

# Global Lighthouse Network: The Mindset Shifts Driving Impact and Scale in Digital Transformation

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The Global Lighthouse Network (GLN) is the leading industry community celebrating the world's top-performing production and operations sites. Network members showcase proven performance improvements and achieve operational excellence across technology, talent and sustainability domains. The Global Lighthouse Network is a World Economic Forum initiative. The initiative was co-founded with McKinsey & Company and is counselled by an advisory board of industry leaders who are working together to shape the future of global manufacturing. The Advisory Board includes Foxconn Industrial Internet, Johnson & Johnson, Koç Holding, McKinsey & Company, Schneider Electric and Siemens. Sites and value chains that join the network are designated by an independent panel of experts.

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# Executive summary

This white paper celebrates six years of the Global Lighthouse Network as the leading learning community for world-class operational excellence in production at scale.

The Global Lighthouse Network (GLN) recognizes leaders in the production ecosystem that have achieved exceptional impact on productivity and sustainability, enabled by digital transformation. After six years, the GLN has expanded from 16 to 189 Lighthouses, representing factory, sustainability and end-to-end value chain categories across 33 countries and 35 subsectors – four times greater than in 2018. This diversity is what powers the GLN – a network of peers that share knowledge and insights to accelerate their transformation journeys.

Among new Lighthouses, 65% cited learning from at least three other Lighthouse sites – often outside their own sector – and two other ecosystem partners during their transformation. These 189 Lighthouses, 1,000+ use cases and 2,000+ metrics prove the Lighthouse transformation playbook. Those who follow it have moved beyond the “pilot purgatory” that early Lighthouses faced – where pilot schemes struggled to reach full scale – to achieve ROI of 2-3x over three years and 4-5x over five years.

The latest 36 Lighthouses have not only followed the playbook but are continuing to innovate. They illuminate three leading-edge lessons:

- **They are tackling the digital “scaling slump”** with a mindset to assetize<sup>1</sup> use cases as enterprise capabilities, while partnering with their frontline workforces to localize adoption.
- **They are investing in their frontline workforce**, focusing on productivity and stability in equal parts. Lighthouses design a range of talent solutions specifically tailored to develop and engage each site’s local workforce.
- **They are progressing towards end-to-end sustainability**, building on top of the tech-enabled eco-efficiency solutions pioneered by early Lighthouses with investments in value chain data and new partnership models, which will underpin circularity in the future.

Amidst the recent AI hype, Lighthouses have cracked the code on site implementation: 77% of the top five use cases of this year’s Lighthouses were enabled by analytical AI and 9% leverage generative AI (GenAI). All have unlocked step-changes in performance – averaging improvements of more than 50% in conversion cost, cycle times and defect rates.

How have Lighthouses found impact where others are still exploring potential? The differentiator is their approach to large language models (LLMs) and other new technologies, which remains consistent with the playbook proven through adoption of earlier technology, such as the industrial internet of things (IIoT). They stay laser-focused on a “value-back” approach to reduce process debt; invest in foundational capabilities across people, process and technology; assetize solutions for scale; and partner with frontlines to localize engagement and adoption. Chapter 2 explores these mindset shifts in detail.

Beyond productivity, Lighthouses also deploy technology across their value chains to drive agility, resilience and sustainability. Data platforms that connect customer, supplier, process, product, market and sustainability data bring visibility and intelligence to the many intricate decisions required to optimize value chain performance. These approaches include:

- Intelligent product introduction tool suites with capabilities for one-click product design, process simulations, pricing and bid preparation.
- Integrated resilience hubs that manage numerous spokes with ensembles of AI models for forecasting demand and disruption, simulating processes, optimizing planning, orchestrating logistics and more.
- Technology- and partnership-enabled circularity solutions to drive lifecycle emissions reduction, with a particular focus on scope 3.

For the value chains flowing through Lighthouse sites, these approaches have delivered 50% reductions in new product introduction times. Lighthouses have experienced eight times less revenue shock than their peers in the wake of the pandemic and have achieved a reduction of between 30% and 50% in scope 1 and 2 emissions, as well as initial improvements in scope 3 emissions. Chapter 3 explores these value chain solutions in detail.

Lighthouses continue to represent the leading edge of holistic performance for sites, production networks and value chains. They have proven that “pilot purgatory” can – and should – be surpassed, with a playbook that has worked for 189 sites and counting. They are continuing to advance the

performance frontier by innovating with impact through technology, talent and sustainability solutions. It has never been easier to learn from this playbook and repeat it.

In the next chapter of the Fourth Industrial Revolution, the focus must shift from learning to doing – the global transformation of industry will require millions of production sites, not hundreds. Fast followers should be celebrated for following the Lighthouse playbook quickly, efficiently and effectively to achieve holistic performance. The Global Lighthouse Network is excited to rise to the occasion, with a rigorous framework that recognizes sites demonstrating operational excellence in all performance domains: technology, talent and sustainability.



1

# Lessons from the latest Lighthouses

Launched in 2018, the Global Lighthouse Network (GLN) – a World Economic Forum initiative co-founded with McKinsey and today led by a coalition of industry partners – showcases leaders who make positive, measurable impacts on productivity and sustainability, enabled by technology.

In today's dynamic and technology-driven industrial age, the leading organizations of the Global Lighthouse Network (GLN) cut through the fog and light the way for others. Launched with a mission to carry forward the ambition of the Fourth Industrial Revolution (4IR), the GLN is now a global beacon for those striving to achieve industry-leading operational performance, with each member an indisputable leader in its respective industry. To reflect these ambitions, the GLN has assembled an advisory board to help steer the Network's future direction, including Foxconn Industrial Internet, Johnson & Johnson, Koç Holding, McKinsey & Company, Schneider Electric and Siemens.

This paper introduces these aspirational Lighthouses and explores how they have pushed through the scaling slump and achieved step-change impact through advanced applications of technology use cases, frontline talent innovations and sustainability solutions. By telling their stories, the GLN seeks to inspire transformational change, foster collaboration and shape a better future for all players in the ecosystem.

Lighthouses in 2024 were evaluated in two cohorts, reflecting the two application waves offered each year. They received recognition for their distinctive performance in digital and sustainability domains (see Table 1)

TABLE 1 In which categories were Lighthouses awarded in 2024?

Awards categories	
Based on the proven impact of solutions	
	<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <h2>Digital Lighthouses</h2>  </div> <div style="width: 45%;"> <h2>Sustainability Lighthouses</h2>  </div> </div>
<b>Description</b>	<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p><b>Digital Lighthouse Awards</b> recognize organizations and production ecosystems (single sites and end-to-end value chains) that have achieved <b>step-change impact in productivity</b> through <b>technology-enabled transformation</b> in their production sites and wider production ecosystems.</p> </div> <div style="width: 45%;"> <p><b>Sustainability Lighthouse Awards</b> recognize organizations, projects and production ecosystems that have achieved <b>step-change impact</b> through <b>industry-leading reductions</b> in energy, emissions, water and waste in pursuit of a holistic set of <b>net-zero, decarbonization</b> and <b>circularity goals</b>.</p> </div> </div>
<b>Impact domains</b>	<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <ul style="list-style-type: none"> <li>– <b>Factory:</b> focuses within the four walls of the factory on asset utilization, worker enablement, quality improvement and resource optimization.</li> <li>– <b>E2E value chain:</b> connects with suppliers and customers to improve planning, service and working capital.</li> </ul> </div> <div style="width: 45%;"> <ul style="list-style-type: none"> <li>– <b>Decarbonization and circularity:</b> achieves or on track to achieve net-zero emissions in factories, supply chains and/or products; transforms resource loops; builds with circular materials; and designs circular products to eliminate lifecycle waste and water.</li> </ul> </div> </div>

**Note:** Award categories will be updated for 2025, reflecting GLN's ongoing commitment to recognize the most operationally excellent production sites and value chains.  
**Source:** Global Lighthouse Network.

# 1.1 The GLN today: a network of inspirational peers

The GLN began as a group of 16 leading factories. Today it includes 189 sites from over 30 countries and 35 industries at the frontier of operational performance.

At the outset, the GLN looked for factories that had escaped pilot purgatory and successfully deployed cutting-edge technology innovations with impact. These pioneering sites and value chains served as early examples of 4IR's capability for transformational change in manufacturing performance and provided a blueprint for achieving it.

