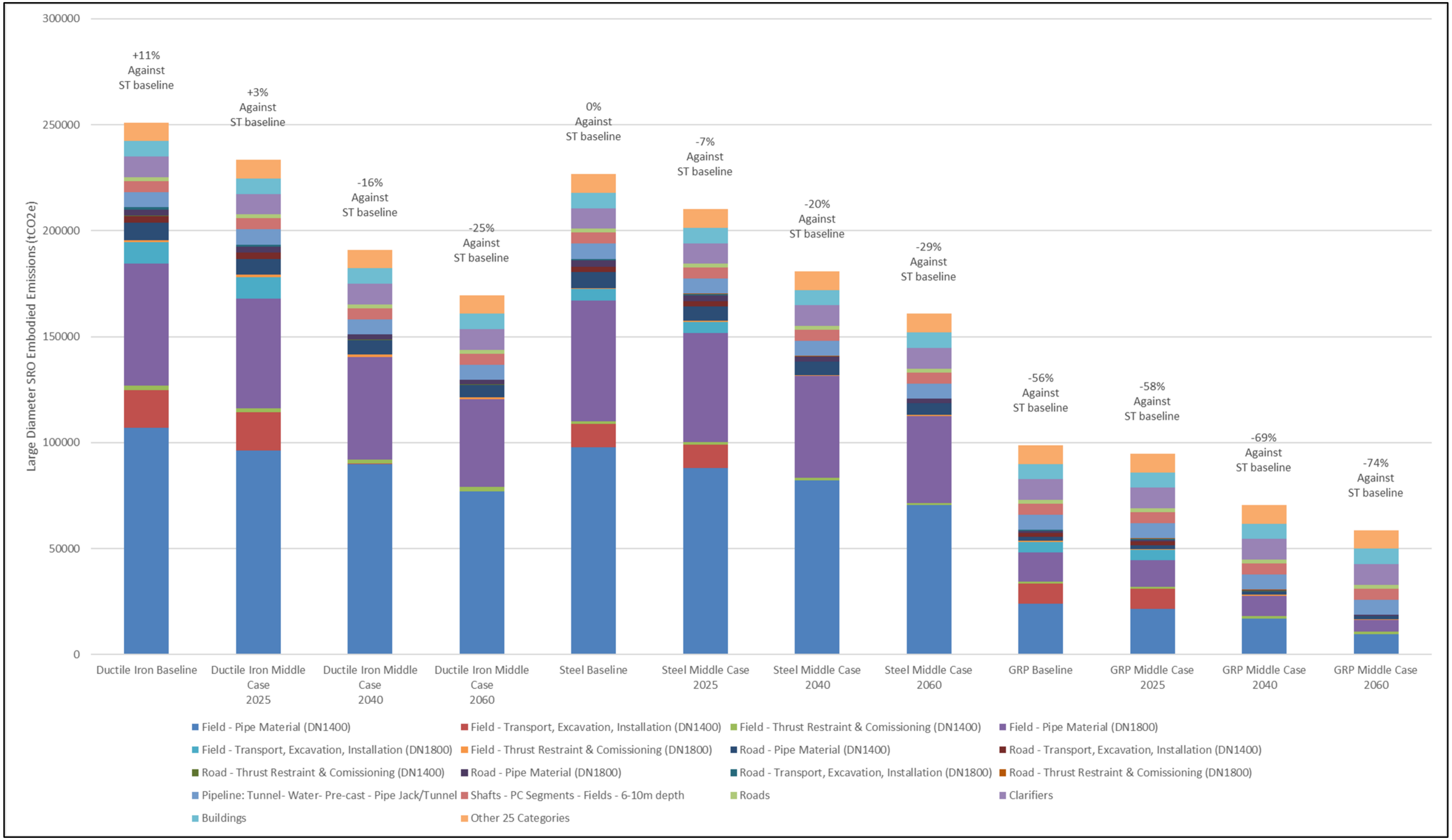

Table 4-6: Middle Case Emissions Summary (DN1400/ DN1800 SRO)

SRO	Baseline Material	Baseline Pipe Material Emissions (tCO2e)	Baseline Plant Emissions (tCO2e)	Year	Pipe Material	Pipe Emissions (tCO2e) & Reduction vs Baseline (%)	Plant Emissions (tCO2e) & Reduction vs Baseline (%)
DN1400 / DN1800	Steel	165,320	19,620	Today	Steel	165,320 (0%)	19,620 (0%)
					Ductile Iron	175,850 (+6%)	32,130 (+64%)
					GRP	40,440 (-76%)	16,590 (-15%)
				2025-2040	Steel	148,790 (-10%)	19,620 (0%)
					Ductile Iron	158,270 (-4%)	32,130 (+64%)
					GRP	36,390 (-78%)	16,590 (-15%)
				2040-2060	Steel	138,870 (-16%)	200 (-99%)
					Ductile Iron	147,710 (-11%)	320 (-98%)
					GRP	28,660 (-83%)	170 (-99%)
				2060-2100	Steel	119,030 (-28%)	(-100%)
					Ductile Iron	126,610 (-23%)	(-100%)
					GRP	16,990 (-90%)	(-100%)

Notes: Reduction percentages are shown against the baseline emissions for that component of the pipeline. E.g. A plant emissions % reduction (right column) is comparing the new plant emissions (right column) against the baseline plant emissions (fourth column).
'Pipe material emissions' refer to the emissions solely for the pipe material. 'Plant emissions' refers to all other emissions associated with installation of the pipe, including excavation, imported fill, and installation.

4.4.3 Analysis Results (Best Case)

Figure 4-8: Decarbonisation of Pipeline Materials Medium Diameter (Best Case)

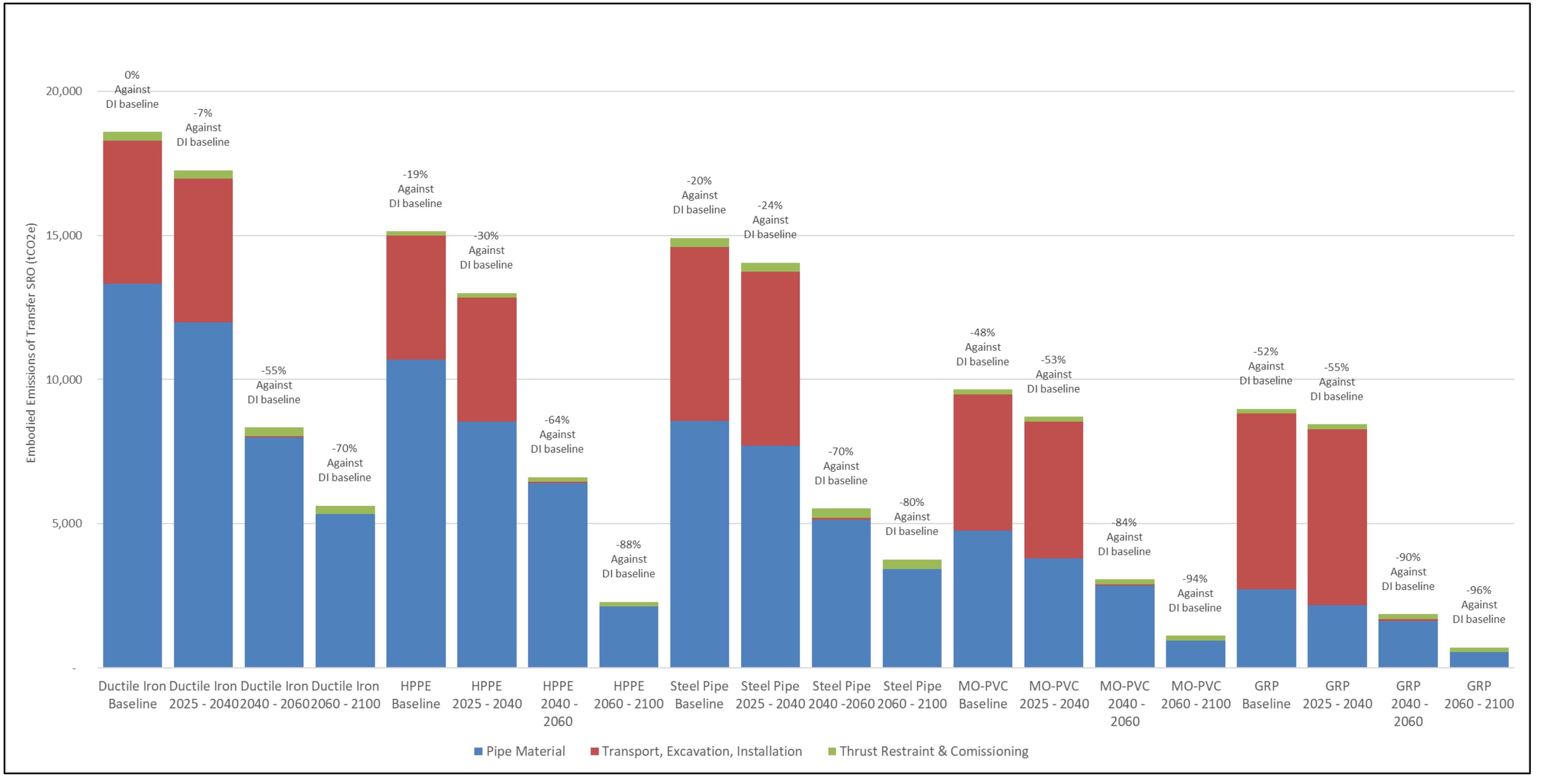

Table 4-7: Best Case Emissions Summary (DN800 SRO)

SRO	Baseline Material	Baseline Pipe Material Emissions (tCO2e)	Baseline Plant Emissions (tCO2e)	Year	Pipe Material	Pipe Material Emissions (tCO2e) & Reduction vs Baseline (%)	Plant Emissions (tCO2e) & Reduction vs Baseline (%)
DN800	Ductile Iron	13,320	4,970	Today	Ductile Iron	13,320 (0%)	4,970 (0%)
					HPPE	10,680 (-20%)	4,300 (-13%)
					Steel	8,560 (-36%)	6,020 (+21%)
					MO-PVC	4,750 (-64%)	4,740 (-5%)
					GRP	2,720 (-80%)	6,100 (+23%)
				2025-2040	Ductile Iron	11,990 (-10%)	4,970 (0%)
					HPPE	8,540 (-36%)	4,300 (-13%)
					Steel	7,710 (-42%)	6,020 (+21%)
					MO-PVC	3,800 (-71%)	4,740 (-5%)
					GRP	2,180 (-84%)	6,100 (+23%)
				2040-2060	Ductile Iron	7,990 (-40%)	50 (-99%)
					HPPE	6,410 (-52%)	40 (-99%)
					Steel	5,140 (-61%)	60 (-99%)
					MO-PVC	2,850 (-79%)	50 (-99%)
					GRP	1,630 (-88%)	60 (-99%)
				2060-2100	Ductile Iron	5,330 (-60%)	(-100%)
					HPPE	2,140 (-84%)	(-100%)
					Steel	3,430 (-74%)	(-100%)
					MO-PVC	950 (-93%)	(-100%)
					GRP	540 (-96%)	(-100%)

Notes: Reduction percentages are shown against the baseline emissions for that component of the pipeline. E.g. A plant emissions % reduction (right column) is comparing the new plant emissions (right column) against the baseline plant emissions (fourth column).
'Pipe material emissions' refer to the emissions solely for the pipe material. 'Plant emissions' refers to all other emissions associated with installation of the pipe, including excavation, imported fill, and installation.

Figure 4-9: Decarbonisation of Pipeline Materials Large Diameter (Best Case)

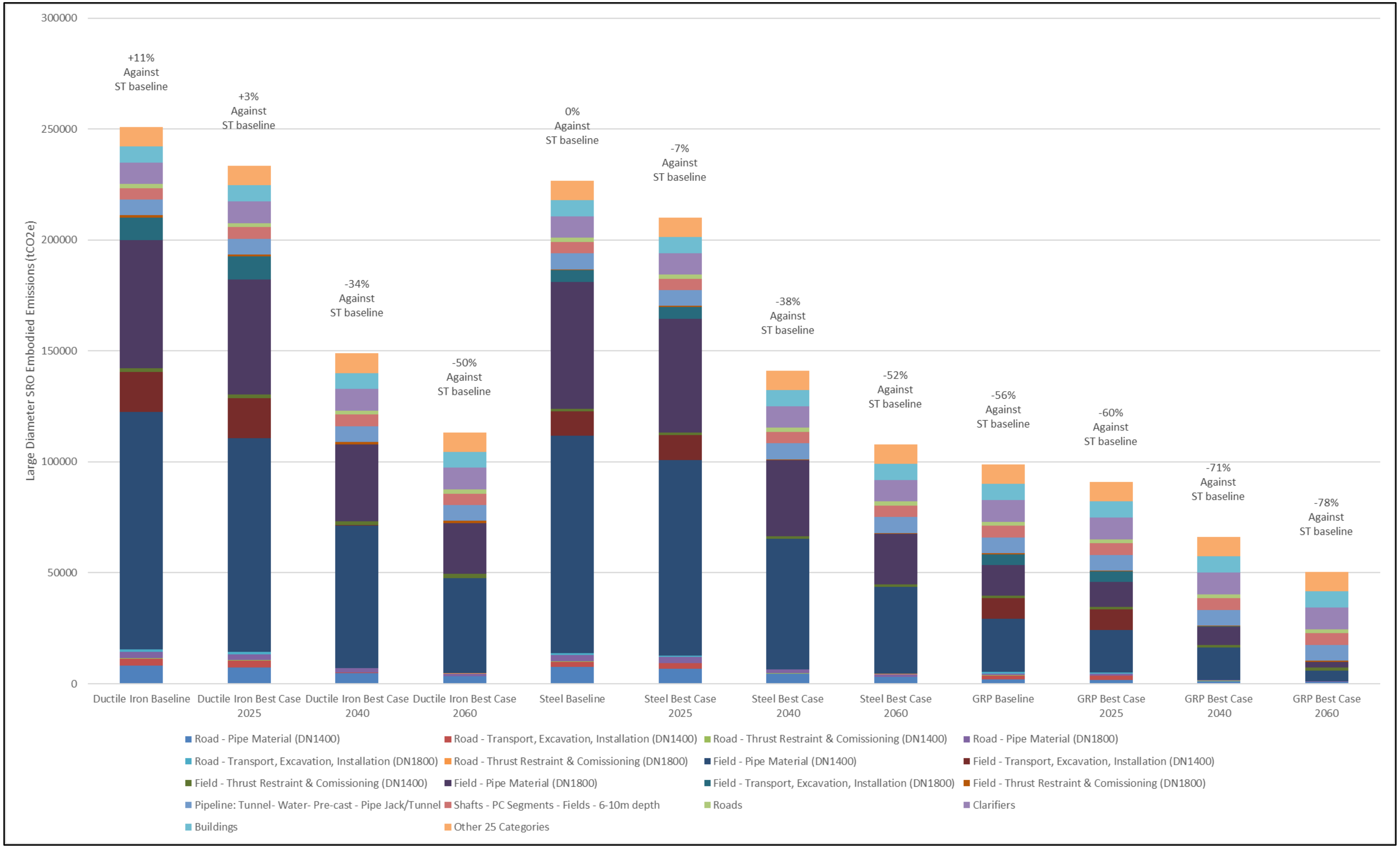

Table 4-8: Best Case Emissions Summary (DN1400/ DN1800 SRO)

SRO	Baseline Material	Baseline Pipe Material Emissions (tCO2e)	Baseline Plant Emissions (tCO2e)	Year	Pipe Material	Pipe Emissions (tCO2e) & Reduction vs Baseline (%)	Plant Emissions (tCO2e) & Reduction vs Baseline (%)
DN1400 / DN1800	Steel	165,320	19,620	Today	Steel	165,320 (0%)	19,620 (0%)
					Ductile Iron	175,850 (+6%)	(-100%)
					GRP	40,440 (-76%)	(-100%)
				2025-2040	Steel	148,790 (-10%)	19,620 (0%)
					Ductile Iron	158,270 (-4%)	(-100%)
					GRP	32,610 (-80%)	(-100%)
				2040-2060	Steel	99,190 (-40%)	200 (-99%)
					Ductile Iron	105,510 (-36%)	(-100%)
					GRP	24,260 (-85%)	(-100%)
				2060-2100	Steel	66,130 (-60%)	(-100%)
					Ductile Iron	70,340 (-57%)	(-100%)
					GRP	8,600 (-95%)	(-100%)

Notes: Reduction percentages are shown against the baseline emissions for that component of the pipeline. E.g. A plant emissions % reduction (right column) is comparing the new plant emissions (right column) against the baseline plant emissions (fourth column).
‘Pipe material emissions’ refer to the emissions solely for the pipe material. ‘Plant emissions’ refers to all other emissions associated with installation of the pipe, including excavation, imported fill, and installation.