Today's 189 Lighthouses represent factory, sustainability and end-to-end value chain categories. The network extends to 30+ countries and 35 subsectors, four times greater than in 2018. Lighthouses have generated 1,000+ use cases and 2,000+ metrics, proving that the pilot

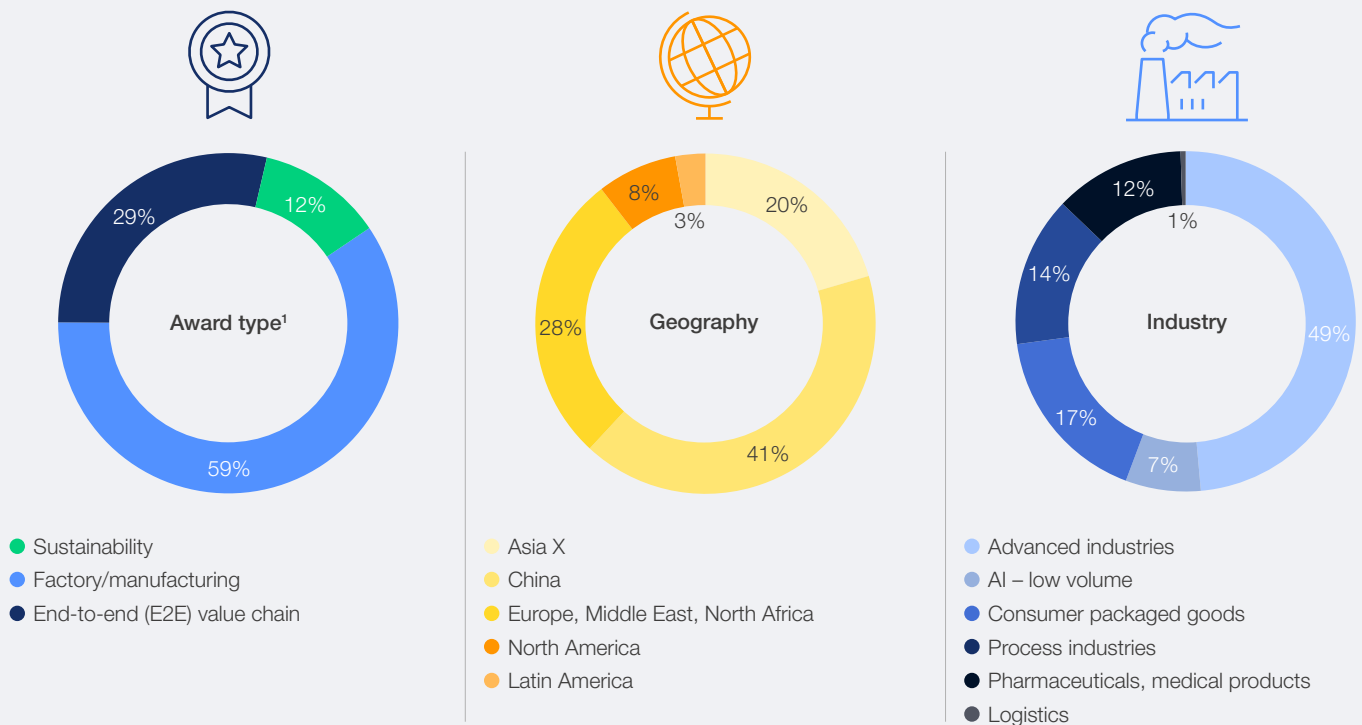
purgatory challenges that were once faced by early Lighthouses can be overcome. The last three Lighthouse cohorts have reported achieving gains from transformations in just 10 to 20 months, or on average 25% to 50% faster than the first three Lighthouse cohorts.<sup>2</sup> This has generated an even higher return on investment (ROI) than the average Lighthouse transformation: two to three times higher over three years and four to five times higher over five years.<sup>3</sup>

Figure 1 illustrates the distribution of Lighthouse sites by award type, geography and industry. Lighthouse representation is growing at an average rate of five new countries per year and 10 new subsectors represented per cohort, with recent growth in heavy equipment, upstream materials and food and beverages and regionally across Central and Southeast Europe, South and Southeast Asia and parts of the Americas.

🗨️ Lighthouses have generated 1,000+ use cases and 2,000+ metrics, proving that the pilot purgatory challenges that were once faced by early Lighthouses can be overcome.

FIGURE 1 Lighthouses are growing in diversity – composition in 2024

% of total Lighthouse sites per award type, geography and industry



1. There were three award types given in 2024: Sustainability, Factory/manufacturing and E2E value chain. For more information on awards, see Table 1.

Source: Global Lighthouse Network.

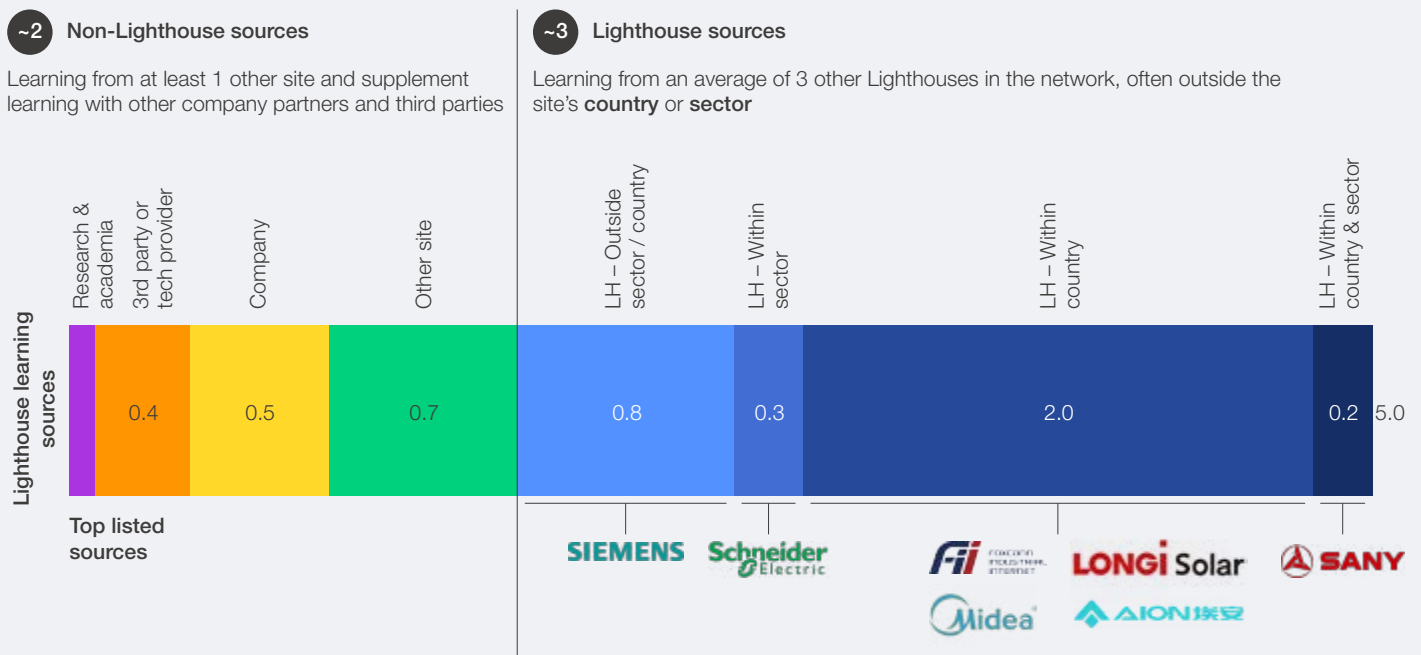
One of the driving forces of the impact of the Global Lighthouse Network lies within its name: it is a network of peers that share knowledge and insights – even between competitors – enabled by the Forum’s platform. This multi-stakeholder, cross-industry collaboration empowers the community to skip past pilots and focus on learning the “how” of transformation. Lighthouses know that transformations are a team sport – and their open secret to deploying and scaling-up technology solutions in six months or less<sup>4</sup> is that they never start completely from scratch. This year, 65% of Lighthouses reported learning from an average of three Lighthouse sites and two other ecosystem

partners throughout their transformation.<sup>5</sup> Surprisingly, only 18% of the learning partners listed by Lighthouses came from their own sector, with some such as automotive, industrial automation and electronics inspiring an average of eight other sector categories, highlighting the importance of cross-industry knowledge-sharing.<sup>6</sup>

Figure 2 shows a breakdown of learning sources for Lighthouses’ transformations. They reported learning from an average of three other Lighthouse sites, often outside their country or sector and two non-Lighthouse sources such as other sites, company partners and third parties.

FIGURE 2 Lighthouses are inspired by others

Number of learning sources listed by Lighthouses<sup>1</sup>



1. Based on non-evaluative survey responses, Cohorts 12 and 13 (awarded in 2024); LH = Lighthouse.

Source: Global Lighthouse Network.



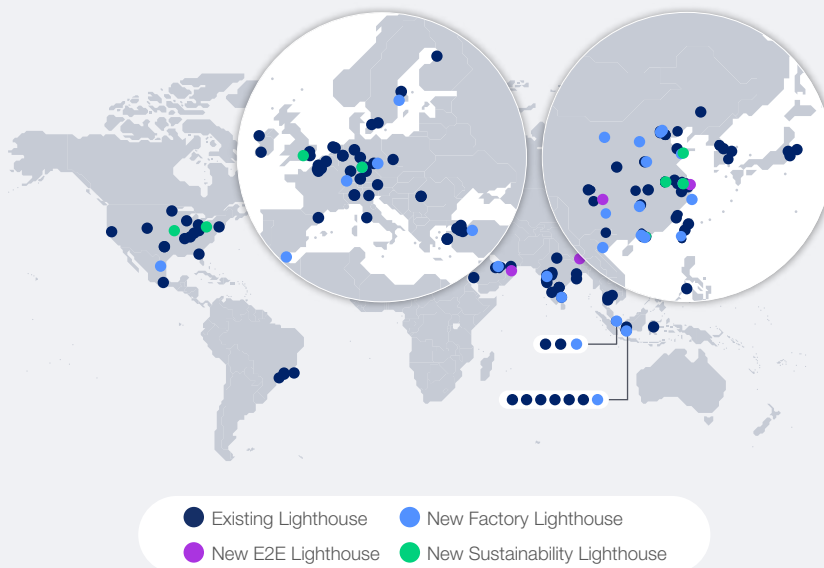
# 1.2 Introducing the new Lighthouses of 2024: raising the bar for operational excellence

Operational excellence is achievable by everyone: new regions, sectors and solutions.

The GLN is proud to welcome an additional 36 Lighthouses assessed in 2024 (see Figure 3). They span 30+ countries, including newcomers

Switzerland, Viet Nam and Morocco, home to the first Lighthouse site on the African continent. They also reflect a wider range of industries – with subsector representation more than quadruple that of 2018<sup>7</sup>– including such sectors as upstream chemical and materials, nuclear energy and wind power.

FIGURE 3 New Lighthouses in 2024



### Automotive



- 1 **Continental**  
Brandys nad Labem, Czech Repub.
- 2 **Valeo Interior Controls**  
Shenzhen, China

### Personal care



- 3 **Unilever**  
Tinsukia, India

### Home appliances



- 4 **Beko**  
Ankara, Turkey
- 5 **Haier**  
Qingdao, China
- 6 **Hisensehitachi**  
Qingdao, China
- 7 Previously awarded – E2E  
**Midea**  
Hefei, China

### Tires



- 8 **CEAT**  
Sriperumbudur, India
- 9 **Guizhou Tyre**  
Guiyang, China

### Non-ferrous metals products



- 10 **Emirates Global Aluminium**  
Al Taweelah, UAE
- 11 **Novelis**  
Uhrichsville, United States
- 12 **CITIC Dicastal**  
Ameur Seflia, Morocco

### Semiconductors



- 15 **United Microelectronics Corporation**  
Tainan

### Energy



- 13 **Sanmen Nuclear**  
Taizhou, China

### Renewable energy



- 14 **Sany Renewable**  
Taizhou, China

### Electronics



- 16 **Foxconn Industrial Internet**  
Bac Giang, Vietnam
- 17 Previously awarded – Factory  
**Foxconn Industrial Internet**  
Shenzhen, China
- 18 **Schneider Electric**  
Monterrey, Mexico

### Pharmaceuticals



- 19 **AstraZeneca**  
Södertälje, Sweden
- 20 **AstraZeneca**  
Wuxi, China
- 21 **Roche**  
Basel, Switzerland

### Steel products



- 22 **Beijing Shougang Cold Rolling**  
Beijing, China
- 23 **Nucor Corporation**  
Sedalia, United States
- 39 **TZ Railway Transit**  
Taiyuan, China

### Food & beverage



- 25 **Coca-Cola**  
Tuas Bay, Singapore
- 26 **Mengniu Dairy**  
Ningxia, China
- 27 **Tsingtao Brewery**  
Qingdao, China
- 28 **Haitian Flavouring & Food**  
Foshan, China

### Oil and gas



- 29 **Aramco**  
North Ghawar, Saudi Arabia

### Industrial automation



- 30 **Siemens**  
Fürth, Germany
- 31 **Siemens**  
Erlangen, Germany
- 32 Previously awarded – E2E  
**Schneider Electric**  
Wuxi, China
- 33 **Schneider Electric**  
Shanghai, China

### Medical equipment



- 34 **GE Healthcare**  
Beijing, China

### Construction project



- 35 **Ferrovial**  
London, UK

### Laboratory equipment



- 36 **Agilent Technologies**  
Shanghai, China
- 37 **Agilent Technologies**  
Penang, Malaysia

### Chemicals



- 24 **Jubilant Ingrevia**  
Bharuch, India

### Industrial equipment



- 38 **Midea**  
Chongqing, China
- 40 **Zhengzhou Coal Mining Machinery**  
Zhengzhou, China

Source: Global Lighthouse Network.

FIGURE 4 | Three lessons from Lighthouses at the leading edge

1.

**With digital technology proliferation, the recipe for scaling-up has largely been solved.**

Leaders break through with a **holistic performance** mindset, starting at the frontline and growing through network-wide knowledge-sharing and collaboration.

2.

**People are the key to transformation success.**

Frontline **adoption** is a critical enabler to performance transformation and an intrinsic sign of its success. The world's leading movers and makers are **localizing** their talent strategies with innovations in work design, planning, attraction and development that have unlocked Lighthouse levels of performance.

3.

**Tech-enabled eco-efficiency was the first horizon for sustainability, but a step change is needed for net zero.**

Leading edge operators are advancing **decarbonization** and **circularity goals** through novel materials and nanoscience, new business models and value chain partnerships. Often enabled by technology, these innovations will define the next chapter of Sustainability Lighthouses.

Source: Global Lighthouse Network.

**Lessons from the latest Lighthouses: technology, talent and sustainability on the path to performance**

What unites Lighthouses is a common playbook committed to sustainable and scalable digital transformations. Instead of technology, these sites attribute their success to a mindset focused on holistic performance – ranging from operational efficiency and environmental impact to frontline capabilities.

**1. Technology**

Today, instead of pilot purgatory, those at the frontier of digital innovation are facing a “scaling slump” where initial pilot successes fail to translate into scalable, sustainable network impact. Lighthouses know that most scaling-up endeavours are born locally – and invest first at the site-level, optimizing processes, cultivating capabilities

and deploying use cases suited to local needs. Lighthouses package assets for network-wide sharing and remove any barriers to transferring knowledge with formats that translate across a diverse operating base.

**2. Talent**

Transformation approaches at Lighthouses are deeply rooted in people: 75% of Lighthouses have deployed solutions in each of five priority areas for frontline talent management – safety, skill development, skill augmentation, work augmentation and worker experience.<sup>8</sup> These sites develop holistic talent approaches adapted to local contexts, across both technical and leadership capabilities. When digital talent is scarce, an ecosystem of partnerships enables Lighthouses to offer a suite of programmes suited to an employee’s unique skillset or development goals.

**EXAMPLE**

**CITIC Dicastal**

CITIC Dicastal in Morocco collaborated with three regional universities and an international education institute to train nearly half of the site’s workforce in new digital skills, based on gaps identified through competency matrix sorting and 360-degree performance assessments. This reduced employee turnover by 21% and replaced 65% of full-time equivalent (FTE) employees from headquarters with local talent.<sup>9</sup>

Lighthouses also build up leadership capabilities alongside technical capabilities, with 61% of them ranking transformation offices (TOs) as one of their top two enablers for transformation.<sup>10</sup>

Cross-network leadership then shares lessons and accelerates scale-up. Lighthouses invest in people capabilities as both an input and an outcome of their performance transformations.