4.5 Discussion

4.5.1.1 Worst Case Scenario

Initial engagement with pipeline manufacturers[7] has indicated that their current decarbonisation efforts are mainly focussed on reducing their Scope 1 and 2 emissions associated with pipe manufacturing. Some suppliers are maintaining a close dialogue with their supply chain to identify more sustainable raw materials, thereby influencing, and reducing Scope 3 emissions, which account for the largest proportion of capital carbon for pipelines (over 80% for GRP)[8].

This worst-case scenario considers a landscape whereby pipe manufacturers do not change their procurement routes for raw materials (fossil-based plastics, and Blast furnace-basic oxygen furnace (BF-BOF) production of iron and steel). The decarbonisation of pipe products is therefore limited to the ambitions and decarbonisation potential within the current raw material industries. In this worst-case scenario, these ambitions are assumed to be modest, with a focus on process efficiency and recycling.

Most pipe materials other than ductile iron require additional imported backfill, which increases construction effort emissions. However, as seen Figure 4-4 and Figure 4-5, ductile iron still results in the largest capital carbon of all pipe materials considered. This is due to the substantially higher carbon intensity of ductile iron pipework and the smaller carbon benefit associated with backfilling with less imported material (as seen in Table 4-3 and Table 4-4).

As low emissions plant is adopted in future time horizons, the carbon intensity of construction effort and imported backfill decreases. This reduces the impact that trench construction and composition have on the overall carbon intensity of transfer SROs. Due to this, in the future time horizons, the capital carbon emissions of the transfer SROs will be mainly based on the carbon intensity of the pipeline materials selected, rather than the pipe and trench characteristics at present.

4.5.1.2 Medium Case Scenario

Similar to the worst-case, this middle-case scenario again considers a landscape whereby pipe manufacturers do not change their procurement routes for raw materials. In this scenario, the decarbonisation ambitions of raw material suppliers are assumed to be moderately ambitious, with a targeted focus on process efficiency, including investments in advanced process technologies and decarbonising power and heat.

A focus on alternative materials in the short term, and a focus on low-emissions plant in the mid to long term offers the greatest reduction in emissions. Due to the more ambitious decarbonisation of raw materials industries, the benefit of selecting an alternative pipe material is enhanced for both the medium and large diameter example SROs (see Figure 4-6, Figure 4-7, Table 4-5, and Table 4-6). It is important to note that this scenario assumes 100% renewable energy is used in raw material production by 2060-2100, which will largely depend on decarbonisation of the energy grid, in addition to overcoming and decarbonising the increased energy load these industries would have on the grid.

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[7] Peak Pipe Systems (HPPE pipe supplier) and Amiblu (GRP pipe supplier)

[8] A wide range of EPDs are available for Amiblu pipelines (https://www.amiblu.com/environmental-product-declarations/)

4.5.1.3 Best Case Scenario

Initial engagement with pipeline manufacturers has indicated that, at present, there is little ambition to consider alternative feedstock materials, with a future focus on decarbonising existing feedstocks. This is mainly due to the firmly established production routes, which have been developed over many years, and are able to reliably meet performance requirements for pipelines.

This scenario considers a best case, whereby significant capital is invested within industry allowing alternative feedstocks (bio-plastics) to meet performance requirements. This scenario also considers significant investment in industry above those considered within the middle case scenario, with a focus on wider adoption of advanced processes, in addition to the deployment of carbon capture technologies.

As seen in Figure 4-8 and Figure 4-9, the increased decarbonisation of pipe materials, compounded with zero-emissions plant, results in substantial reductions in capital carbon emissions of transfer SROs when compared to today's baseline.

4.6 RAG Scale

Table 4-9 shows a summary red/amber/green (RAG) scale of the overall capital emission savings for the 'middle case'. Critically it compares all the variations against installing ductile iron pipe in today's conventional industry standard. The RAG scale can be broken down as follows:

- A 0-25% reduction against the baseline emissions is red
- A 26-75% reduction against the baseline emissions is amber
- A 75+% reduction against the baseline is green

Table 4-9: RAG scale for transfer pipelines – middle case

Item	***Pipeline option –*** *including material capital carbon and installation capital carbon**	***2025-2040***	***2040-2060***	***2060-2100***
		(% Reduction Against Capital Carbon Baseline)		
Medium diameter. Baseline: ductile iron construction using today's methods.	DI	7%	39%	48%
	HPPE	24%	59%	77%
	Steel	25%	60%	66%
	MO-PVC	51%	82%	90%
	GRP	53%	89%	94%
Large diameter Baseline: Steel construction using today's methods.	Steel	9%	25%	36%
	DI	-3%	20%	32%
	GRP	71%	84%	91%

Notes: "Baseline" in this case is defined as a do nothing approach, whereby the pipeline is constructed with conventional plant used today. The % reduction figures represent savings against the capital carbon of a pipeline scheme, not including any pump stations or water treatment works.
*Bedding and surround are included in the pipeline options relevant to each type of material. The quantities of bedding are incorporated in the carbon models used for pipelines

While carbon savings are achieved simply by switching materials (as evidenced by reading down a column), one can also note that carbon savings are driven for a given pipe material by manufacturing process improvements and installation improvements (evidenced by reading across a row). The latter might be useful for water companies who have asset standards which specify a given pipe material, and are therefore more concerned with how to reduce carbon for a given material. The specific gains from manufacturing processes or installation method were described in Section 4.4.

4.7 Recommendations for Gate 2 Application

For pipelines, it is again recommended to use the middle case as the most likely trajectory (based on current industry pace), assuming a good level of supply chain engagement. As recommending a pipeline material is outside the scope of this report and subject to many technical considerations, we make the following general recommendations which apply to most pipelines.

- **For medium diameter pipelines**, **GRP and MO-PVC offer the lowest capital carbon**, if meeting the technical requirements for a given project. In general, the middle case assumes that pipe manufacturers do not change their feedstocks, but that the feedstock manufacturers (ductile iron, plastics, etc) decarbonise their processes. The Water Companies can help accelerate this by working with feedstock manufacturers to investigate process efficiency gains, and the decarbonising of power and heat. Similar to the reservoir SROs, Water Companies can also engage with the supply chain to promote lower carbon construction and haulage plant to reduce installation emissions.
- **For large diameter pipelines**, **GRP offers the lowest capital carbon**, if meeting the technical requirements for a given project. The same recommendations apply as for the large diameter pipelines.

It is recognised that with pipelines most of the capital carbon rests in the pipe material, and is therefore outside the direct control of the Water Companies. Water Companies could therefore use this project to influence directly the construction and haulage plant used on the project, and investigate whether standards can be modified to allow for lower carbon pipe materials. Communication of this ‘change in standards’ to pipe suppliers, could stimulate suppliers to invest in reducing embodied carbon so as to not lose out on market share.

- **If outperformance of the ‘middle case’ is desired**, the largest reduction will come from working with the supply chain to source alternative feedstocks (e.g. bio-plastics) that can still meet performance requirements. Another avenue for deeper carbon reductions is working with suppliers to achieve further cuts in process emissions during manufacturing, such as by decarbonising power and heat earlier or employing carbon capture technologies.

5 Desalination and Water Reuse

5.1 SRO types and asset information

Desalination and water reuse SROs share common process technologies, equipment, consumables and ancillary asset components, resulting in similar carbon hotspots and decarbonisation opportunities. Both have been therefore analysed in this section. One example for desalination and one for water reuse have been selected for the analysis presented in this section. Table 5-1 summarises the key asset information and assumptions used in each example.

While the carbon hotspot analysis and decarbonisation opportunities have been focusing on capital carbon emissions (for the construction of assets as well as emissions associated with chemicals), we have also shown operational emissions from grid electricity to understand how significant these may be for the overall whole life emissions in different timescales, as the grid is decarbonising.

Table 5-1: Desalination & Water Reuse SRO Asset information and assumptions used in the analysis

Baseline Asset Information	Desalination SRO	Water Reuse SRO
Deployable Output	75MLD	75MLD
Electricity Consumption (annual)[9]	130,000MWh/y	48,200 MWh/y
Chemical Consumption:	Average Bulk Consumption (tonnes/ year)	
Sodium Hypochlorite	160	-
Poly-Aluminium Chloride	1,242	-
Sodium Hydroxide	23	-
Sodium Bisulphite	29	-
Anti-Scalant	13	26
Polymer	3	2
Methanol	-	4,970
Ferric Chloride	-	1,280
Lime	-	1,710
Carbon Dioxide	-	1,020
Hydrogen Peroxide	-	430
Membranes:		
Material	Composite polyamide	Composite polyamide
Replacement Frequency	8 years	8 years

5.1.1 Operational Carbon Emissions from electricity use

5.1.1.1 Proportion of Whole Life Emissions

The carbon emissions associated with annual electricity consumption largely depends on the carbon intensity of the UK electricity grid, which is forecast to significantly decarbonise over the timeframes considered by WRSE (as seen in Figure 5-1)[10].

Considering the carbon intensity of the electricity grid over a 60-year period between 2025 and 2085, the electricity consumption estimates for both SROs in Table 5-1 result in carbon emissions of ~135,000 tCO2e

[9] Estimated electricity consumption for continuous operation of generic 75MLD desalination and water reuse SROs

[10] Department for Business, Energy, and Industrial Strategy - Treasury Green Book supplementary appraisal guidance on valuing energy use and greenhouse gas (GHG) emissions, supporting tables.

and 50,000 tCO_2e for desalination and water reuse SROs respectively, over this 60-year period. This is the largest source of carbon emissions of these SROs, accounting for ~72% and ~65% of whole life carbon emissions for desalination and water reuse respectively. This is due to the assumption that the SROs will be constructed by 2025 and will source electricity from the grid.

Considering the carbon intensity of the electricity grid over a 60-year period between 2040 and 2100 results in carbon emissions of ~55,000 tCO_2e and ~22,000 tCO_2e for desalination and water reuse SROs respectively, over this 60-year period. This is still the largest source of carbon emissions for these SROs, however, the reduction in emissions results in these accounting for 52% and 44% of whole life carbon emissions for desalination and water reuse respectively.

Estimated whole life emissions between 2025 and 2085 for both SROs are presented within Figure 5-2 and Figure 5-3 below, with estimates between 2040 and 2100 presented within Figure 5-4 and Figure 5-5. Within this analysis, the utilisation factor has been assumed to be 100%.

Figure 5-1: Forecast Carbon Intensity of UK Electricity Grid

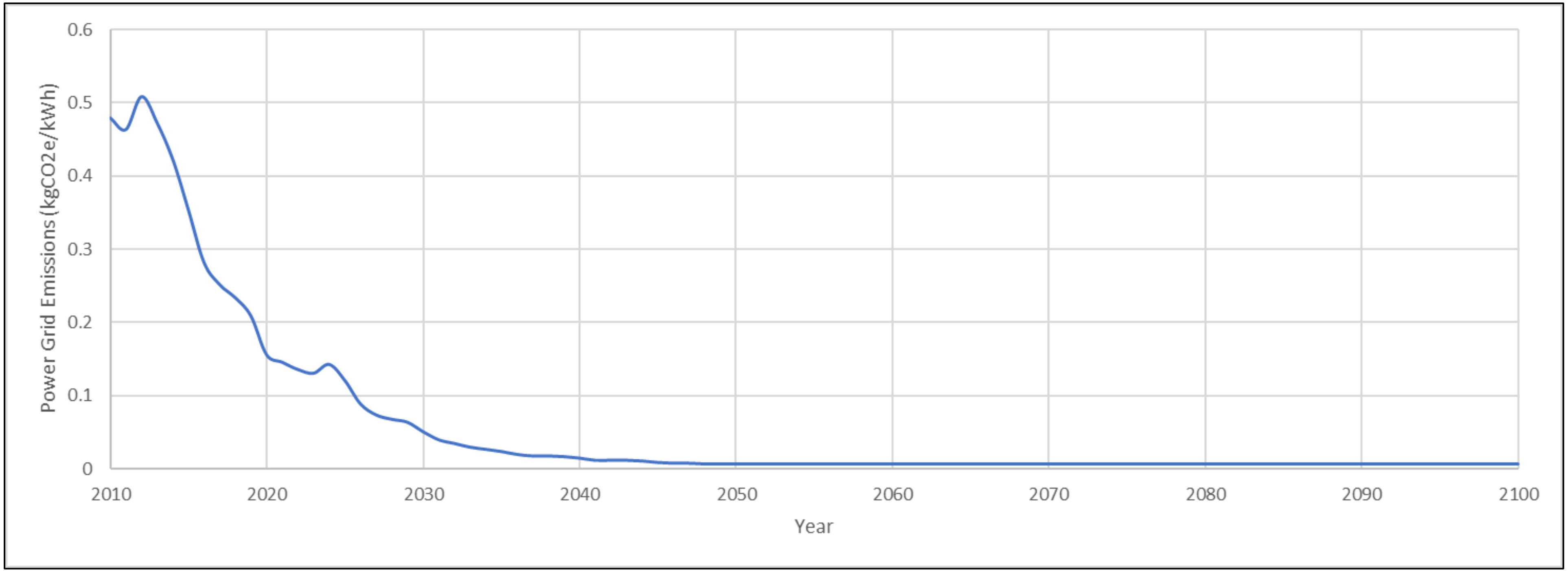


Figure 5-2: Desalination SRO Estimated Cumulative Whole Life Carbon Emissions - 2025-2084

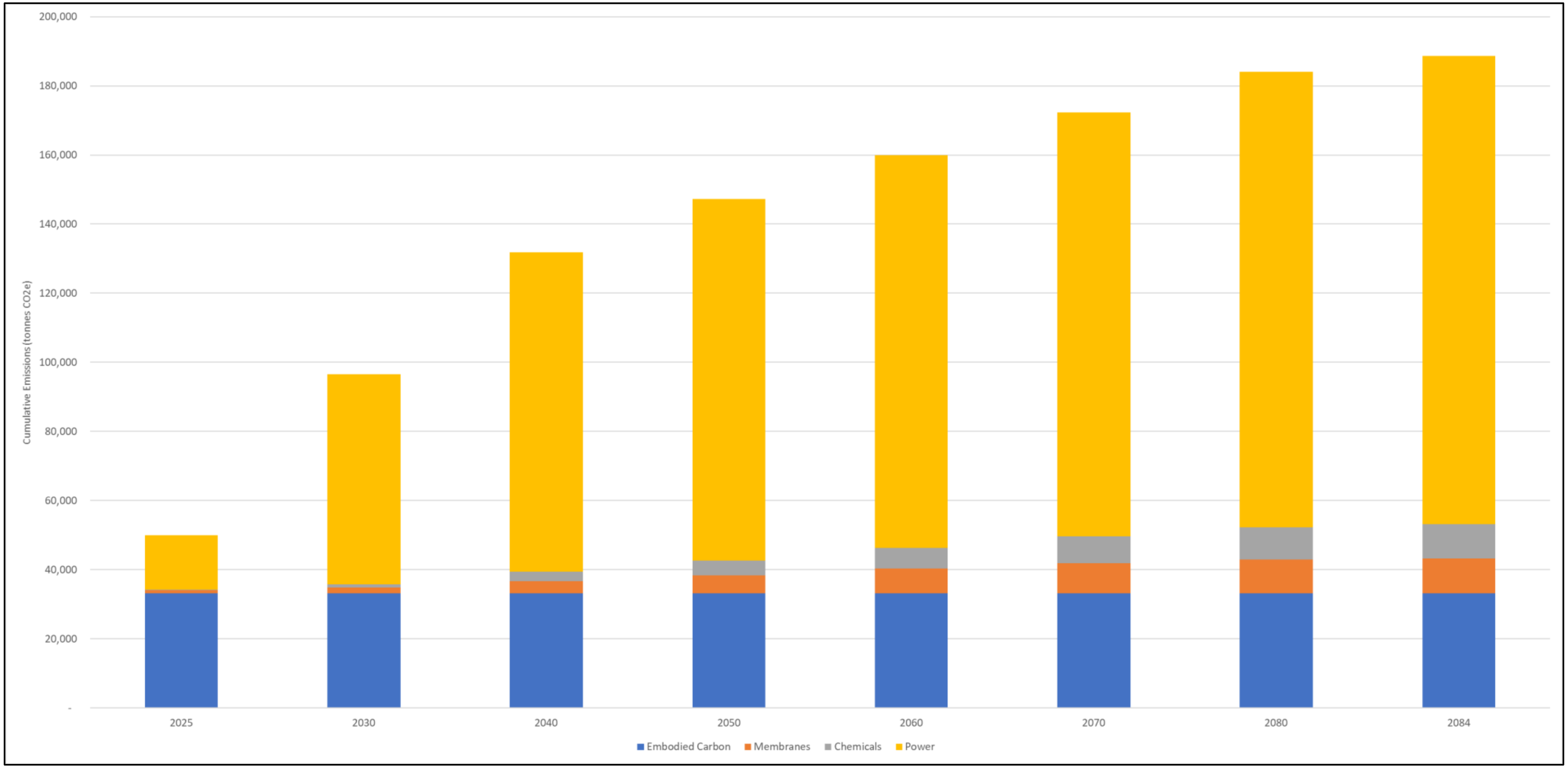


Figure 5-3: Water Reuse SRO Estimated Cumulative Whole Life Carbon Emissions - 2025-2084