#### EXAMPLE

#### The Coca-Cola Company

Coca-Cola in Singapore participated in monthly global “show & tells” with leadership across 18 sites, enrolled site leads in over 5,000 hours of training at Coca-Cola’s global digital academy and welcomed subject matter experts from seven regional sites on short-term exchanges to facilitate knowledge sharing.<sup>11</sup>

### 3. Sustainability

Tech-enabled digital transformation is advancing sustainability ambitions and providing the platform for more holistic circularity and decarbonization innovations with real business benefits. These benefits include enhanced supply chain resilience, with a 25-50% reduction in inventory and 15-30%

improvements to on-time delivery, as well as resource efficiency, with an average reduction of 30% in material waste and 25% in energy and water consumption – often in response to concerns for local resource availability and cost.<sup>12</sup> Lighthouses are also improving value chain sustainability with circular business models, material science and product or packaging design.

#### EXAMPLE

#### Midea, Foxconn Industrial Internet and Ferrovial

**Midea** in China optimized product designs for simplified structures and reduced or alternative materials with AI-enabled carbon lifecycle analysis and simulation models, reducing scope 3 emissions by 28%. **Foxconn Industrial Internet** in China overcame metallurgical challenges to closed-loop recycling of aluminium tailings with suppliers, replacing virgin input by 75%. **Ferrovial** in the United Kingdom created a closed loop for excavated construction waste, diverting nearly 100% from landfill by using it to fill foundations or create new aggregate at the London Heathrow Airport site.<sup>13</sup>

These pioneering sites demonstrate that it is the mindset that matters – tuning out noise to stay hyper-focused on holistic impact, designing with and for the workforce and investing in

scalability and adoption. The 2024 cohorts highlight how this approach continues to be essential to Lighthouses’ success. Chapter 2 explores this in more detail.



# 1.3 Trends in technology: AI hype and Lighthouse adoption

“ On average, AI-enabled use cases have driven an improvement of more than 50% in conversion costs, cycle times and defect rates for Lighthouses.

Much of the discussion around AI is still focused on potential rather than proven applications. Many lament how AI is falling short, even hindering workers’ productivity. A report in July 2024 found that despite 96% of C-suite executives expecting AI to boost efficiency, 77% of employees reported it adding to their workload.<sup>14</sup> In production settings, AI’s lack of real-world impact<sup>15</sup> has stalled deployment relative to the global average, with a recent survey revealing a 35 percentage point (p.p.) drop year-over-year in leaders planning to increase AI spend (down from 93% in 2023).<sup>16</sup> Some organizations are finding it difficult to make the business case for investment, especially in some countries where the requisite talent is expensive. For example, in the US, hiring just three key roles for AI development can cost nearly a half million dollars.<sup>17</sup>

This is not unusual. Just five years ago, there was similar hype around IIoT and its promise of real-time connectivity. Today, mindful of the costs of connection, sites deploy IIoT selectively in domains offering the highest returns – such as predictive maintenance, inventory management and asset tracking. AI breakthroughs are following a similar

trend. As with IIoT, Lighthouses remain ahead of the curve: 77% of their top five use cases feature analytical AI, up from an average 62% in 2023 and 9% now feature generative AI (GenAI).<sup>18</sup> Figure 5 shows the growth in AI-enabled use cases among Lighthouses’ top five presented during site evaluations and a breakdown of AI applications by domain for the 2024 cohorts. On average, these use cases have driven an improvement of more than 50% in conversion costs, cycle times and defect rates<sup>19</sup> for Lighthouses.<sup>20</sup>

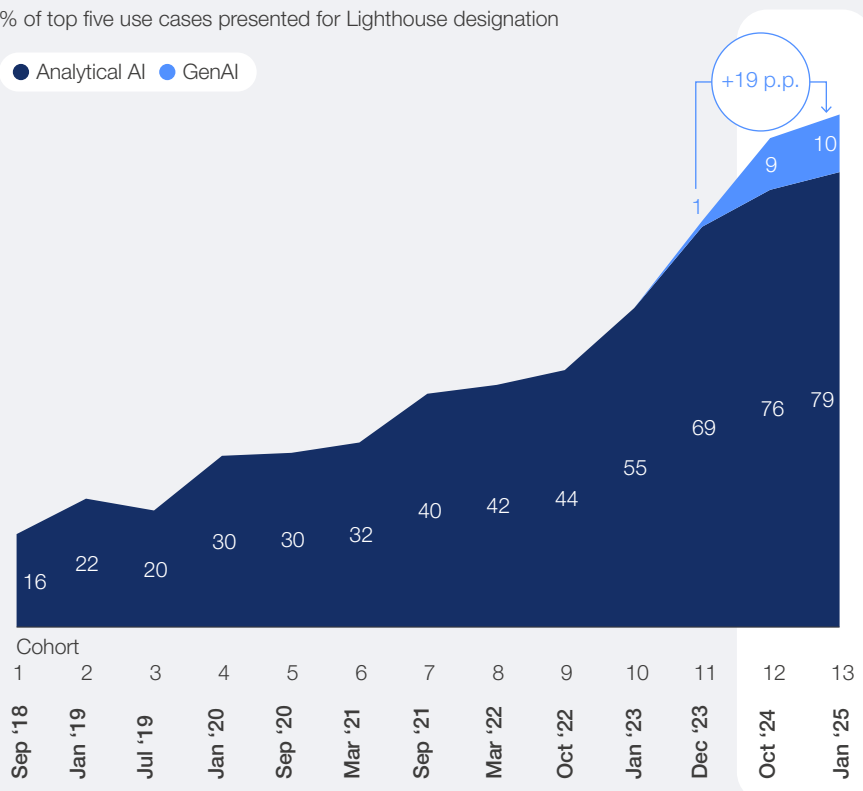
From digital twins<sup>21</sup> to LLMs, each technology innovation is as new to Lighthouses as it is to everyone else. It is easy to forget that commercial-grade LLMs first became available only a few years ago. What has stayed consistent for Lighthouses is their mindset: value-backed approaches, rooted in real business needs.

The following chapters will delve deeper into the mindsets that distinguish Lighthouses from the rest and provide practical examples of how they have cut through the hype in both their production sites and value chains.

FIGURE 5 Analytical and GenAI use case composition<sup>1</sup> by Lighthouse cohort

% of top five use cases presented for Lighthouse designation

● Analytical AI ● GenAI



2024 cohorts applied AI across the value chain, # of use cases by domain



1. Out of top five use cases for each Lighthouse

Source: Global Lighthouse Network.

2

# The mindset for making digital transformation stick

Competing in a dynamic technology landscape demands a mindset and investment approach focused on enabling the people on the frontline of transformational change.

“ For every \$2 spent on tech innovation, Lighthouses spend \$3 on process debt reduction and \$5 on scaling-up and adoption.

Lighthouses resist the temptation to invest in every new technology trend, instead investing roughly four times as much on the process and people enablers as they do on new technology. That means for every \$2 spent on tech innovation, Lighthouses spend \$3 on process debt reduction and \$5 on scale and adoption. By contrast, most players in the production space spend closer to one or two times their tech investment on these same enablers.

Lighthouses are embracing four approaches to implementing and sustaining impact at scale (see Figure 6):

- Preventing process debt.
- Investing in people, process and technology capabilities.
- Assetizing for scale, meaning the deployment of structures and tools to scale solutions quickly
- Taking a localized approach to solution adoption by the local frontline talent.

This chapter will explore each of these approaches and what they mean in practical terms, presenting real examples from the 2024 Lighthouse cohorts.

FIGURE 6 Lighthouse approaches to implement and sustain impact at scale

Preventing process debt

What process changes and solutions do I deploy site-wide?

- Understanding process debt
- Optimizing information flows
- Designing data flows to enable people and material

Localizing adoption with the frontline

How do I give the frontline tools to drive digital change?

- Designing human-centric processes
- Investing in the frontline
- Building adoption programmes to make digital stick

Investing in your capabilities

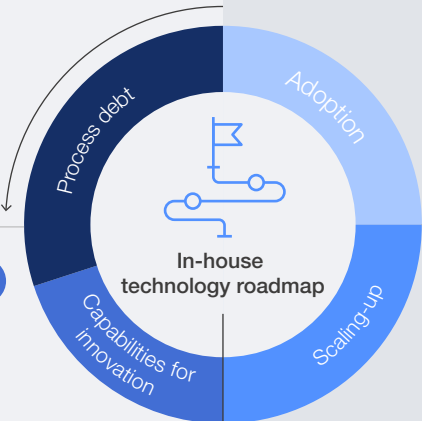
Who do I need to bring digital to the frontier?

- Selecting the right development approach
- Being digitally driven, but not just by technologists

Assetizing for scale

What do I need to scale-up solutions network-wide?

- Deploying composable assets (modular, reusable components for scalability)
- Empowering the workforce with low/no-code tools



What differentiates enabling use cases vs. sustainable investment for Lighthouses is an **in-house technology roadmap** with clearly defined priorities. This often enables sites to develop technical capabilities simultaneously across centres of excellence (CoE) to support large-scale deployment.

Source: Global Lighthouse Network.

## 2.1 Preventing process debt

### Understanding process debt

All Chief Information Officers (CIOs) know of technical debt, which accumulates when many disjointed solutions are deployed over time, compounding the costs to ultimately fix and integrate them. Eventually a “tax” must be paid to improve system-wide performance – a costly barrier to scaling-up endeavours.<sup>22</sup>

In today’s tech-enabled world, all Chief Operating Officers (COOs) should think similarly about their process debt. The value-add of a new technology is rarely in the technology itself, but in the process improvements it enables. Counsel on how to introduce new technology comes in adages such as: “Don’t automate a bad process”, or “Don’t optimize that which shouldn’t exist”. The more new technologies are deployed at a production line without corresponding process changes, the more process debt is accrued and the more investment may be needed in process changes, SOP updates<sup>23</sup>

and training to capture the full potential value of already-deployed technologies.

Process debt therefore refers to the “tax” a company pays as it redresses accumulated waste and suboptimal practices of any operation – paid in the form of inefficiencies that eat into the value-adding potential of new technologies.<sup>24</sup>

### Optimizing information flows across people, material and data

Sources of variability and waste naturally accumulate across systems, raising the total cost of ownership (TCO).<sup>25</sup> Lighthouses invest to fully understand flows of information across people, material and data before redesigning them – going directly to the frontline to learn all the human elements of a process, conducting process mining exercises to map true material flows and tracing data pipelines to ensure accuracy and scalability of digital solutions.

#### EXAMPLE Haitian

Haitian in China mapped out its craftsmen-led production processes to identify that their AI-enabled smart “nose” solution, a machine learning-based olfactory analysis platform leveraging aroma sensor data, left gaps in communicating results to necessary team members. To address the process debt, they invested in features to auto-alert the right people to act on non-compliant batches of soy sauce. To supplement this, given that bad batches could be delivered to the lab on automated guided vehicles (AGVs) and that failure inspection results were now digitalized, their QC engineers and responsible operators could spend more time on the production shopfloor. This solution improved inspection capacity by over 4x.<sup>26</sup>

Lighthouses such as Haitian leverage data to streamline interactions between people and material flows. They do this by not only integrating

tools that present trustworthy information and recommendations, but also by redesigning the processes around those tools to capture total value.



FIGURE 7: | Lighthouse design solutions to optimize interactions between people, data and materials



1. Smart andon: a digital system that uses real-time data and alerts to signal and manage operational issues.

2. OEE: Overall equipment effectiveness – an indicator used to measure the efficiency and effectiveness of equipment. It is calculated by multiplying three factors: availability, performance and quality.

3. Tenure: refers to the length of time that an individual has been employed or has held a specific position or role.

Source: Global Lighthouse Network.

## Designing data flows to enable people and material

Based on information from Lighthouse applications, the volume of ingested and stored data increases by two to three orders of magnitude during digital transformation.<sup>27</sup> Keeping it organized and streamlined is not

easy – especially as an increasing number of tech vendors create exponential new nodes in the factory data value stream. The efficient integration and management of technology is now essential.

Designing tech-heavy processes to be integration-light was a guiding principle for Continental in the Czech Republic and Agilent in Malaysia.

### EXAMPLE

#### Continental

To enable customization of material logistics, Continental, a producer of electronic parts for the automotive sector, collaborated with a start-up on a unified fleet management platform for their autonomous mobile robots (AMRs). Integrated across five suppliers, the platform acts as a central hub, where each new supplier module can be independently managed, enabling route optimization and planning in mixed zones (where human-operated vehicles may come across AMRs) and seamless system-wide upgrades, such as a collision avoidance system across multiple vehicle types (see Figure 8).<sup>28</sup>

### EXAMPLE

#### Agilent

Agilent in Malaysia took a similar approach to Continental in another domain. To scale-up production of parts at high risk for supply disruption, the site developed a low-cost and open-source 3D printing platform that integrates with IIoT sensors and an AI vision system for real-time quality control. The printer-agnostic platform integrates with ERP to automate printer job setups based on the production schedule, which is essential for frequent new product introductions (NPI). This platform, known as the additive manufacturing production system (AMPS), has turned the site into a centre of excellence (CoE),<sup>29</sup> achieving an 83% reduction in cost of 3D printed parts and 75% reduction in manufacturing lead time.<sup>30</sup>

“ The volume of ingested and stored data increases by two to three orders of magnitude during digital transformation.

These approaches not only redesigned processes to solve the needs of today, but designed data platforms capable of handling the technologies of tomorrow – be it new types of AMRs or new and unknown product and part requirements – with flows optimized for frequent upgrades and integrations, making growth less costly and

difficult. Lighthouses do not deploy advanced digital tools in a system burdened with waste – just as it would not make sense to deploy AGVs to manoeuvre in suboptimal line layouts. Instead, they ensure the digital tools they deploy leverage data that mirrors the physical systems it is collected from.



FIGURE 8 | Continental reimaged processes for a future-forward tech ecosystem

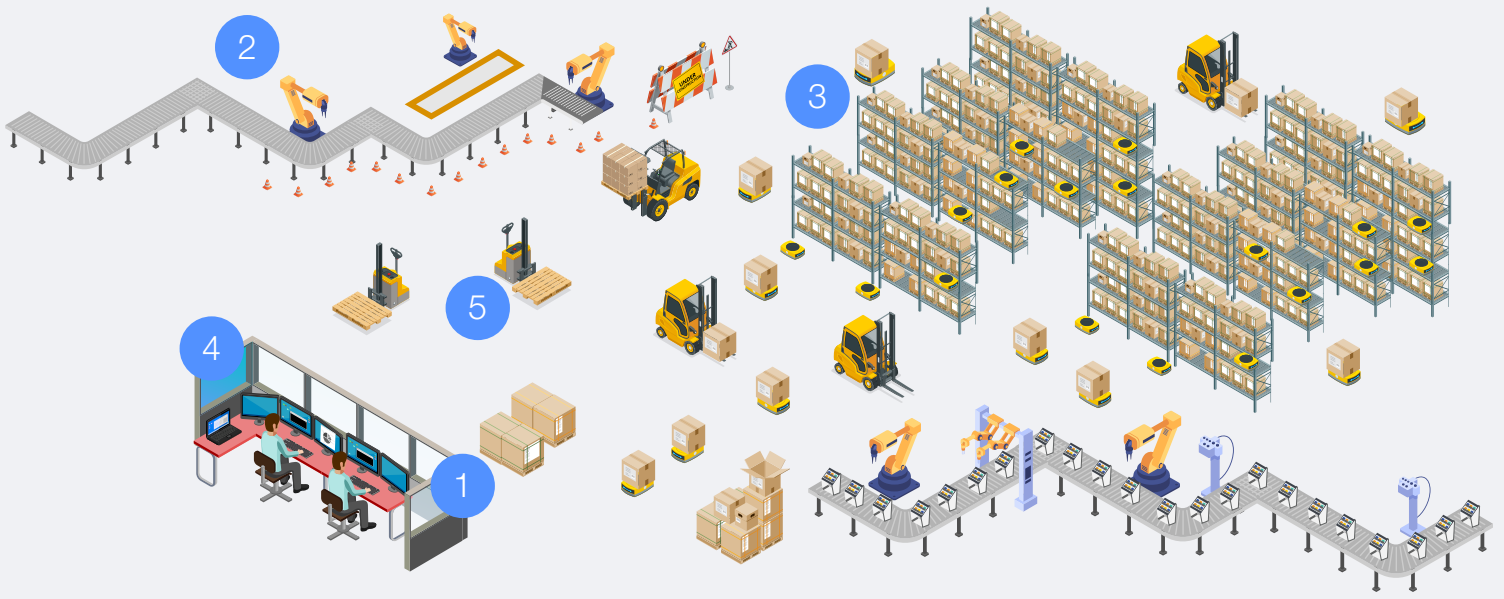


Illustration of deployed use cases and impact

Solution	Description	Impact		
1	Virtual commissioning powered by digital twin	Generates 3D models of all software in a future production line	-75%	Equipment commissioning time
2	Layout optimization with digital simulations	Simulations to experiment and identify optimal process flows	+16%	Return on invested capital
3	“Lights-out” warehouse with intelligent sorting	AI-enabled continuous and autonomous inventory sorting	-37%	Warehouse space
4	New product failure prediction with production data	Real-time process root cause analysis for new product R&D	-49%	Scrap cost
5	Brand-agnostic AMR control platform	Centralized hub to manage and optimize AMR fleet	+67%	AMR productivity

Source: Global Lighthouse Network.