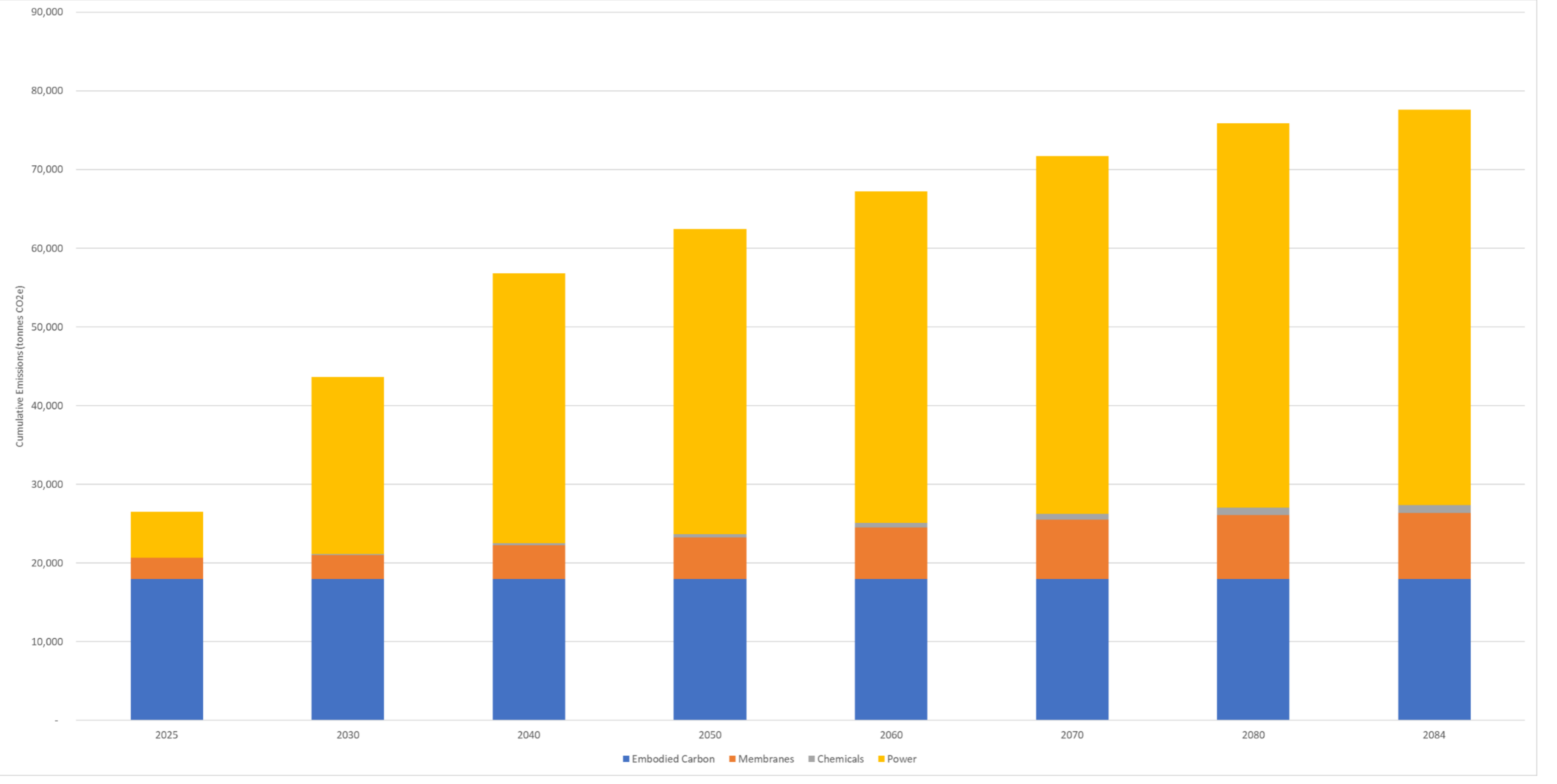


Figure 5-4: Desalination SRO Estimated Cumulative Whole Life Carbon Emissions - 2040-2099

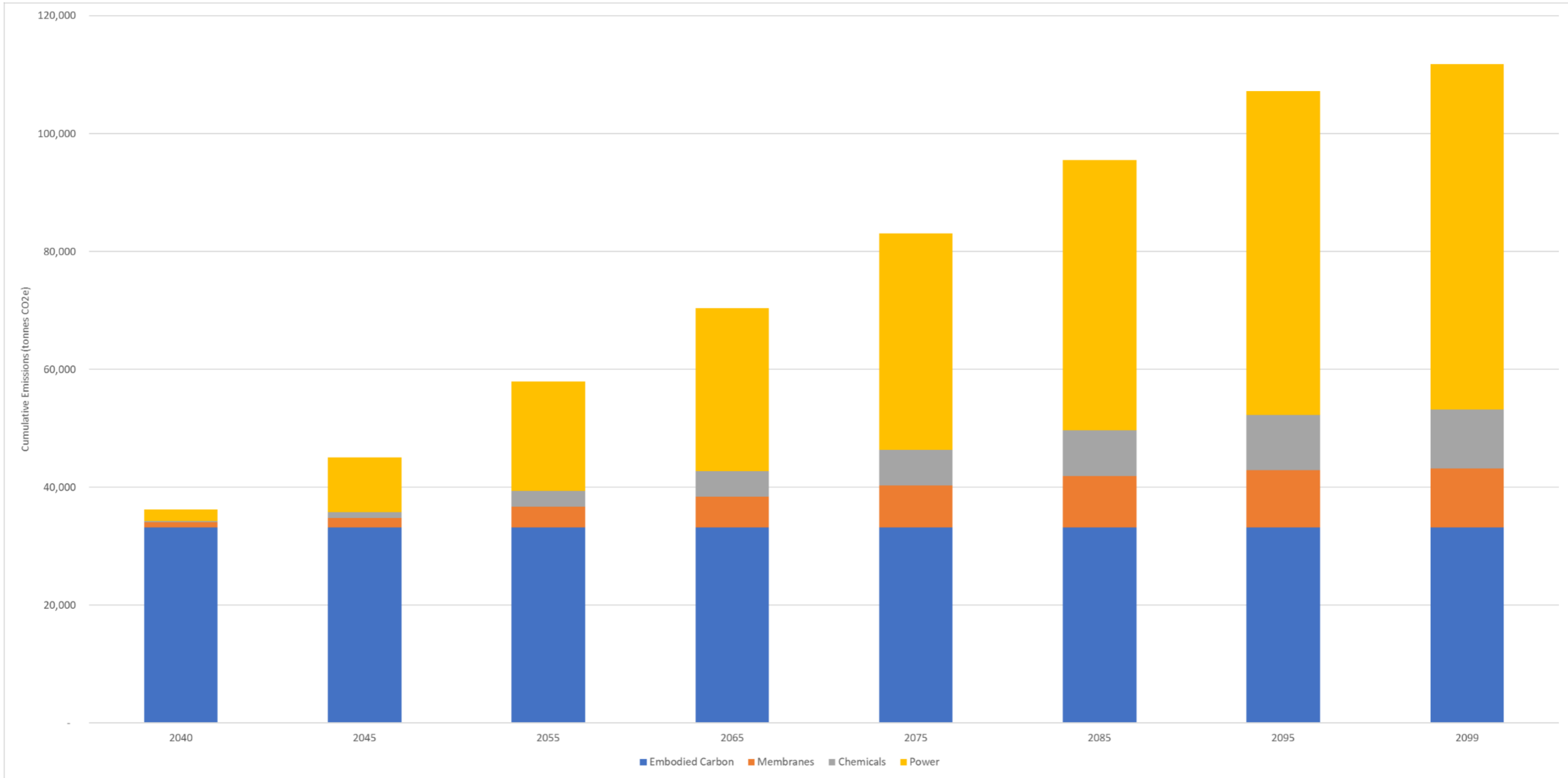
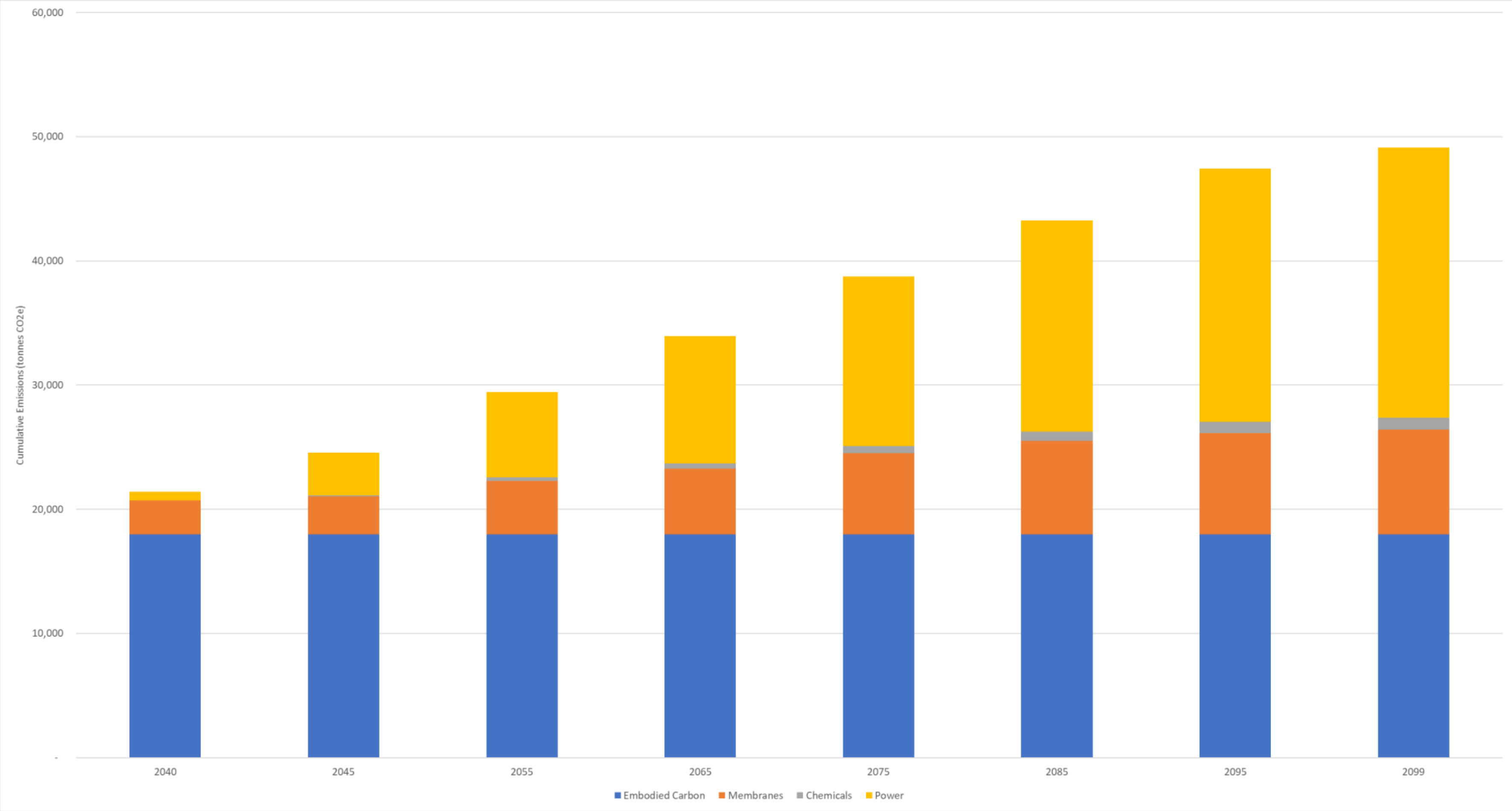


Figure 5-5: Water Reuse SRO Estimated Cumulative Whole Life Carbon Emissions - 2040-2099



5.1.1.2 Decarbonisation Potential of Power

As seen in Figure 5-1, the carbon intensity of the energy grid is forecast to fall by ~95% between 2022 and 2050, with the grid remaining at this reduced level onward to the year 2100. As such, the carbon emissions resulting from power consumption of desalination and reuse SROs largely depends on the level of decarbonisation within the energy grid when the SRO becomes operational.

Figure 5-10 and Figure 5-11 have been produced to estimate the cumulative carbon emissions resulting from SRO power consumption over an assumed 60-year operational lifespan. As seen in these figures, the higher carbon intensity of the UK energy grid up to 2050, results in substantially larger carbon emissions for both SROs. As such, delaying the first operational year of these SROs until 2040 and 2060 results in a 50% and 55% reduction in total carbon emission from power, when compared to the first operational year being within 2025.

Figure 5-6: Desalination SRO – Cumulative Power Consumption Carbon Emissions

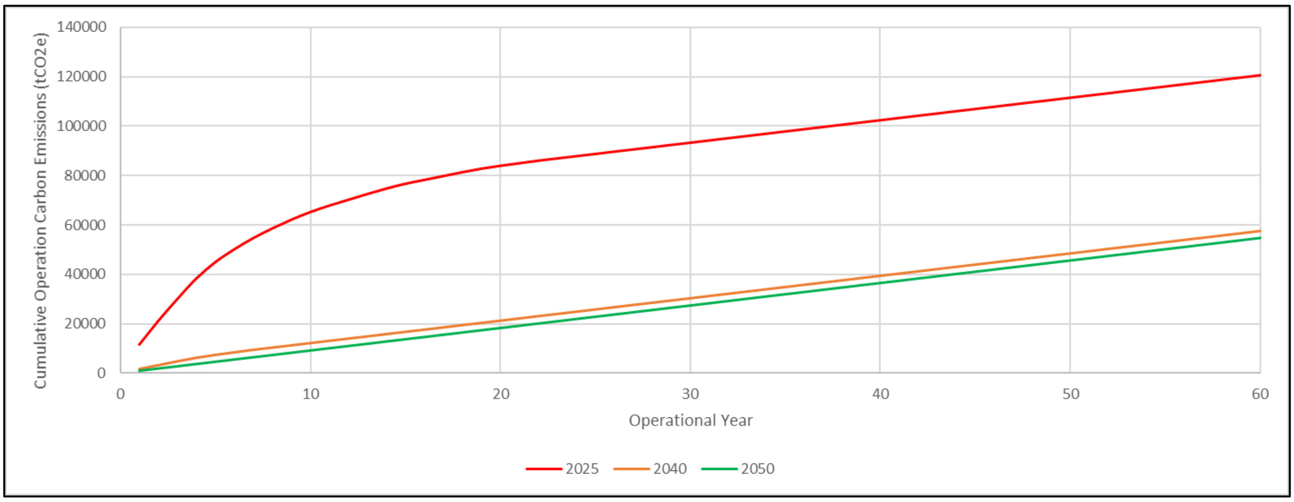
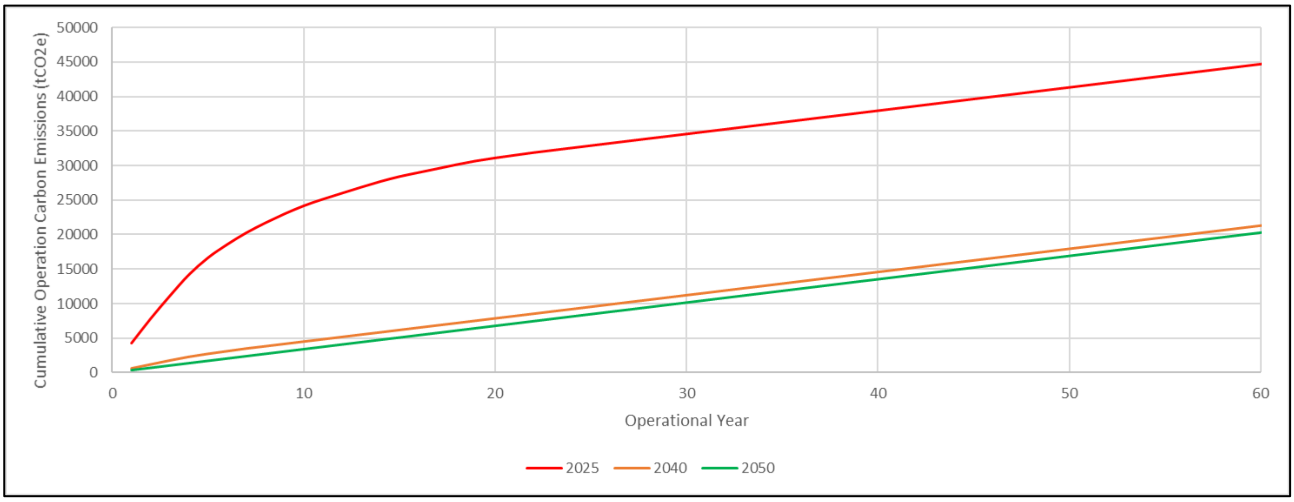


Figure 5-7: Reuse SRO – Cumulative Power Consumption Carbon Emissions



5.1.2 Capital Carbon & Chemicals

As summarised in Figure 5-8 and Figure **5-9**, hotspot analysis performed on existing capital carbon estimates for both example SROs identified buildings, tanks and foundations as the main hotspots, accounting for over 60% of capital carbon emissions. These emissions are due to the large quantities and carbon intensity of construction materials, such as concrete and steel. Pipelines have also been identified as a carbon hotspot, accounting for 5% to 9% of capital carbon emissions for the water reuse and desalination SROs respectively.

The hotspots identified above consider capital carbon only. However, as seen in Table 5-1, the ongoing replacement of membranes and consumption of chemicals are likely to contribute to the whole life emissions of both SROs.

Figure 5-10 and Figure 5-11 shows the impact that chemical consumption and membrane replacement has on the whole life emissions of the SROs. Indicating that chemical consumption accounts for ~5% and 20% of whole life emissions (excluding power) for water reuse and desalination SROs respectively. Considering replacement every 5 and 7 years for ultrafiltration and reverse osmosis membranes accounts for ~20% of whole life emissions (excluding power) for both water reuse and desalination SROs.

Due to the significant capital carbon associated with buildings, tanks and foundations, in addition to the whole life emissions associated with membrane replacement and chemical consumption, the decarbonisation potential of these hotspots has been assessed in the following sections.

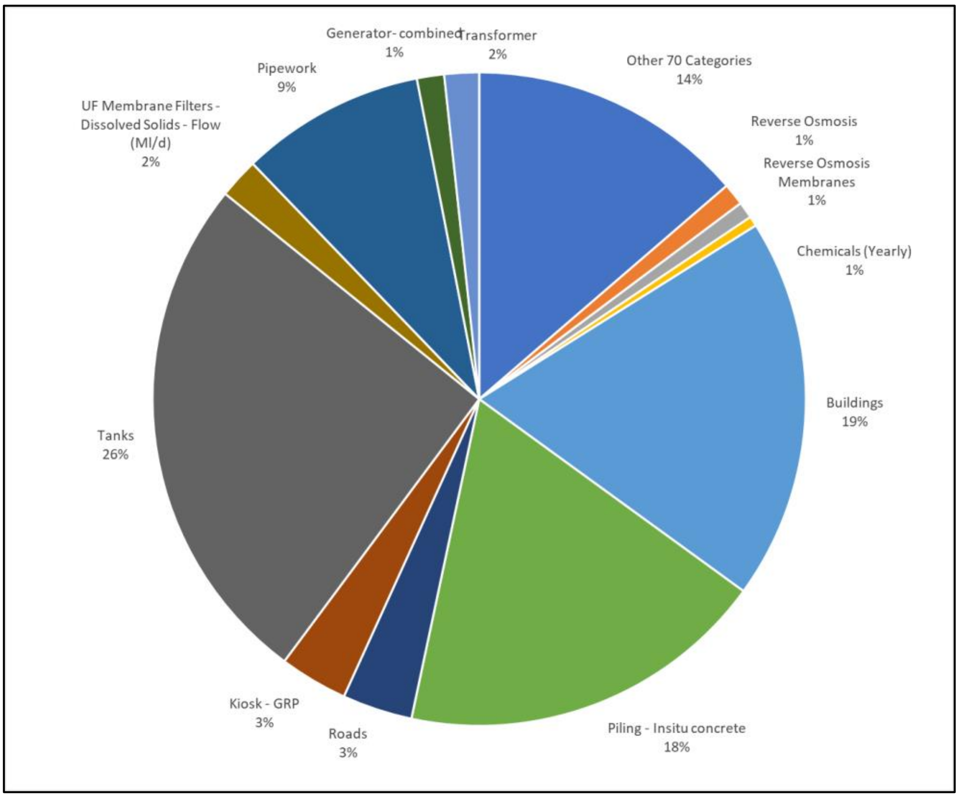


Figure 5-8: 75MLD Desalination SRO – Capital Carbon Hotspots (Excluding Replacement)

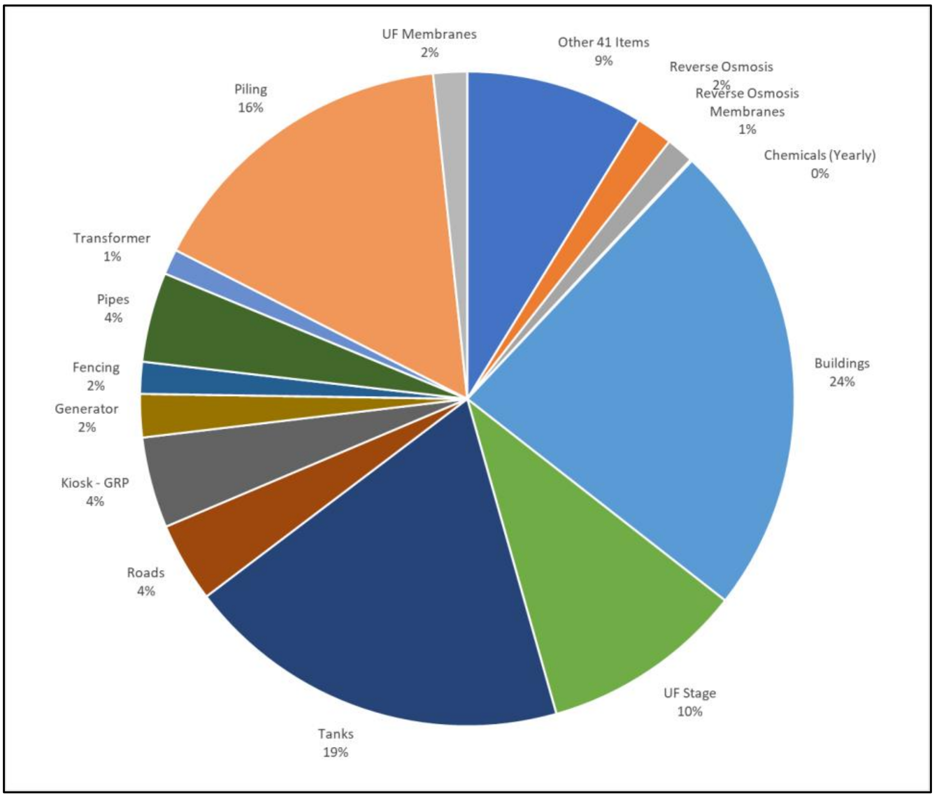


Figure 5-9: 75MLD Water Reuse SRO – Capital Carbon Hotspots (Excluding Replacement)

Figure 5-10: Desalination SRO - Cumulative Whole Life Carbon Emissions (Excluding Power)

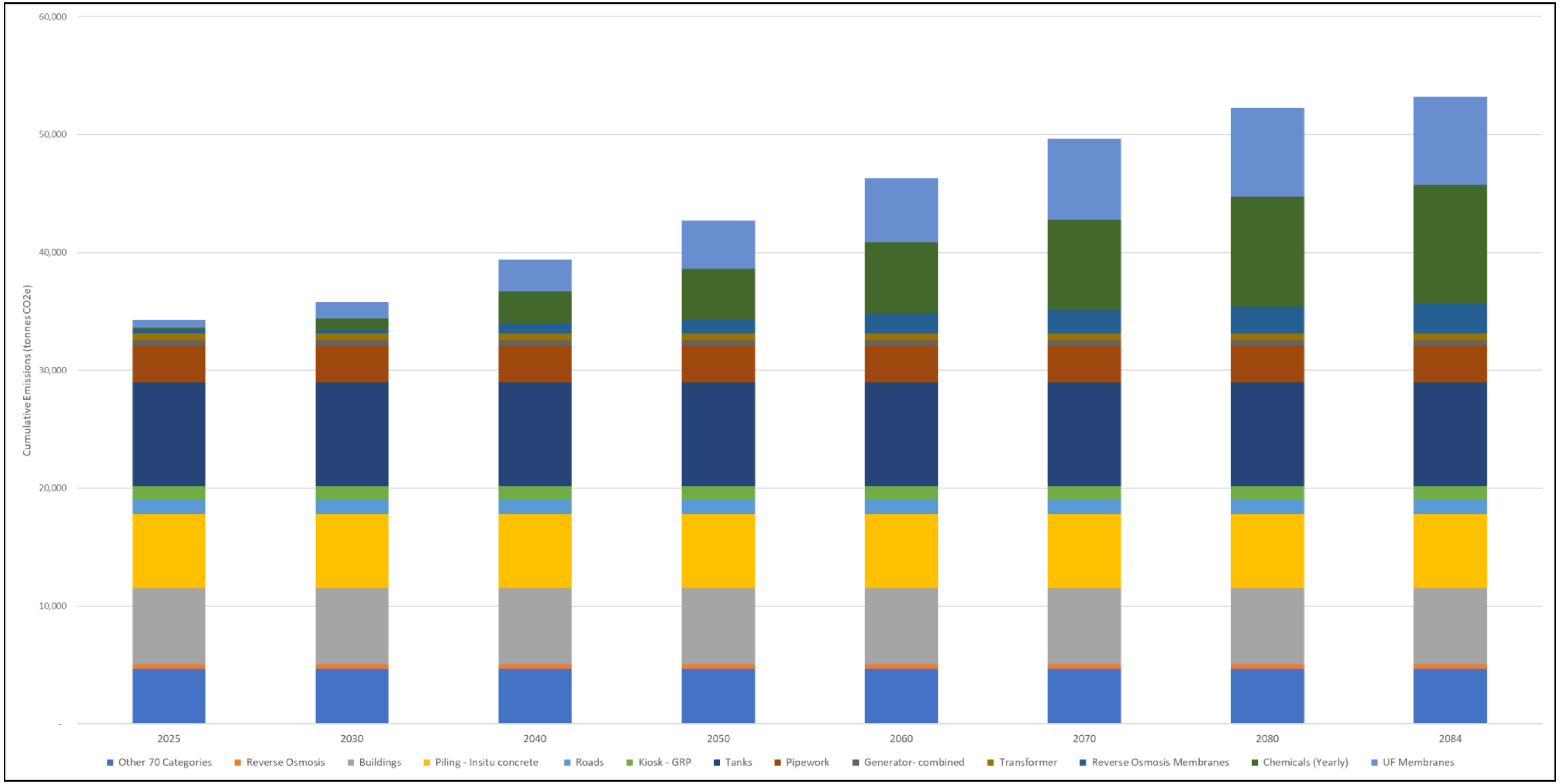


Figure 5-10 above shows the estimated whole life carbon emissions for an asset constructed in 2025. This figure estimates whole life emissions by accounting for capital carbon, and both chemical consumption and membrane replacement over a 60-year operational lifespan. As the decarbonisation potential of electricity consumption has been discussed previously, this has been removed from the graph for clarity.

Figure 5-11: Water Reuse SRO - Cumulative Whole Life Carbon Emissions (Excluding Power)

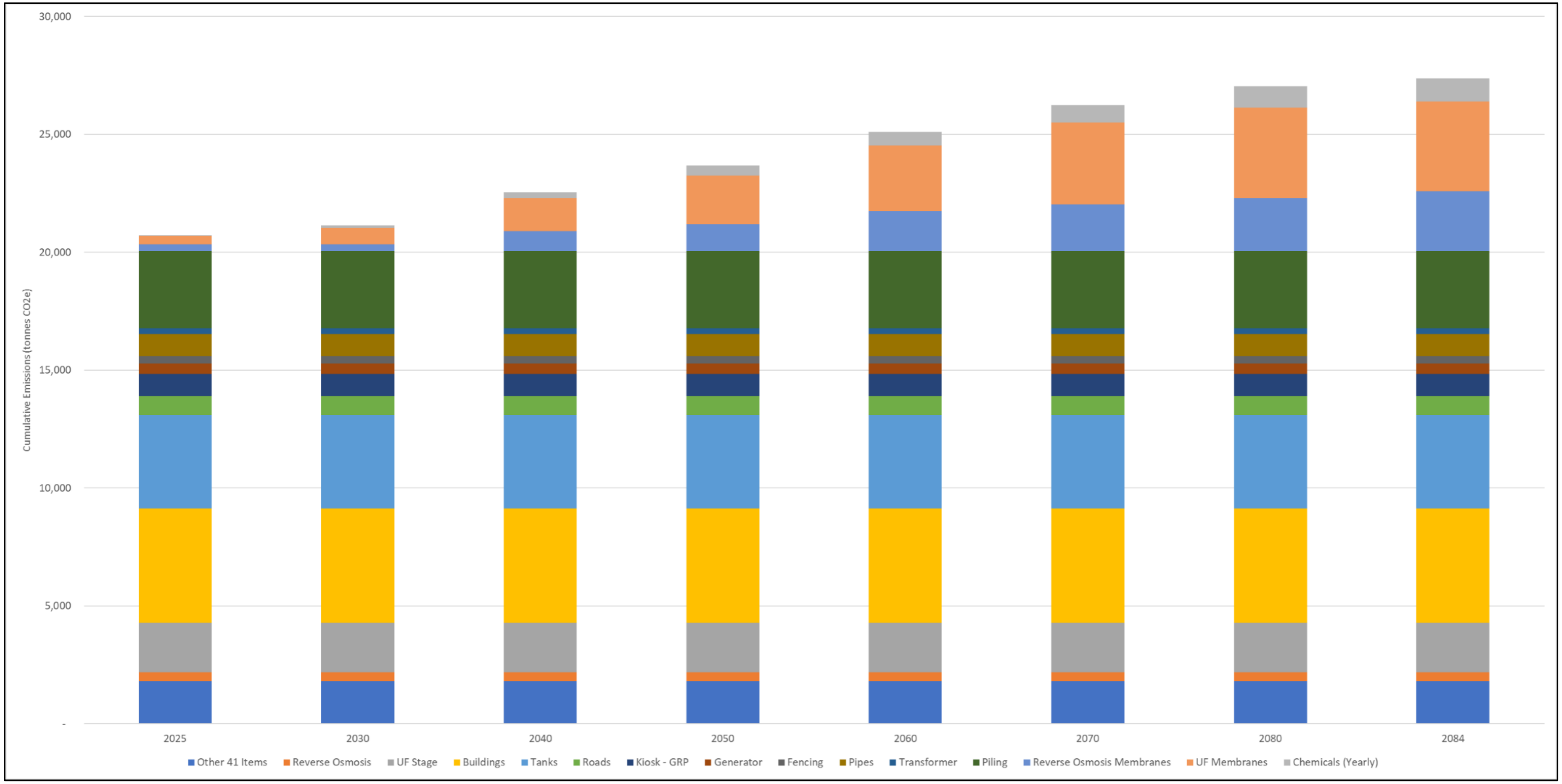


Figure 5-11 above shows the estimated whole life carbon emissions for an asset constructed in 2025. This figure estimates whole life emissions by accounting for capital carbon, and both chemical consumption and membrane replacement over a 60-year operational lifespan. As the decarbonisation potential of electricity consumption has been discussed previously, this has been removed from the graph for clarity.

5.2 Low Carbon Alternatives

A review of the Green Construction Board's Low Carbon Concrete Routemap has provided the insights noted in the following sections.

5.2.1 Low Carbon Concrete (LCC)

As noted in Section 5.1.2, over 60% of capital carbon emissions associated with buildings, tanks, and foundations is due to the use of concrete. With concrete accounting for approximately 1.2% of the UK's GHG emissions[11], considerable investigation into low-carbon alternatives has already taken place within industry. In general, the decarbonisation of concrete can be split into three categories: new technologies (e.g., alternative cement mixtures and/or cement replacement products), updating standards and legislation to adopt new technologies, and the utilisation of carbon sequestration and capture at the cement manufacturing facilities.

5.2.1.1 Emerging Technologies

A central area of focus for decarbonising the use of concrete is the adaptation of more sustainable cement mixtures and replacement products, in particular utilising supplementary cementitious materials (SCM's) to reduce the total capital carbon of existing cement options. The use of ground granulated blast-furnace slag (GGBS) and fly-ash as SCM's are currently popular solutions, however there are concerns over their long-term supply due to a reliance on the dwindling use of blast furnaces/coal-fired power plants. Therefore, it is important to closely manage the transition by considering a wider range of alternatives, some of which may not be market-ready in the short term. Promising technologies such as alkali-activated materials (AAM's) can be made from several aluminosilicate minerals as well as GGBS and fly-ash, therefore providing an alternative whereby its research can run in parallel to commonly adopted SCM's. The Green Construction Board's low carbon concrete routemap notes the potential to develop alternative SCMs, such as fly ash, limestone powder, calcined clay, and volcanic ash, in addition to developing AACMs based on calcined clays or volcanic ash. The routemap also notes the potential to develop carbon-negative synthetic SCMs, AACMs and aggregates for direct injection of carbon dioxide into fresh concrete, and for concretes that cure by carbonation.