## 2.2 Investing in your capabilities

### Selecting the right development approach

AI tools are becoming more commodified. Start-ups are building foundation models that can serve the industrial space; meanwhile, cloud providers are offering increasingly robust AI/ML ops<sup>31</sup> developer toolkits. This has enabled

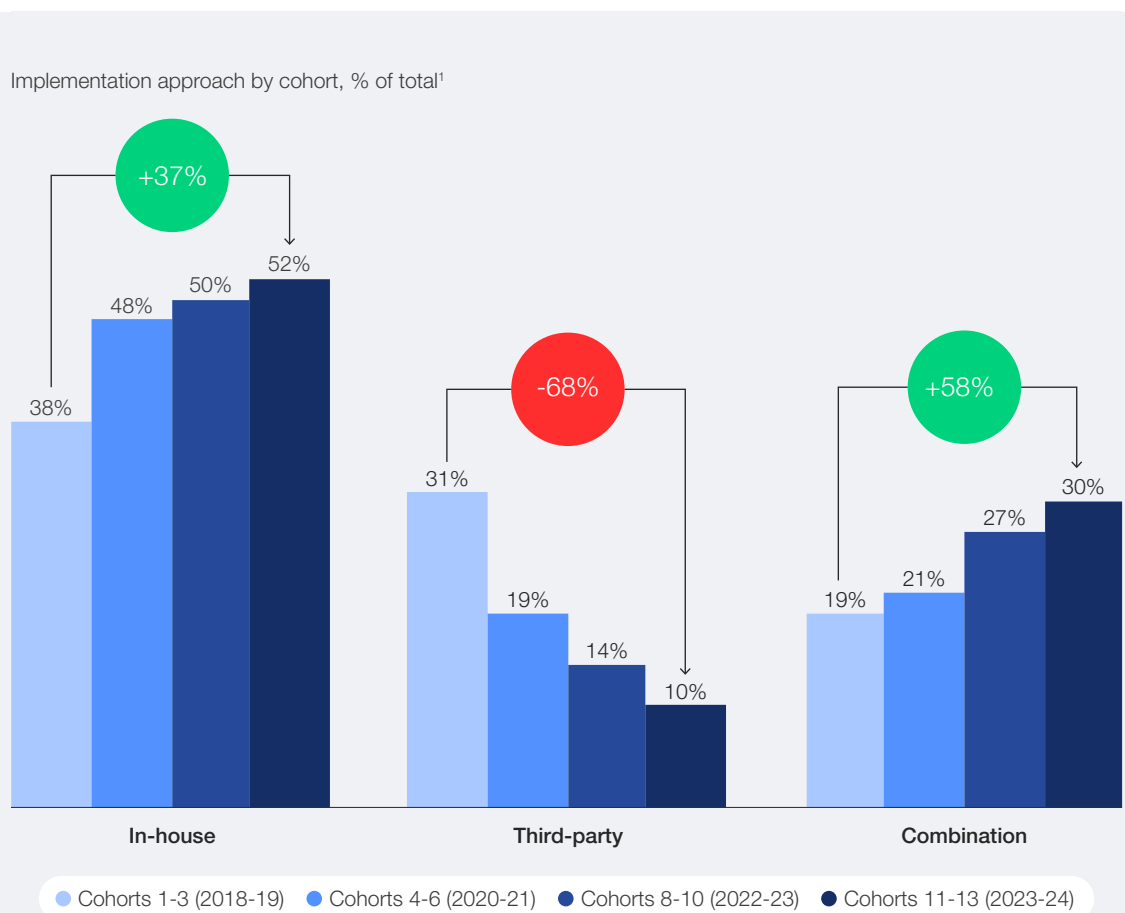
Lighthouses to choose to go in-house for development 37% more often than they did in 2019-2020 – primarily in roles related to AI architecture, design and integration (see Figure 9).<sup>32</sup> As a result, while third parties continue to provide services, Lighthouses increasingly opt to own more of their information value chain and outsource only specific elements of tech stack and solution development.

#### EXAMPLE Midea

Select in-house capabilities have enabled Lighthouses to deliver more tailored solutions to local sites – Midea in China, for instance, built their own flexible and scalable platforms for product lifecycle management (PLM) R&D, IoT and cloud computing. This platform has enabled agile development and continuous delivery, with 20+ major upgrades per year.<sup>33</sup>

🗨️ Lighthouses increasingly opt to own more of their information value chain and outsource only specific elements of tech stack and solution development.

FIGURE 9 Lighthouses are shifting solution development in-house



1. Excludes licensed, acquired and academia approaches (Waves 1-3: 12%, Waves 4-6: 12%, Waves 8-10: 9%, Waves 11-13: 8%)

Source: Global Lighthouse Network.

FIGURE 10 | Hisensehitachi – two approaches to solution development

Illustration of deployed use cases and impact



Source: Global Lighthouse Network.

For many other use cases, Lighthouses take strategic “combination” approaches to deployment, prioritizing opportunities that augment local capabilities through extended thinking partnerships. These involve deep collaboration between in-house teams and external partners, with clear agreements that delineate IP ownership of joint development.

Integrated teams embed external expertise to facilitate a transfer of knowledge and skills. Hisensehitachi in China is a great example of this, treating their partnerships as a strategic investment that builds on in-house expertise and adjusting team composition according to the solution (see Figure 10).

## Digitally driven, but not just by technologists

Lighthouses are dispelling the notion that technology alone drives digital transformation. Instead, they make digital transformation everyone’s job – embedding the technology and people capabilities needed to deliver reimagined processes. On average, this translates into 25 new transformation roles hired per 1,000 factory FTE, of which nearly half are business and operations roles (see Figure 11).<sup>34</sup> In early

development, they typically establish centres of excellence (CoE)<sup>35</sup> to design and deploy practical, innovative solutions across the network. Some focus on technologies such as manufacturing execution systems (MES) or “digital twins”, while others focus on processes like “prototyping” or “batch release”.<sup>36</sup> These CoEs often partner with enterprise teams and third-party providers to fill capability gaps, but over time they render themselves obsolete by upskilling frontline site operations and technology leaders, who take on the responsibility of deploying and scaling-up these new technologies in localized contexts.