5.2.1.2 Standards & Legislation

The nature of how critical concrete performance is within its many applications gives an indication as to how carefully any changes to standards are processed. This must start from the Government, who must ensure sufficient funding is available to encourage pilots of LCC technologies, provide the ability to rapidly scale-up successful technologies, and introduce legislation for economic incentive for reducing capital carbon. In addition, regulation should also be provided through continuing to be dynamic with technical standards, consistently reviewing the benchmarking for alternative technologies. Furthermore, Clients should require contractors to abide by PAS 2080, ensuring they're contractually liable for the carbon management of individual projects.

5.2.1.3 Carbon Sequestration & Capture

Although many carbon sequestration/capture technologies are in their infancy and not commercially ready, it is important to consider their potential impact in the medium-long term. Carbon dioxide 'captured' may be used or stored; with the preference being to directly use it, as there may be fewer processes and less long-term risk. Direct-separation technologies currently capture carbon produced through the chemical decomposition of limestone, whereas oxyfuel capture systems are used during the direct combustion of fuel

[11] Low Carbon Concrete Routemap, ICE, Low Carbon Concrete Routemap | Institution of Civil Engineers (ICE)

to provide heat for cement production. However, these technologies are currently energy-intensive, therefore said energy must also come from a renewable resource[12].

5.2.2 Steel (Reinforcement)

Due to its high economic value, rebar is already highly recycled within the UK. Engagement with structural design teams, indicates that, at present, reducing emissions associated with rebar mainly focusses on procuring rebar with high recycled content. Alternative fibre reinforcement technologies, such as Glass Fibre Reinforced Polymer (GFRP) and Basalt Fibre-Reinforced Polymer (BFRP) are emerging on the market, however, these are yet to be widely adopted as an alternative to steel reinforcement.

Rebar with a high recycled content offers significant carbon savings, as this is produced via a secondary electric arc furnace (EAF) production process, avoiding production via the carbon-intensive primary basic oxygen furnace (BOF) production route.

Research indicates that BFRP could provide a saving of 22% of global warming potential when compared to 100% recycled steel rebar (cradle to gate)[13]. However, this analysis does not consider the future decarbonisation potential of EAF steel production, through grid decarbonisation.

The carbon reduction potential of reinforcement technology is therefore highly dependent on the future availability of steel alternative reinforcement, the future availability of recycled steel, the carbon intensity of the steel industry, and the carbon intensity of the energy grid (impacting EAF production emissions).

5.2.2.1 Scenarios

A range of scenarios have been developed to model the transition to low-carbon concrete and steel reinforcement alternatives and the potential carbon reductions this could achieve over the three time horizons considered by WRSE. These scenarios are summarised in Table 5-2 below.

Table 5-2: Concrete and Rebar Decarbonisation Scenarios

Material	Scenario	Description
Concrete[14]	Worst Case	Optimising current practice and technology, including fly ash from stockpiles and widespread adoption of mixes that use limestone powder, calcined clay, and/or volcanic ash as SCMs
	Middle Case	Optimising current practice (as with route one), but also adopting AACMs based on calcined clays or volcanic ash
	Best Case	Optimising current practice (as with route one) and adopting sequestration of captured carbon dioxide within concrete. • The captured carbon dioxide is used to manufacture carbon-negative synthetic SCMs, AACMs and aggregates; for direct injection of carbon dioxide into fresh concrete; and for concretes that cure by carbonation.
Rebar[15]	Worst Case	Continued use of steel reinforcement technologies Current levels of rebar recycling are sustained Decarbonisation of steel rebar based on the following industry decarbonisation activities: • Existing trends in energy efficiency and decarbonisation continue • Major decarbonisation options including stove flue gas recycling and steam or power plant upgrades

[12] Low Carbon Concrete Routemap, ICE, Low Carbon Concrete Routemap | Institution of Civil Engineers (ICE)

[13] Sustainability of alternative reinforcement for concrete structures: Life cycle assessment of basalt FRP bars, Pavlović et al, Construction and Building Materials 334, pg. 12, 2022. Sustainability of alternative reinforcement for concrete structures: Life cycle assessment of basalt FRP bars | Elsevier Enhanced Reader

[14] Low Carbon Concrete Routemap, ICE, Low Carbon Concrete Routemap | Institution of Civil Engineers (ICE) - Analysis within the routemap has estimated the reduction in annual GHG emissions of the concrete industry under the above pathways. For the purposes of this study, it is assumed that the carbon intensity of concrete products decarbonises at the same rate as the concrete industry.

[15] Scenarios obtained from the Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050, commissioned by the DECC and BIS in 2015. Analysis assumes that the carbon intensity of steel products would reduce by a similar percentage as the industry as a whole

Material	Scenario	Description
	Middle Case	Continued use of steel reinforcement technologies Current levels of rebar recycling are sustained Decarbonisation of steel rebar based on the following industry decarbonisation activities: • Increased deployment of stove flue or top gas recycling in most BF-BOF sites • Rebuild of plants with advanced steel production technology
	Best Case	Continued use of steel reinforcement technologies Current levels of rebar recycling are sustained Decarbonisation of steel rebar based on the following industry decarbonisation activities: • Half of existing BF-BOF sites have been rebuilt using advanced technologies and integrated carbon capture • The other half of existing sites have been retrofitted with carbon capture

5.2.3 Buildings

The capital carbon emissions of industrial buildings are mainly due to the high carbon intensity of typical construction materials such as concrete, steel, cladding, etc. A review of an existing carbon model for an industrial building has been conducted to identify carbon hotspots within industrial buildings. As the building itself comprises many elements and materials, decarbonisation of these may be discussed in other sections of this report and are signposted in Table 5-3 below.

Table 5-3: Industrial Building - Carbon Hotspots

Hotspot	Proportion of Capital Carbon Emissions	Decarbonisation Commentary
Piling	32%	*Discussed in Section 5.2.4*
Cladding	31%	Discussed below
Concrete Base Slab	15%	*Discussed in Section 5.2.1*
Structural Steel Members	15%	Discussed below
Base Slab Reinforcement	7%	*Discussed in Section 5.2.1*

5.2.3.1 Structural Members and Cladding

Having identified structural members and cladding as key carbon hotspots for industrial buildings, discussions with design teams have been undertaken to understand the decarbonisation opportunities in these areas.

Cladding materials for industrial steel-frame buildings are typically brick or steel. Brickwork and steel are fairly carbon intensive materials due to the heat requirement in production processes. In addition, the mortar required for brick cladding (typically comprising CEM1 cement) contributes significantly towards its carbon intensity. Considering both cladding options, steel cladding appears to offer a lower carbon solution than brickwork at present. Decarbonisation of heat and the development of alternative cements will influence the carbon intensity of these materials.

Discussions with design teams have indicated that, at present, alternative materials are not typically considered in the place of structural steel members, due to the anticipated structural loads and spans required within industrial buildings. As noted for the steel cladding above, the decarbonisation of heat within the steelmaking process will influence the carbon intensity of steel members.

At present, decarbonisation efforts for industrial buildings are focused on design efficiency to reduce the number/ size of structural members and sourcing reclaimed brickwork for cladding. Considering the reuse of building fabric across multiple lifecycles, and recycling/ reuse of steel members is likely to reduce the carbon intensity of industrial buildings in the future. This will require increased modularity in design to support deconstruction and reuse of structural members, in addition to a higher level of material recovery for brickwork.

5.2.3.2 Scenarios

A range of scenarios have been developed to model the decarbonisation of steel members and cladding over the three time horizons considered by WRSE. The decarbonisation of these elements is focused on the decarbonisation of heat in industry and the uptake of reuse/ recycling. These scenarios are summarised in Table 5-4 below.

Table 5-4: Structural Members & Cladding Decarbonisation Scenarios

Material	Scenario	Description
Steel Members & Cladding[16]	Worst Case	Continued use of steel for structural members and steel/brick for cladding 95% of steel components (structural members and cladding) recycled at end of lifecycle Decarbonisation of steel based on the following industry decarbonisation activities: • Existing trends in energy efficiency and decarbonisation continue • Major decarbonisation options including stove flue gas recycling and steam or power plant upgrades
	Middle Case	Continued use of steel for structural members and steel/brick for cladding At the end of lifecycle for assets constructed in the 2060-2100 timeframe: • 20% of steel components reused • 80% of steel components are recycled Decarbonisation of steel rebar based on the following industry decarbonisation activities: • Increased deployment of stove flue or top gas recycling in most BF-BOF sites • Rebuild of plants with advanced steel production technology
	Best Case	Continued use of steel for structural members and steel/brick for cladding At the end of lifecycle for assets constructed in the 2060-2100 timeframe: • 50% of steel components reused • 50% of steel components are recycled Decarbonisation of steel rebar based on the following industry decarbonisation activities: • Half of existing BF-BOF sites have been rebuilt using advanced technologies and integrated carbon capture • The other half of existing sites have been retrofitted with carbon capture

5.2.3.3 Recycling and Reuse

As noted in Section 5.2.3.1, reuse and recycling at the end of an asset's life offer an opportunity to reduce the carbon impact of building materials by considering the benefits those materials may offer outside of its current lifecycle, these benefits are considered as 'Module D' within PAS2080, and are not typically considered or accounted for at the beginning of an asset's lifecycle. It is important to note that there are different ways in which accounting for the benefits of reuse and recycling can be considered.

For this study, the 'end of life' approach has been used, as this is the basis of the World Steel Lifecycle Inventory Methodology for recycling. This approach considers credits between different product systems across different lifecycles.

In the case of recycling, at the end of the current lifecycle, recycling steel provides the current lifecycle with a credit based on offsetting the demand or for virgin material production in the next life cycle. This credit is calculated following the World Steel methodology noted above.

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[16] Scenarios obtained from the Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050, commissioned by the DECC and BIS in 2015. Analysis assumes that the carbon intensity of steel products would reduce by a similar percentage as the industry as a whole

Similar to recycling, for reuse of entire structural members/ cladding, at the end of the current lifecycle, reusing steel members provides the current lifecycle with a credit based on offsetting the demand for material production in the next life cycle. At present, no such methodology has been identified to quantify this credit, however, for the purposes of this study, the credit is assumed to be equal to Module A1 to A3 carbon emissions associated with raw material supply and manufacture.

It is important to note that, for this assessment, the end-of-life benefits of reuse/ recycling have been attributed to capital carbon estimates at the beginning of the asset lifecycle. This has been done to simply provide an indication of the impact that reuse/ recycling may have on the whole life emissions of SROs. When considering individual SROs, Module D benefits should be reported separately and accounted for at end of each lifecycle.

5.2.4 Piled Foundations

The carbon emissions of piled foundations are associated with the carbon intensity of the concrete and rebar, accounting for ~90% of capital carbon estimates. The decarbonisation of piled foundations largely depends on the decarbonisation potential of concrete and rebar, which is discussed in Section 5.2.1. Approximately 5% of carbon emissions from tanks are associated with transport and construction effort. In the decarbonisation analysis for desalination and water reuse SROs, it has been assumed that the worst-case scenario for low-emissions plant (detailed within Section 3.3) is followed.

In addition to reducing the carbon intensity of materials, discussions with geotechnical designers have noted that design efficiencies are also likely to contribute to the carbon reduction of piled foundations. These efficiencies are gained by reducing overdesign of foundations and by adopting alternative, innovative pile designs[17].

5.2.4.1 Scenarios

A range of scenarios have been developed to model the decarbonisation of piled foundations over the three time horizons considered by WRSE. The decarbonisation of these elements is focused on the decarbonisation of concrete and rebar, in addition to design efficiencies. These scenarios are summarised in Table 5-5 below.

Table 5-5: Piled Foundations – Decarbonisation Scenarios

Material	Scenario	Description
Foundations	Worst Case	• Design efficiency saving of 5% and 10% for assets constructed in the 2040-2060 and 2060-2100 timeframes • This scenario considers that: ○ No alternative pile designs are adopted, with decarbonisation efforts being focused on design efficiencies for standard pile designs • Carbon intensity of concrete and rebar as per worst case scenario in Table 5-2

	Middle Case	• Design efficiency saving of 10% and 20% for assets constructed in the 2040-2060 and 2060-2100 timeframes
		• This scenario considers that:
		  ○ Design efficiencies of current pile designs are widespread by 2040-2060
		  ○ Moderate uptake of alternative pile designs by 2060-2100
		• Carbon intensity of concrete and rebar as per middle case scenario in Table 5-2

	Best Case	• Design efficiency saving of 10%, 20%, and 40% for assets constructed in the 2030-2040, 2040-2060 and 2060-2100 timeframes
		• This scenario considers that:
		  ○ Design efficiencies of current pile designs are widespread by 2030-2040
		  ○ Moderate uptake of alternative pile designs by 2040-2060

[17] "Lalicata LM, Stallebrass SE, McNamara A and Panchal JP (2022), Design method for the 'impression pile'. Proceedings of the Institution of Civil Engineers – Geotechnical Engineering 175(1): 75–85,

Material	Scenario	Description
		○ Widespread adoption of alternative pile designs by 2060-2100 • Carbon intensity of concrete and rebar as per best case scenario in Table 5-2

5.2.5 Tanks

The carbon emissions of reinforced concrete tanks are associated with the carbon intensity of the concrete and rebar, accounting for ~90% of capital carbon estimates. The decarbonisation of these assets largely depends on the decarbonisation potential of concrete and rebar, which is discussed in Section 5.2.1. Approximately 8% of carbon emissions from tanks are associated with transport and construction effort. In the decarbonisation analysis for desalination and water reuse SROs, it has been assumed that the worst-case scenario for low-emissions plant (detailed within Section 3.3) is followed.

5.2.6 Pipelines

The decarbonisation potential of pipelines has been discussed previously in Section 4.2. As an array of pipeline material choices are available for <DN800, it has been assumed that steel pipelines are selected instead of ductile iron pipelines for both SROs. As such, the worst, middle, and best-case decarbonisation potential for steel pipelines (including low-emissions plant) has been applied to pipeline elements within the decarbonisation analysis for desalination and water reuse SROs.

5.2.7 Membranes

As noted in Section 5.1.2, due to their replacement frequency, membranes account for ~20% of whole life emissions (excluding power), for both desalination and water reuse SROs. Consultation with technical experts has identified that longer lifespans are likely to be achieved for composite plastic membranes currently in use today, this due to ongoing improvements of design and durability as more products become available. Consultation has also noted that ceramic membranes have the potential to offer longer lifespans than composite plastic membranes. Ceramic membranes are a relatively new technology, with only a small number of plants using this technology within the UK for ultrafiltration. The capability of ceramic membranes for reverse osmosis has not yet been demonstrated.

5.2.7.1 Scenarios

A range of scenarios have been developed to model the potential improvement of membrane lifespans over the three time horizons considered by WRSE. These scenarios are summarised in Table 5-6 below.

Table 5-6: Membrane Replacement Frequency & Material

Membranes	Timeframe	Worst Case		Middle Case		Best Case	
		Material	Lifespan	Material	Lifespan	Material	Lifespan
Ultra-Filtration	2020s	Composite Plastic	3-7 years	Composite Plastic	3-7 years	Composite Plastic	3-7 years
	2030s				4-8 years	Ceramic	15-20 years
	2040s				5-9 years		
	2050s				6-10 years		
	2060s				7-11 years		
Reverse Osmosis	2020s	Composite Plastic	5-10 years	Composite Plastic	5-10 years	Composite Plastic	5-10 years
	2030s				6-11 years		7-12 years
	2040s				7-12 years		9-14 years
	2050s				8-13 years		11-15 years

Membranes	Timeframe	Worst Case		Middle Case		Best Case	
		Material	Lifespan	Material	Lifespan	Material	Lifespan
	2060s				9-14 years	Ceramic	15-20 years

5.2.8 Chemicals

There is a substantial lack of information available within the chemicals industry to accurately determine the carbon intensity of chemical products. In addition to this, there is a noted absence of a sector-level decarbonisation trajectory. Both of these are likely due to the complexity of the chemicals industry itself, with many chemicals being imported from around the world.

In the absence of published decarbonisation trajectories, a literature review has been undertaken to identify alternative processes that could be adopted with the potential to reduce the carbon intensity of chemicals. The outcome of this review is presented in Table 5-7.

Due to the uncertainties surrounding the carbon intensity and decarbonisation potential of chemicals, the analysis presented within Section 5.3 assumes that chemicals do not decarbonise.

Further investigation is required to understand the decarbonisation potential of chemicals, and it is recommended that further discussions are held between the ACWG and their suppliers to strengthen the understanding in this area.