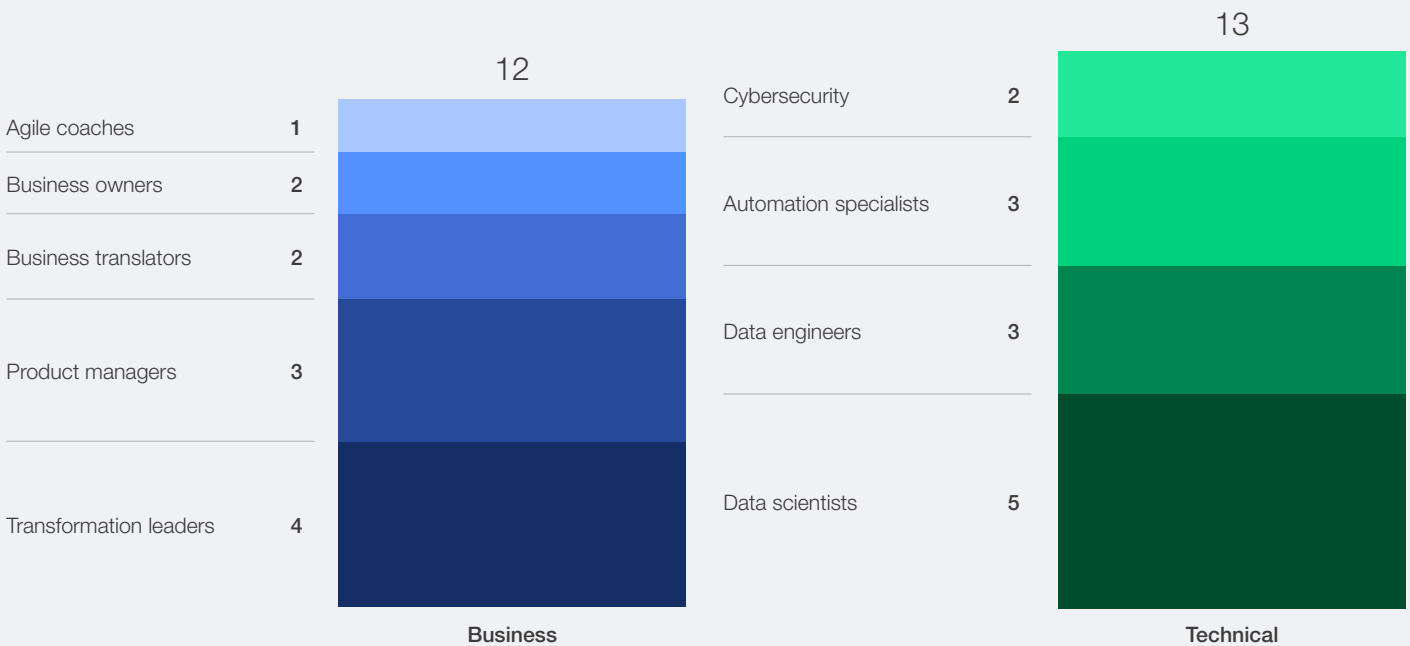
### EXAMPLE

#### Siemens

Siemens has long fostered a CoE-led approach in the context of its digitalization programme “Lean Digital Factory” (LDF). Their experts gather around core digitalization technologies and build up capabilities through pilot projects carried out in dedicated sites. As the insight around a specific tool matures within the CoE, knowledge is shared within the LDF network and the mandate to scale the technology is shifted to the plants. The role of the local expert then concentrates on managing the development backlog and supporting a potential external distribution.<sup>37</sup>

FIGURE 11 | Lighthouses build holistic transformation teams

Digital transformation roles added by domain<sup>1</sup>  
# FTEs added per 1,000



1. Original question from GLN Research Survey (July 2024): “What are the roles that you have added over the past 2-3 years to enable digital transformation across your lighthouse site(s) and corporate teams?”

Source: Global Lighthouse Network.

At Siemens and elsewhere, site leaders are taking back the responsibility of identifying and integrating advanced technology solutions. As this happens, a new focus has emerged on ensuring these frontline roles are upskilled to match the implications of

future technology on their processes and advanced capabilities are democratized (e.g. via low/no code) to enable employees without coding knowledge to become “citizen developers” who create, modify and optimize applications.

## 2.3 Assetizing for scale

“ Nearly every new Lighthouse in 2024 has a solution for production scheduling, predictive maintenance or facilities management in their top five solutions presented in site evaluations.

Assetization is a systematized approach to developing, managing and deploying reusable assets for scalable digital transformations across an organization.<sup>38</sup>

Those piloting new use cases without playbooks had to learn by trial and error. But today, many applications have matured. Nearly every new Lighthouse in 2024 has a solution for production scheduling, predictive maintenance or facilities management in their top five solutions presented in site evaluations. The breakthrough from Lighthouses is the speed and scale of deployment for these solutions; the innovation is “assetization” – a practice long utilized by the software industry. Assetization in production settings consists of composable and universally accessible standard

manuals, procedures and tools that enable frontline workers to harness the power of digital solutions without specialized knowledge.

### Deploying composable assets

Composability is a design principle that emphasizes the ability to assemble and reassemble components, allowing for more agile systems. By focusing on composability, Lighthouses develop flexible and scalable infrastructure that adapts to changing business needs, enabling faster innovation, reduced time to market and incremental improvements rather than large, disruptive rollouts.

#### EXAMPLE

#### Siemens

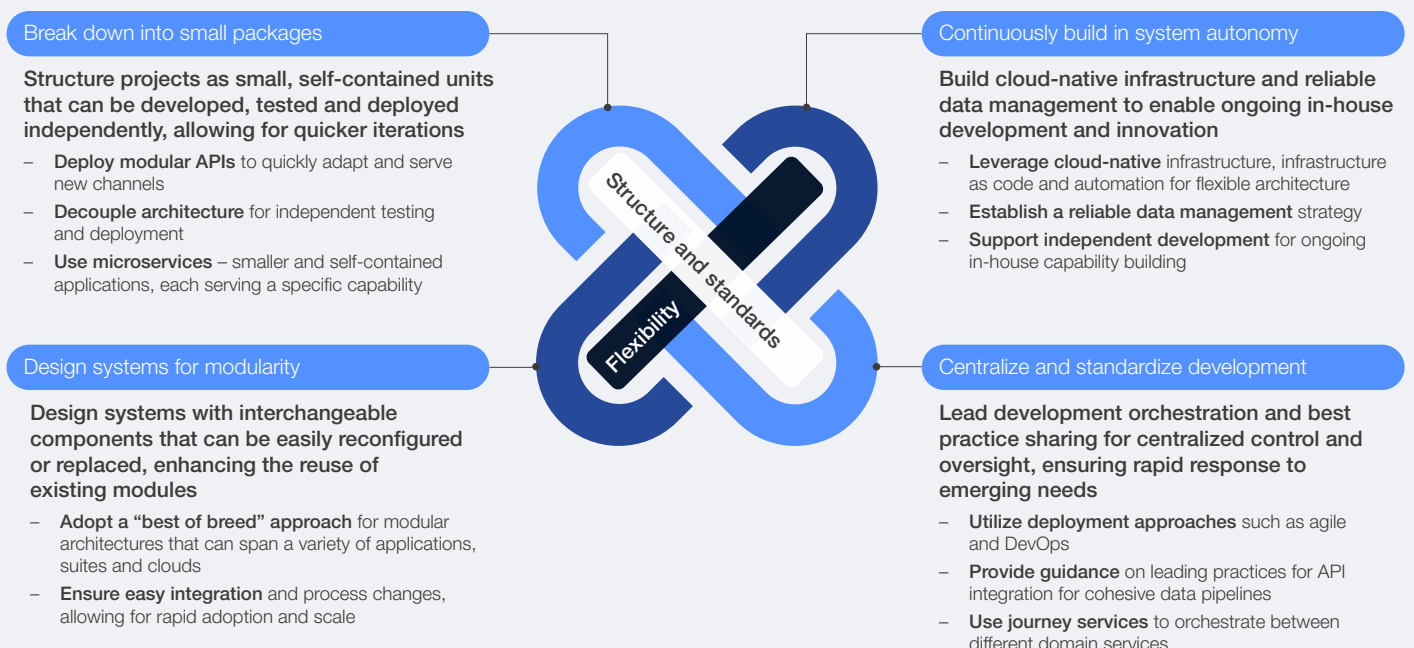
Siemens established their own way of composability, driven by the urge to use the software distributed by their software branch in their own factories. Complementary applications are also developed mostly on this basis. Business case optimization demands that those applications are developed in co-creation with software providers and marketed for external customers too. This leads to increased re-useable technology assets that enable local innovation.<sup>39</sup>

Lighthouses see every operation as unique, requiring assets and tools that offer both the flexibility needed to adjust in local contexts and the sturdiness to scale-up with the same underlying foundations over time<sup>40</sup> – a fine line to tread. They do this by designing

assets with composable elements, such as cloud-based and containerized microservices, application programming interfaces (APIs) and data models capable of communicating across diverse systems and processes (see Figure 12).

FIGURE 12

### Lighthouses balance standardization and flexibility in their composable assets



Sources: Gartner,<sup>41</sup> Global Lighthouse Network.

## Empowering the workforce with low/no-code tools

For the latest Lighthouses, low-code and no-code platforms have become ubiquitous: 76% of the 2024 cohort has deployed some version of the technology.<sup>42</sup> Even as models get more sophisticated, pain points continue to be hyper-local. Individual machines often require unique optimizations only understood by on-site

operators or technicians. Low/no code platforms enable the frontline to make direct adjustments, leveraging their intimate knowledge of equipment and processes.