Table 5-7: Chemical Decarbonisation Potential

Chemical	Typical production process	Other production methods	Decarbonised production process - potential
Sodium Hypochlorite	Electrolysis of brine		Decarbonising of electricity sector, as power and sodium chloride (present in brine) are the main requirements.
Poly-Aluminium Chloride	Reaction between aluminium and hydrochloric acid. Various aluminium-containing raw materials can be used including aluminium metal, aluminium chloride, aluminium hydroxide…		60% of the CO2 emissions are from electricity consumed during smelting so decarbonising electricity generation biggest opportunity. Using an inert material instead of carbon in anodes could eliminate direct emissions from electrolysis. Using scrap aluminium instead of fresh[18].
Sodium Hydroxide	Electrolysis of brine		Decarbonising of electricity sector, as power and sodium chloride (present in brine) are the main requirements.
Methanol	Reforming natural gas with steam, distilling the resulting gas to produce pure methanol	1. Gasification of coal to produce synthetic gas (carbon monoxide and hydrogen) 2. Gasification of glycerine (biomass by-product of biodiesel production)	1. Hydrogenation of carbon dioxide - decomposing water to produce hydrogen gas (using renewable energy), which bonds with the carbon dioxide on a catalyst to create methanol[19][20] 2. Hydrogenation of carbon dioxide, using CO2 from biogas or other fermentation plants, or flue gas[21] 3. Gasification of municipal waste or biogas
Ferric Chloride	Reaction of ferrous oxide and hydrochloric acid[22]	Can be produced using various ferric sources: Iron scraps and chlorine gas, by ferric chloride recycling Soft iron and chlorine gas, by ferric chloride recycling Ferric oxide and hydrochloric acid Mixed oxides, hydrochloric acid and chlorine gas Pickling liquors and chlorine gas, with final concentration	Chlorine produced by electrolysis of brine, so decarbonisation of electricity sector will assist this. Prioritising iron scraps vs. fresh iron would have some benefits but only a finite amount. New reduction agents are required in steel industry to decarbonise - options include using hydrogen, reduce iron ore in electrolysis or to use bio-char instead of coke (this is primarily for steel production).[23]

[18] Cousins, S (2021) The 75 per cent problem: aluminium's carbon footprint", RICS MODUS Article

[19] "Borisut P and Nuchitprasittichai A (2019) Methanol Production via CO2 Hydrogenation: Sensitivity Analysis and Simulation—Based Optimization. Front. Energy Res. 7:81.

[20] Penn State. (2018, June 28). Carbon dioxide-to-methanol process improved by catalyst. ScienceDaily

[21] ETIP Bioenergy (2020) Methanol from Biomass Fact Sheet

[22] 3V Tech (2022) Ferric Chloride Production Overview

[23] Lechtenböhmer S, Nilsson L.J:, Åhman M., Schneider C.: (2016): Decarbonising the energy intensive basic materials industry through electrification – implications for future EU electricity demand, Energy (2016), Volume 115, Part 3, 15 November 2016, Pages 1623–1631

Chemical	Typical production process	Other production methods	Decarbonised production process - potential
Carbon Dioxide	Food-grade CO_2 produced as by-product of ammonia production (hydrogen + nitrogen reaction) - main source of hydrogen is methane from natural gas.	Other fossil fuel sources can be used (coal, heavy fuel oil). Can be captured from other sources where it is a waste material (e.g. brewing beer)	Capturing as a waste product from other industries - e.g. biogas (goes through scrubbers to remove ca. 45% CO_2)[24] [25]
Hydrogen Peroxide	Reaction of hydrogen with atmospheric oxygen, using anthraquinone and palladium catalyst, has high energy consumption.		Alternative catalysts being developed aiming to produce green h2o2, at ambient temperatures.[26]
Sodium Bisulphite	Reaction of sulphur dioxide gas in alkaline hydroxide (sodium hydroxide or sodium carbonate).		Decarbonising of electricity sector in the production of sodium hydroxide. Sulphuric acid requires burning/incinerating sulphur, there is potential for energy recovery or improved catalysts but not much consideration seems to be happening.
Lime	Limestone extracted from quarries, converted to quicklime by heating (1000°C) and hydrated with water.		R&D happening to electrify the production of quick lime and capture the CO_2 from limestone.[27]
Anti-Scalant	Can be made from polyacrylic acid (a derivative of acrylic acid) - synthetic organic, from hydrocarbons (probably oil).		Potential to use biological hydrocarbon source instead of oil in the future.
Polymer	Synthetic organic, from hydrocarbons (probably oil).		Potential to use biological hydrocarbon source instead of oil in the future.

[24] IEA Bioenergy: Task 37: 11 2020 Production of food grade sustainable CO2 from a large biogas facility

[25] Pro Gases UK (2022) Green carbon dioxide

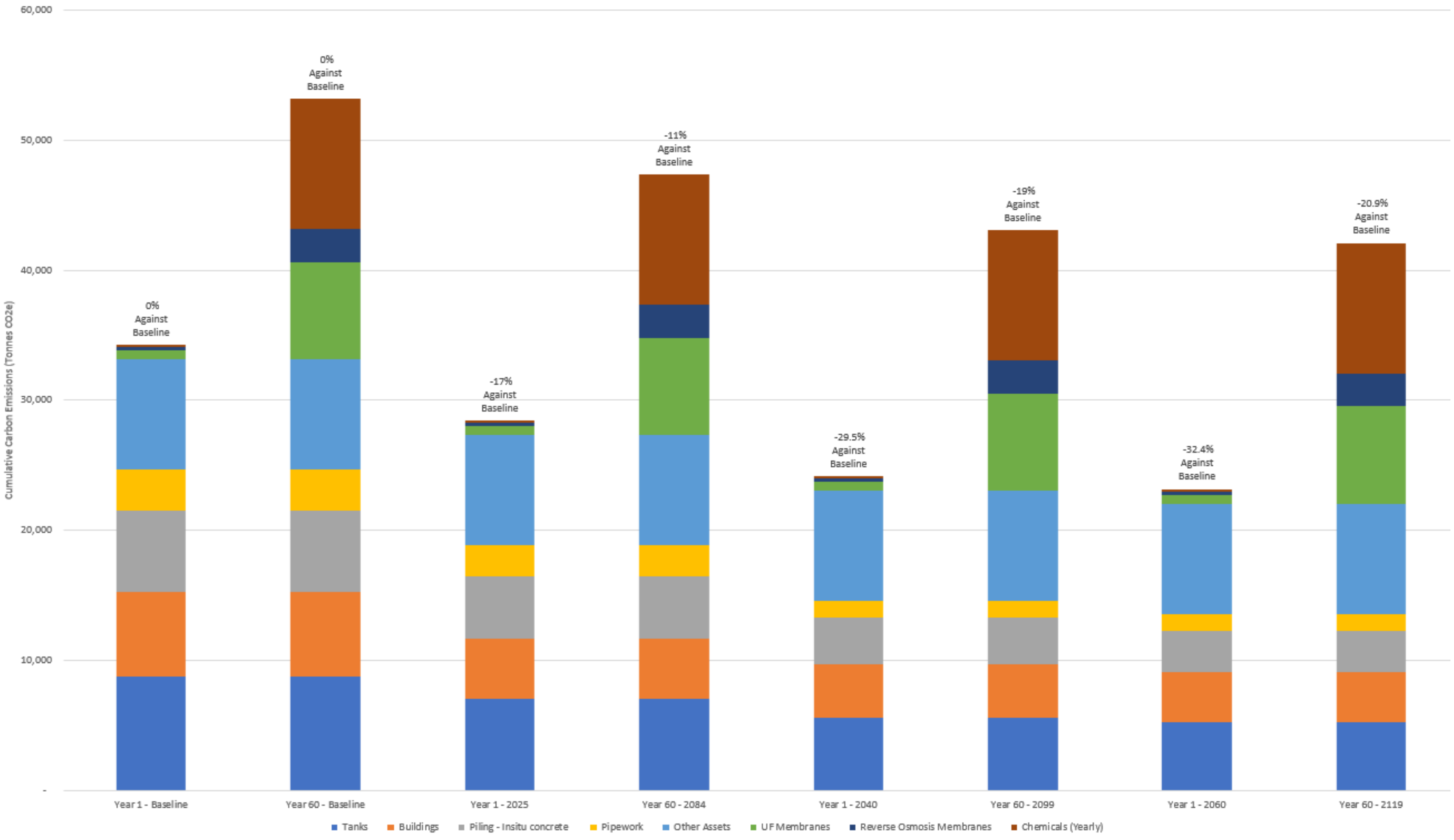
[26] ANSTO (2020) Producing less costly, greener hydrogen peroxide

[27] SaltX Technology (2022) New technology from SaltX enables production of "green quick lime" – results verified by the industry

5.3 Decarbonisation Potential

5.3.1 Analysis Results (Worst Case)

Figure 5-12: 75MLD Desalination SRO - Decarbonisation Potential - Worst Case (Whole Life Emissions, Excluding Power)

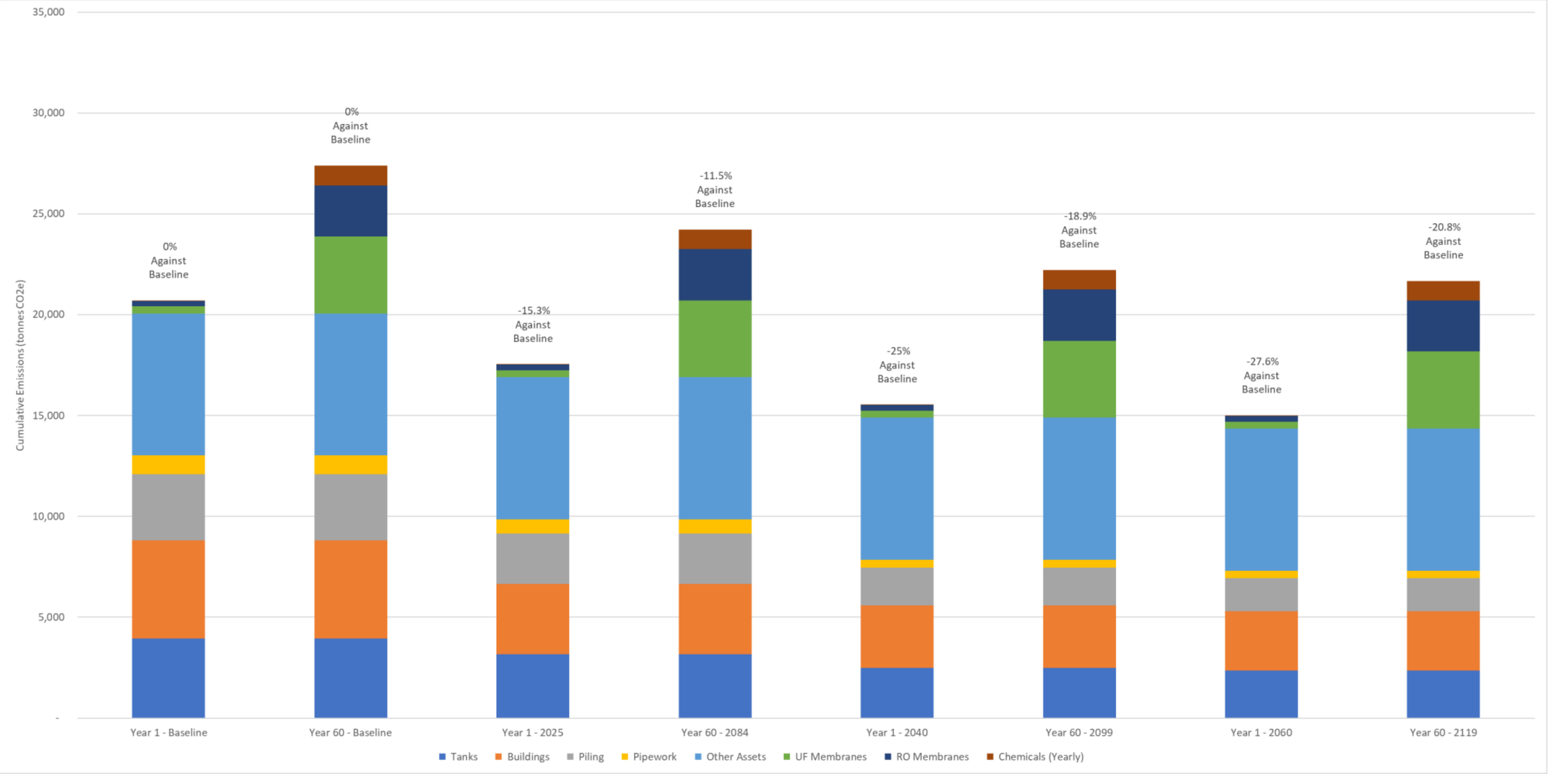


The figure above shows the estimated cumulative whole life emissions of the SRO during its first and last year of operation if it were constructed during the 2025-2040, 2040-2060 and 2060-2100 timeframes. This estimate includes capital carbon, chemical consumption, and membrane replacement, allowing for decarbonisation of hotspots noted in the previous sections.

Table 5-8: Desalination SRO - Decarbonisation Potential - Worst Case

SRO	Year	Hotspot	Year 1 Capital Carbon Emissions (tCO2e) & Reduction vs Baseline (%)	Replacement of Membranes and Chemical Consumption Over the Whole Life of the Asset (tCO2e) & Reduction vs Baseline (%)
75 MLD Desalination	2025-2040	Tanks	7,035 (-20%)	-
		Buildings	4,655 (-28.2%)	-
		Piling	4,785 (-23.9%)	-
		Pipework	2,380 (-24%)	-
		Other Assets	8,460 (0%)	-
		UF Membranes	-	7,500 (0%)
		RO Membranes	-	2,530 (0%)
		Chemicals	-	10,025 (0%)
		Subtotal	*27,315 (-17.6%)*	*20,055 (0%)*
	2040-2060	Tanks	5,560 (-36.7%)	-
		Buildings	4,120 (-36.5%)	-
		Piling	3,595 (-42.8%)	-
		Pipework	1,315 (-58%)	-
		Other Assets	8,460 (0%)	-
		UF Membranes	-	7,500 (0%)
		RO Membranes	-	2,530 (0%)
		Chemicals	-	10,025 (0%)
		Subtotal	*23,050 (-30.5%)*	*20,055 (0%)*
	2060-2100	Tanks	5,235 (-40.4%)	-
		Buildings	3,900 (-39.9%)	-
		Piling	3,165 (-49.6%)	-
		Pipework	1,285 (-58.9%)	-
		Other Assets	8,460 (0%)	-
		UF Membranes	-	7,500 (0%)
		RO Membranes	-	2,530 (0%)
		Chemicals	-	10,025 (0%)
		Subtotal	*22,045 (-33.5%)*	*20,055 (0%)*

Figure 5-13: 75MLD Water Reuse SRO - Decarbonisation Potential - Worst Case (Whole Life Emissions, Excluding Power)



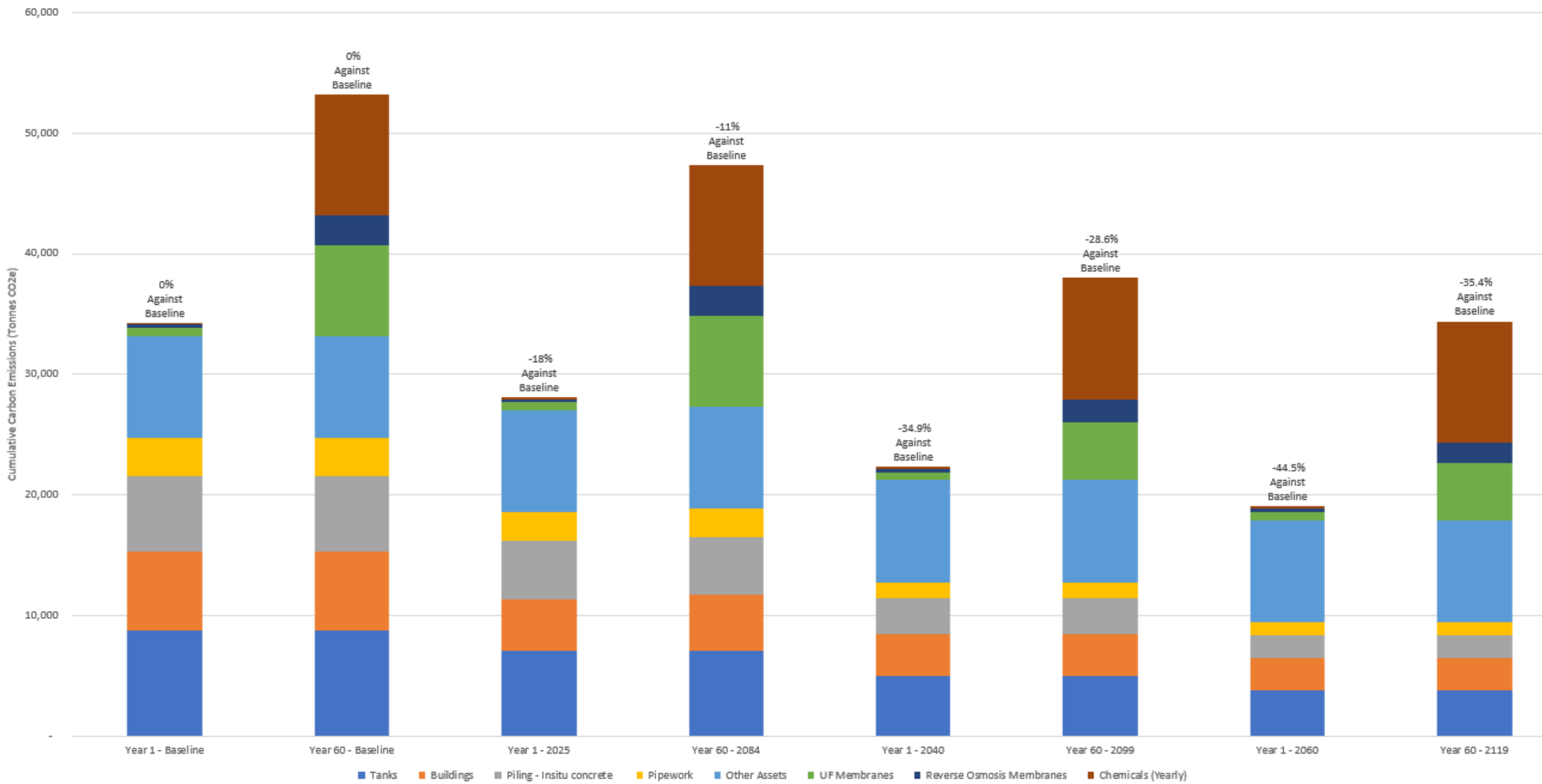
The figure above shows the estimated cumulative whole life emissions of the SRO during its first and last year of operation if it were constructed during the 2025-2040, 2040-2060 and 2060-2100 timeframes. This estimate includes capital carbon, chemical consumption, and membrane replacement, allowing for decarbonisation of hotspots noted in the previous sections.

Table 5-9: Water Reuse SRO - Decarbonisation Potential - Worst Case

SRO	Year	Hotspot	Year 1 Capital Carbon Emissions (tCO2e) & Reduction vs Baseline (%)	Replacement of Membranes and Chemical Consumption Over the Whole Life of the Asset (tCO2e) & Reduction vs Baseline (%)
75 MLD Water Reuse	2025-2040	Tanks	3,160 (-20%)	-
		Buildings	3,500 (-28.1%)	-
		Piling	2,495 (-23.8%)	-
		Pipework	700 (-23.9%)	-
		Other Assets	7,045 (0%)	-
		UF Membranes	-	3,815 (0%)
		RO Membranes	-	2,530 (0%)
		Chemicals	-	975 (0%)
		Subtotal	*16,900 (-15.8%)*	*7,320 (0%)*
	2040-2060	Tanks	2,495 (-36.8%)	-
		Buildings	3,095 (-36.4%)	-
		Piling	1,875 (-42.7%)	-
		Pipework	385 (-58.2%)	-
		Other Assets	7,045 (0%)	-
		UF Membranes	-	3,815 (0%)
		RO Membranes	-	2,530 (0%)
		Chemicals	-	975 (0%)
		Subtotal	*14,895 (-25.7%)*	*7,320 (0%)*
	2060-2100	Tanks	2,355 (-40.4%)	-
		Buildings	2,930 (-39.8%)	-
		Piling	1,650 (-49.6%)	-
		Pipework	375 (-59.2%)	-
		Other Assets	7,045 (0%)	-
		UF Membranes	-	3,815 (0%)
		RO Membranes	-	2,530 (0%)
		Chemicals	-	975 (0%)
		Subtotal	*14,355 (-28.4%)*	*7,320 (0%)*

5.3.2 Analysis Results (Middle Case)

Figure 5-14: 75MLD Desalination SRO - Decarbonisation Potential - Middle Case (Whole Life Emissions, Excluding Power)

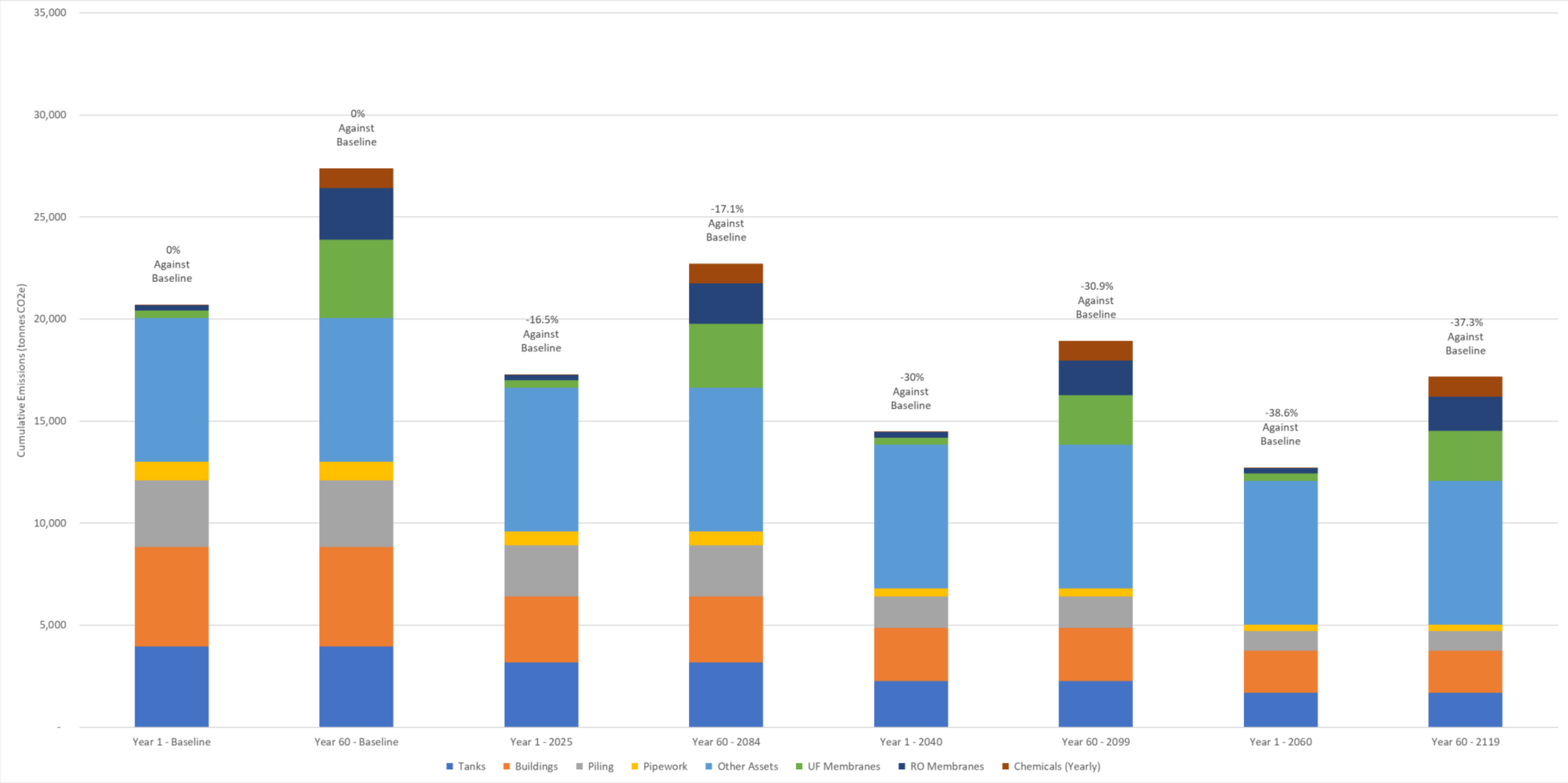


The figure above shows the estimated cumulative whole life emissions of the SRO during its first and last year of operation if it were constructed during the 2025-2040, 2040-2060 and 2060-2100 timeframes. This estimate includes capital carbon, chemical consumption, and membrane replacement, allowing for decarbonisation of hotspots noted in the previous sections.

Table 5-10: Desalination SRO - Decarbonisation Potential - Middle Case

SRO	Year	Hotspot	Year 1 Capital Carbon Emissions (tCO2e) & Reduction vs Baseline (%)	Replacement of Membranes and Chemical Consumption Over the Whole Life of the Asset (tCO2e) & Reduction vs Baseline (%)
75 MLD Desalination	2025-2040	Tanks	7,035 (-20%)	-
		Buildings	4,320 (-33.4%)	-
		Piling	4,785 (-23.9%)	-
		Pipework	2,380 (-24%)	-
		Other Assets	8,460 (0%)	-
		UF Membranes	-	6,820 (-9.1%)
		RO Membranes	-	2,250 (-11.1%)
		Chemicals	-	10,025 (0%)
		Subtotal	*26,980 (-18.6%)*	*19,095 (-4.8%)*
	2040-2060	Tanks	5,005 (-43.1%)	-
		Buildings	3,475 (-46.4%)	-
		Piling	2,975 (-52.7%)	-
		Pipework	1,285 (-58.9%)	-
		Other Assets	8,460 (0%)	-
		UF Membranes	-	4,775 (-36.3%)
		RO Membranes	-	1,970 (-22.1%)
		Chemicals	-	10,025 (0%)
		Subtotal	*21,200 (-36%)*	*16,770 (-16.4%)*
	2060-2100	Tanks	3,740 (-57.5%)	-
		Buildings	2,760 (-57.4%)	-
		Piling	1,845 (-70.6%)	-
		Pipework	1,095 (-65%)	-
		Other Assets	8,460 (0%)	-
		UF Membranes	-	4,775 (-36.3%)
		RO Membranes	-	1,690 (-33.2%)
		Chemicals	-	10,025 (0%)
		Subtotal	*17,900 (-46%)*	*16,490 (-17.8%)*

Figure 5-15: 75MLD Water Reuse SRO - Decarbonisation Potential - Middle Case (Whole Life Emissions, Excluding Power)



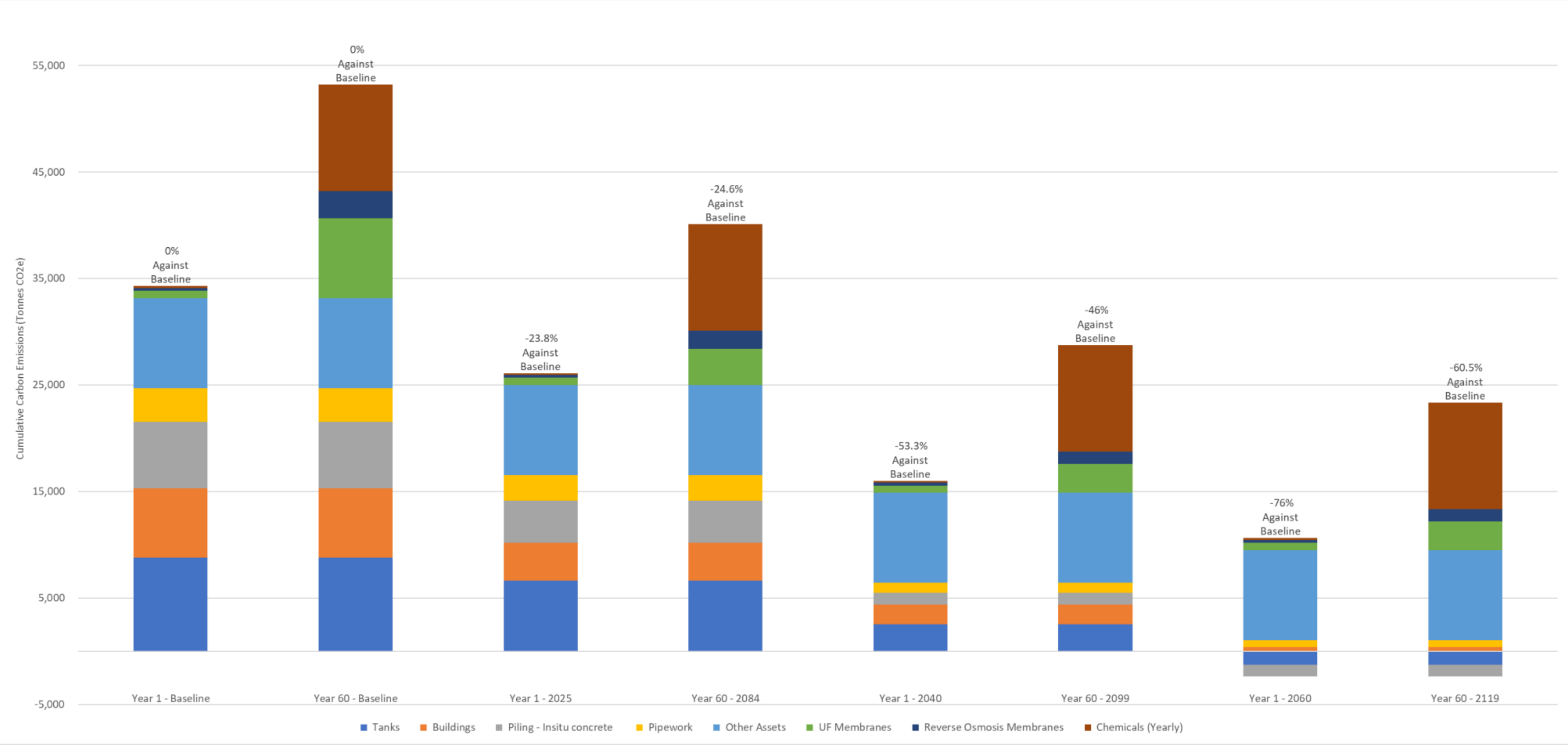
The figure above shows the estimated cumulative whole life emissions of the SRO during its first and last year of operation if it were constructed during the 2025-2040, 2040-2060 and 2060-2100 timeframes. This estimate includes capital carbon, chemical consumption, and membrane replacement, allowing for decarbonisation of hotspots noted in the previous sections.

Table 5-11: Water Reuse SRO - Decarbonisation Potential - Middle Case

SRO	Year	Hotspot	Year 1 Capital Carbon Emissions (tCO2e) & Reduction vs Baseline (%)	Replacement of Membranes and Chemical Consumption Over the Whole Life of the Asset (tCO2e) & Reduction vs Baseline (%)
75 MLD Water Reuse	2025-2040	Tanks	3,160 (-20%)	-
		Buildings	3,245 (-33.4%)	-
		Piling	2,495 (-23.8%)	-
		Pipework	700 (-23.9%)	-
		Other Assets	7,045 (0%)	-
		UF Membranes	-	3,120 (-18.2%)
		RO Membranes	-	1,970 (-22.1%)
		Chemicals	-	975 (0%)
		Subtotal	*16,645 (-17%)*	*6,065 (-17.1%)*
	2040-2060	Tanks	2,250 (-43%)	-
		Buildings	2,610 (-46.4%)	-
		Piling	1,550 (-52.7%)	-
		Pipework	375 (-59.2%)	-
		Other Assets	7,045 (0%)	-
		UF Membranes	-	2,430 (-36.3%)
		RO Membranes	-	1,690 (-33.2%)
		Chemicals	-	975 (0%)
		Subtotal	*13,830 (-31.1%)*	*5,095 (-30.4%)*
	2060-2100	Tanks	1,680 (-57.5%)	-
		Buildings	2,075 (-57.4%)	-
		Piling	960 (-70.7%)	-
		Pipework	320 (-65.2%)	-
		Other Assets	7,045 (0%)	-
		UF Membranes	-	2,430 (-36.3%)
		RO Membranes	-	1,690 (-33.2%)
		Chemicals	-	975 (0%)
		Subtotal	*12,080 (-39.8%)*	*5,095 (-30.4%)*

5.3.3 Analysis Results (Best Case)

Figure 5-16: 75MLD Desalination SRO - Decarbonisation Potential - Best Case (Whole Life Emissions, Excluding Power)

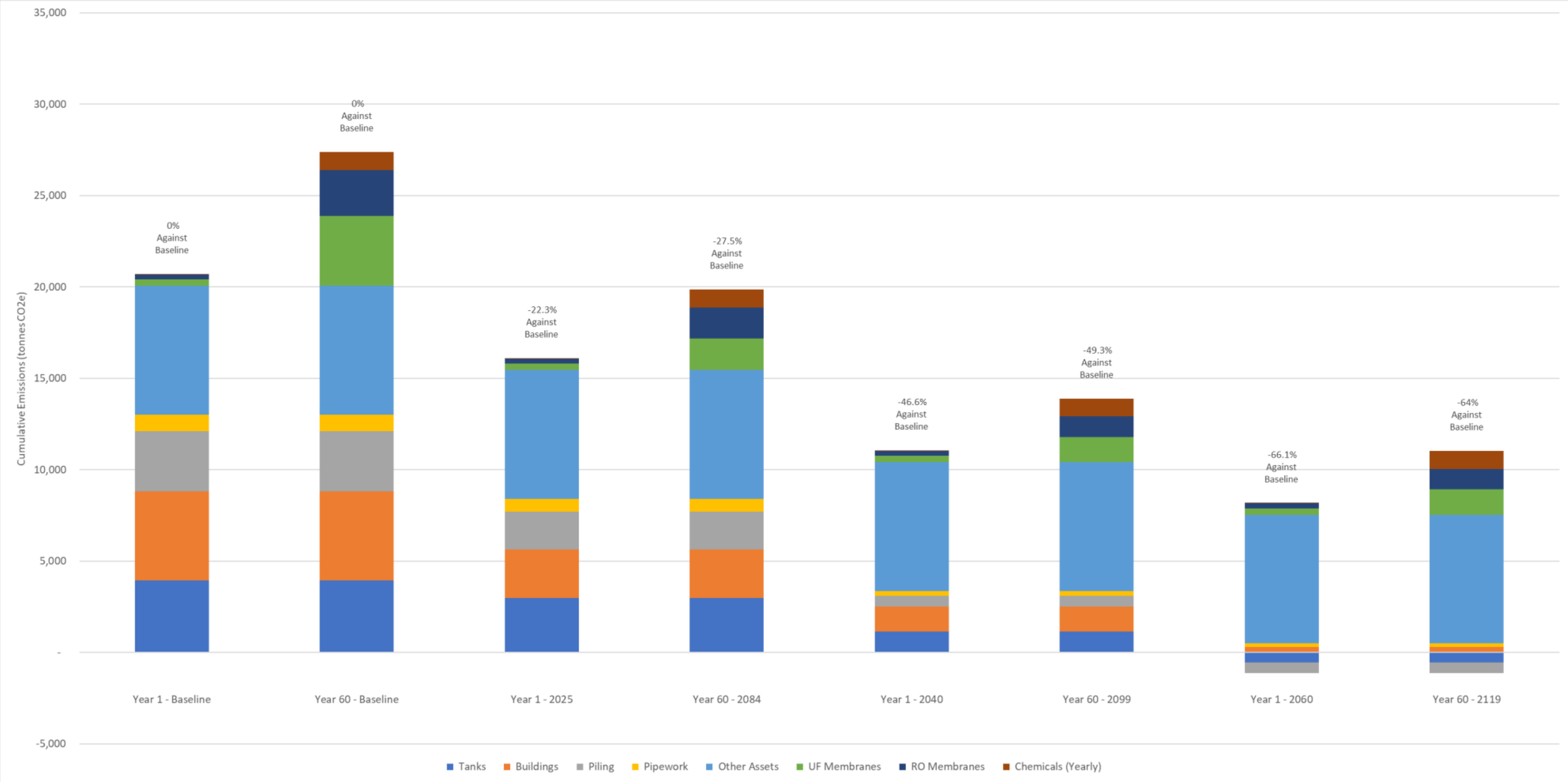


The figure above shows the estimated cumulative whole life emissions of the SRO during its first and last year of operation if it were constructed during the 2025-2040, 2040-2060 and 2060-2100 timeframes. This estimate includes capital carbon, chemical consumption, and membrane replacement, allowing for decarbonisation of hotspots noted in the previous sections.

Table 5-12: Desalination SRO - Decarbonisation Potential - Best Case

SRO	Year	Hotspot	Year 1 Capital Carbon Emissions (tCO2e) & Reduction vs Baseline (%)	Replacement of Membranes and Chemical Consumption Over the Whole Life of the Asset (tCO2e) & Reduction vs Baseline (%)
75 MLD Desalination	2025-2040	Tanks	6,655 (-24.3%)	-
		Buildings	3,515 (-45.8%)	-
		Piling	3,980 (-36.7%)	-
		Pipework	2,380 (-24%)	-
		Other Assets	8,460 (0%)	-
		UF Membranes	-	3,410 (-54.5%)
		RO Membranes	-	1,690 (-33.2%)
		Chemicals	-	10,025 (0%)
		Subtotal	*24,990 (-24.6%)*	*15,125 (-24.6%)*
	2040-2060	Tanks	2,545 (-71%)	-
		Buildings	1,835 (-71.7%)	-
		Piling	1,095 (-82.6%)	-
		Pipework	940 (-70%)	-
		Other Assets	8,460 (0%)	-
		UF Membranes	-	2,725 (-63.7%)
		RO Membranes	-	1,125 (-55.5%)
		Chemicals	-	10,025 (0%)
		Subtotal	*14,875 (-55.1%)*	*13,875 (-30.8%)*
	2060-2100	Tanks	-1,240 (-114.1%)	-
		Buildings	405 (-93.8%)	-
		Piling	-1,135 (-118.1%)	-
		Pipework	625 (-80%)	-
		Other Assets	8,460 (0%)	-
		UF Membranes	-	2,725 (-63.7%)
		RO Membranes	-	1,125 (-55.5%)
		Chemicals	-	10,025 (0%)
		Subtotal	*7,115 (-78.5%)*	*13,875 (-30.8%)*

Figure 5-17: 75MLD Water Reuse SRO - Decarbonisation Potential - Best Case (Whole Life Emissions, Excluding Power)



The figure above shows the estimated cumulative whole life emissions of the SRO during its first and last year of operation if it were constructed during the 2025-2040, 2040-2060 and 2060-2100 timeframes. This estimate includes capital carbon, chemical consumption, and membrane replacement, allowing for decarbonisation of hotspots noted in the previous sections.

Table 5-13: Water Reuse SRO - Decarbonisation Potential - Best Case

SRO	Year	Hotspot	Year 1 Capital Carbon Emissions (tCO2e) & Reduction vs Baseline (%)	Replacement of Membranes and Chemical Consumption Over the Whole Life of the Asset (tCO2e) & Reduction vs Baseline (%)
75 MLD Water Reuse	2025-2040	Tanks	2,990 (-24.3%)	-
		Buildings	2,640 (-45.8%)	-
		Piling	2,075 (-36.6%)	-
		Pipework	700 (-23.9%)	-
		Other Assets	7,045 (0%)	-
		UF Membranes	-	1,735 (-54.5%)
		RO Membranes	-	1,690 (-33.2%)
		Chemicals	-	975 (0%)
		Subtotal	*15,450 (-23%)*	*4,400 (-39.9%)*
	2040-2060	Tanks	1,145 (-71%)	-
		Buildings	1,375 (-71.8%)	-
		Piling	570 (-82.6%)	-
		Pipework	275 (-70.1%)	-
		Other Assets	7,045 (0%)	-
		UF Membranes	-	1,385 (-63.7%)
		RO Membranes	-	1,125 (-55.5%)
		Chemicals	-	975 (0%)
		Subtotal	*10,410 (-48.1%)*	*3,485 (-52.4%)*
	2060-2100	Tanks	-560 (-114.2%)	-
		Buildings	305 (-93.7%)	-
		Piling	-590 (-118%)	-
		Pipework	185 (-79.9%)	-
		Other Assets	7,045 (0%)	-
		UF Membranes	-	1,385 (-63.7%)
		RO Membranes	-	1,125 (-55.5%)
		Chemicals	-	975 (0%)
		Subtotal	*6,385 (-68.2%)*	*3,485 (-52.4%)*

5.4 Discussion

5.4.1 Worst Case Scenario

As seen in Section 5.3.1 embodied carbon for both desalination and water reuse SROs are reduced by ~15% in the 2025-2040 timeframe, and up to 30% in the 2060-2100. This is achieved principally though decarbonising concrete via optimisation of current practice and technology, in addition to design efficiencies and through a modest decarbonisation of heat and power within the steel industry.

In this worst-case scenario, only civil construction hotspots are anticipated to decarbonise, with no improvement in membrane replacement frequency. As such, across all timeframes considered, the majority of whole life emissions (excluding power) are associated with membranes, accounting for between 20% and 30% of emissions. As the reduction in emissions from chemical consumption has not been quantified, this too contributes significantly towards whole-life emissions.

As noted in Figure 5-8 and Figure **5-9**, 71 and 41 asset/ equipment classes are responsible for 14% and 9% of capital carbon emissions across the desalination and water reuse SROs. As this analysis has focused on the decarbonisation of major hotspots, the carbon emissions from other smaller assets/equipment become a key contributor towards the capital carbon emissions for SROs, accounting for between 40% and 50% of capital carbon emissions (when considering the worst-case decarbonisation of major capital carbon hotspots). Although the decarbonisation of these smaller assets/ equipment has not been assessed in this study, it is likely that many of these comprise similar materials to those underpinning the carbon emissions for larger hotspots and are inherently likely to decarbonise also.

5.4.2 Middle Case Scenario

As seen in Section 5.3.2, capital carbon for both desalination and water reuse SROs is reduced by ~20% in the 2025-2040 timeframe, and up to 40% in the 2060-2100. Like the worst-case scenario, this is achieved principally though decarbonising concrete via optimisation of current practice and technology. However, the development and adoption of AACMs are critical to unlocking further decarbonisation of concrete.

In addition to the decarbonisation of concrete, this middle-case scenario will require further efforts to achieve design efficiencies, improve reuse and recycling, and will rely on more ambitious targets to enable the decarbonisation of heat and power within the steel industry.

In this middle-case scenario, membrane lifespans are assumed to gradually improve over time. As such, greater efficiencies are seen when constructing assets in the 2040-2060 and 2060-2100 timeframes, achieving up to a 30% reduction in carbon emissions from membranes.

As noted in Section 5.4.1, as the larger carbon hotspots decarbonise, smaller assets/ equipment classes become a key contributor to carbon emissions of SROs. As the major hotspots are decarbonised further in this middle case, the smaller assets and equipment become even larger contributors, accounting for between 50% and 60% of capital carbon emissions (when considering the middle-case decarbonisation of major capital carbon hotspots). Although the decarbonisation of these smaller assets/ equipment has not been assessed in this study, it is likely that many of these comprise similar materials to those underpinning the carbon emissions for larger hotspots and are inherently likely to decarbonise also.

5.4.3 Best Case Scenario

As seen in Section 5.3.3, capital carbon for both desalination and water reuse SROs is reduced by ~30% in the 2025-2040 timeframe, and up to ~60% in the 2060-2100. Similar to the two previous scenarios, this is achieved principally though decarbonising concrete via optimisation of current practice and technology, and adoption of AACMs. However, technological developments facilitating carbon sequestration within concrete are critical to achieving high levels of decarbonisation.

As seen in Table 5-12 and Table 5-13, a best-case combination of carbon-negative concrete, low-carbon steel reinforcement, and the use of zero-emissions plant, indicates an opportunity to construct carbon-negative tanks and foundations if carbon sequestration within concrete is achieved.

In addition to the decarbonisation of concrete, this best-case scenario will require substantial efforts to allow a significant rate of reuse of steel components, in addition to relying on highly ambitious targets to enable the decarbonisation of heat and power within the steel industry.

In this best-case scenario, membrane lifespans are assumed to significantly improve over time, in addition to the adoption of ceramic membranes. As such, greater efficiencies are seen when constructing assets in the 2040-2060 and 2060-2100 timeframes, achieving up to a 65% reduction in carbon emissions from membranes.

As discussed previously, as the major hotspots are decarbonised further in this best case, the smaller assets and equipment become even larger contributors, accounting for up to 90% of capital carbon emissions (excluding carbon sequestration of concrete tanks and foundations). Although the decarbonisation of these smaller assets/ equipment has not been assessed in this study, it is likely that many of these comprise similar materials to those underpinning the carbon emissions for larger hotspots and are inherently likely to decarbonise also.

5.5 RAG Scale

Table 5.14 shows a summary red/amber/green (RAG) scale of the overall capital emission savings for the 'middle case' desalination SRO. Wastewater reuse SROs are expected to be similar. The RAG scale can be broken down as follows:

- A 0-25% reduction against the baseline emissions is red
- A 26-75% reduction against the baseline emissions is amber
- A 75+% reduction against the baseline is green

Table 5.14: RAG scale for Desal SROs

Item	***Scenario***	***Construction before 2025***	***2025-2040***	***2040-2060***
		(% Reduction Against Baseline)		
Operational Carbon	Starts operation 2025 (This is the baseline case)	0%	-	-
	Starts operation on or after 2040	-	50-55% (against whole life carbon)	
Desal and Reuse Capital Carbon	Worst case	11%	19%	21%
	Mid case	11%	29%	35%
	Best case	25%	46%	61%

Notes: "Baseline" in this case is defined as a do nothing approach, whereby the desal plant is constructed with conventional plant used today, and put into operation in 2025. Operational carbon savings are shown against the whole life carbon of the project. Capital carbon savings are shown relative to the baseline capital carbon (emissions arising from power are omitted). Note: capital carbon also includes membrane replacements and chemical consumption over a 60 year operating lifespan.

While operational carbon emissions are simply a function of electrical grid factor decarbonising with time, capital carbon reductions arise from a multitude of sources. Some reductions may be harder than others, for example reducing emissions from tanks compared with buildings. In light of that, a summary table is provided below for a desalination plant, to show where the emission reductions come from (Table 5.15). The numbers for a wastewater reuse SRO are similar, but have been omitted for clarity.

Table 5.15: Contributions to capital carbon for desalination plants – middle case

Item	*Constructed before 2025*	*2025-2040*	*2040-2060*
	% Reduction against baseline		
Tanks	3%	7%	9%
Buildings	3%	6%	7%
Piling	3%	6%	8%
Pipework	1%	3%	4%
Other assets	0%	0%	0%
UF Membranes	0%	5%	5%
RO Membranes	0%	1%	2%
Chemicals	0%	0%	0%
Total Capital Carbon Savings	11%	29%	35%

Note: Emissions from chemicals are not assumed to reduce in any of the scenarios, as discussed in Section 5.2.8, given their complex global supply chains and the lack of published decarbonisation trajectories for the industry.
Baseline refers to the capital carbon for the whole project, plus membrane replacements and chemical consumption over a 60 year operating life.

5.6 Recommendations for Gate 2 Application

The largest emissions savings would arise from a operating the SROs further into the future when grid electricity has further decarbonised. The decision of when these schemes are delivered, however, will be driven by other priorities – such as availability of water, resilience, etc. Therefore, aside from delaying delivery of these SROs or having direct renewable energy (ie, embedded generation sources with private wire), Water Companies can focus efforts on reducing capital carbon.

Following the current industry pace, and with a good level of supply chain engagement, the middle case can be used as a likely trajectory for both desalination and reuse plants Achieving the ‘middle case’ in capital carbon would require:

- **Concrete**: Optimising current practice and technology, including fly ash from stockpiles and widespread adoption of mixes that use limestone powder, calcined clay, and/or volcanic ash as SCMs
- **Concrete long term**: Engage with supply chain to also adopt AACMs based on calcined clays or volcanic ash
- **Reinforcement Steel**: Maintain current levels of rebar recycling. Engage with supply chain to increase deployment of stove flue or top gas recycling in most BF-BOF sites. Rebuild of plants with advanced steel production technology

- **Membranes**: Work with and challenge suppliers to develop longer lasting composite plastic membranes.

If outperformance of the ‘middle case’ is desired progressing towards the best case, acceleration in any of the capital carbon hotspots (concrete, steel, buildings, or membranes) could be targeted. The greatest leverage point would be to accelerate decarbonisation of concrete, which would require close engagement with the supply chain to promote lower concrete alternatives as noted in the discussion section above.

It is important for water companies to have a more strategic engagement with chemicals suppliers, through Water UK or other industry bodies to better understand the manufacturing processes, global supply chain logistics as well as the potential to swap chemicals with lower carbon alternatives for any of the desal or reuse options. UKWIR has done a research project over the years on chemicals and greenhouse gas emissions however the sector’s understanding needs to significantly improve.

A. Annex

A.1 Supplier Outreach

The production of the content within this report was supported by a range of suppliers. Table A.1.1 shows a list of suppliers engaged during the assembly of this report.

Table A.1.1: Suppliers engaged during assembly of report

Name	Company, Role	Info
Leon Woods	Amiblu, Technical Sales Manager	Correspondence on future decarbonisation of GRP
Barry Price	Electrosteel, Head of Technical and Quality	Correspondence on future decarbonisation of ductile iron (pipelines)
Ian Harding	FT Pipeline Systems, Managing Director	Correspondence on future decarbonisation of steel (pipelines)
Marc Hennessy	Peak Pipe Systems, Commercial Director	Correspondence on future decarbonisation of HPPE
Neil Hodgkinson	Radius, National Sales Manager	Correspondence on future decarbonisation of HPPE

Attempts to reach out to the suppliers listed in Table A.1.2 were unsuccessful.

Table A.1.2: Suppliers for which engagement was unsuccessful

Company	Info
Saint-Gobain	DI
Molecor	MoPVC
Westwood Pipes	HPPE
Aliaxis	HPPE
Severn Trent Water	Chemical
Enviro UK	Chemical
Chemiphase	Chemical