Tools such as these also empower the non-developer community, ensuring scalability across the network. Especially as technologies become more sophisticated, Lighthouses understand a solution is only truly composable if it is easy to do the composing.

### EXAMPLE **Roche**

Roche in Switzerland created a no-code innovation hub to empower operators to build and deploy their own applications. Built by a citizen development community of 80+ app builders, the hub supports an industrialization and assetization strategy focused on standard operating models with risk-based and modular validation approaches, such as pre-validation templates. This was critical for Roche to maximize time to value for digital solutions in the regulated life sciences and pharmaceuticals industries and today the hub hosts 100+ user-developed applications.

## 2.4 Localizing adoption with the frontline

“ Lighthouses design systems and interfaces that augment human strengths, where technology supports people’s abilities rather than supplanting them.

Adoption remains the elusive factor in digital transformation. Lighthouses have realized that sustaining impact from transformation requires a human-centric approach to design, deployment and change management rather than a one-size-fits-all mentality. They design systems and interfaces that augment human strengths, where technology supports people’s abilities rather than supplanting them. They invest in their workforces and work environments to foster environments where more improvement ideas come from the frontline than from management. They involve operators holistically in the design and development of new solutions.

### Designing human-centric processes

Lighthouses are transforming the look and feel of frontline work through human-centric process redesign, redesigning the task balance of the workforce to look more like technicians and reasoners, while automating-out tougher, non-value-added or more dangerous work. They design-out hazards and other barriers, such as specialized licences or physical limitations, for more inclusive work environments.

### EXAMPLE **Foxconn Industrial Internet and Sanmen Nuclear**

Operators at Foxconn Industrial Internet in Vietnam used to reset automation equipment when errors would occur, lacking any root-cause evidence or suggested solutions. To address this, the site built an LLM-enabled machine failure handling system that visualizes potential root causes in a dashboard with references to machine handbooks, reducing unplanned downtime by 90%.

Sanmen Nuclear in China deployed radiation-resistant magnetic wall-climbing robots with image analytics algorithms for inspection, eliminating the need for operators to conduct tasks that could expose them to radiation.<sup>43</sup>

“ Lighthouses know that what matters most is not the model or the algorithm, but rather how effectively the intended user will interact with it.

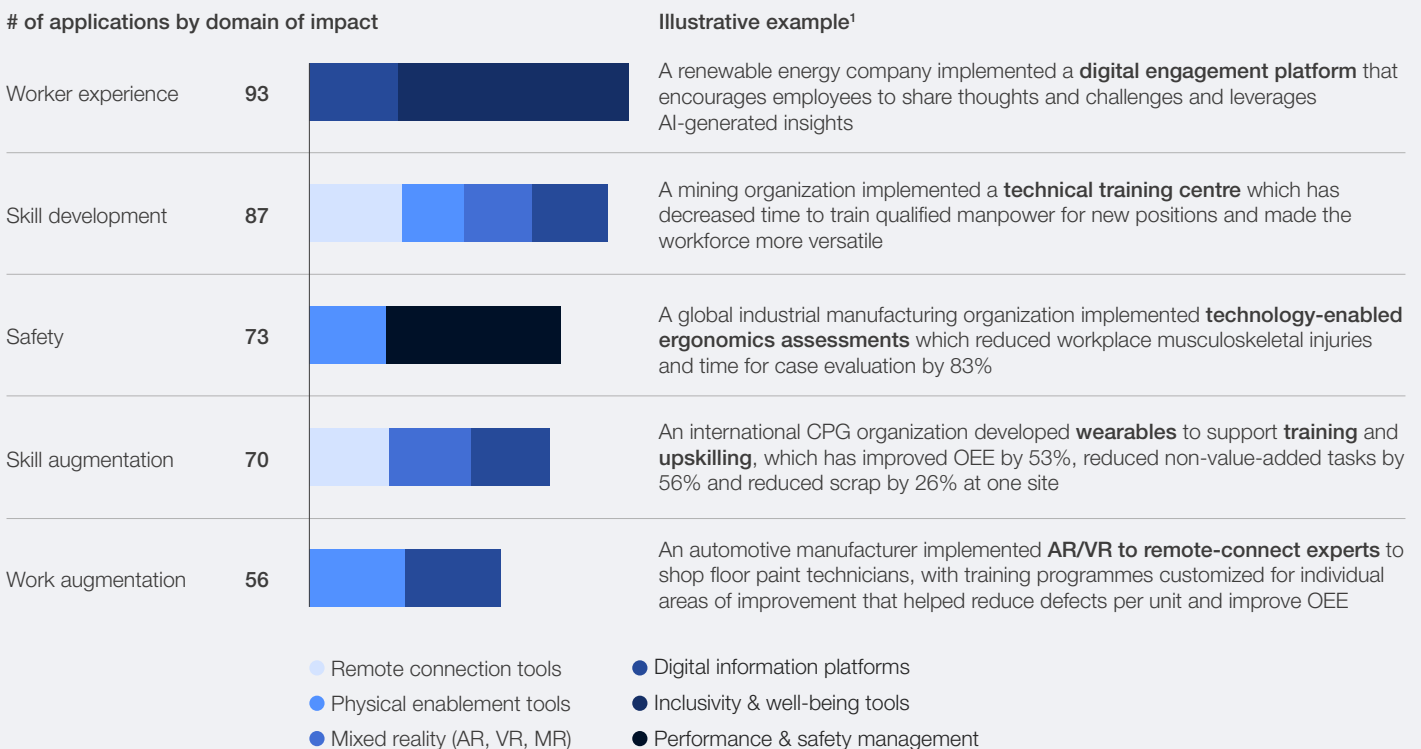
Similarly, because frontline operators serve as the touchpoint to production, they must be armed with user-friendly decision-making and troubleshooting tools. Lighthouses know that what matters most is not the model or the algorithm, but rather how effectively the intended user will interact with it. That means designing intuitive interfaces that people will engage with in their daily tasks and flows where operators play an active role in problem-solving and issue resolution.

## Investing in the workforce

Since 2020, Lighthouses have dedicated an average 10% of their use case portfolio to workforce priorities, including worker experience, skill development, safety, skill augmentation and work augmentation.<sup>44</sup> These Lighthouses have achieved an average 10-20% reduction in non-value-added tasks and 25-30% improvement in labour productivity.<sup>45</sup>

What is interesting about Lighthouses is their holistic approach – with more than 75% of them deploying solutions that span all dimensions of the frontline experience (see Figure 13).

FIGURE 13 Frontline use cases at Lighthouses



1. Examples from original publication of Global Lighthouse Network Research Survey, published July 2024

Source: Global Lighthouse Network

### EXAMPLE | CEAT and Sanmen Nuclear

In one skill development use case example, CEAT in India improved overall equipment effectiveness (OEE) by 16p.p., addressing losses due to minor stoppages by connecting their performance management system with operator training curricula. They leverage actual performance data to generate personalized learning programmes in virtual reality (VR) for faster, targeted reskilling. They see this training as a two-way street, collecting feedback from operators on why processes may be difficult to execute, including ideas for improvement.<sup>46</sup>

In a safety example, Sanmen Nuclear Power combined digital twin with physical and digital simulation technologies to imitate emergency response scenarios. The solution has accelerated the training process, which traditionally took at least five years to qualify a reactor operator and has reduced incidents due to human error by 88%.<sup>47</sup>

## Building adoption programmes to make digital stick

Solutions aren't just *for* the workforce, they are *with* the workforce. The most advanced sites source more ideas for continuous improvement from their frontline than across the rest of the company – but only when they intentionally invest in the upskilling and engagement

of operators, who can make or break the speed of transformation.

Since every workforce is different, Lighthouses do not take a one-size-fits-all approach to adoption. Instead, they give sites just enough structure to ensure local requirements are met and resources are sufficiently allocated to drive sustainable change but maintain flexibility and autonomy to personalize and customize at the site level.

### EXAMPLE

#### The Coca-Cola Company

Localized adoption programmes typically involve a few elements. At Coca-Cola, in Singapore, adoption focused on driving employees' continued engagement and commitment to the transformation effort. The site engaged with the workforce through monthly "show & tells" with equipment vendors and other third parties, 21 "Sway" digital newsletters that provided plant-wide transformation updates and success stories and hands-on experiences with AGVs, co-bots and virtual and augmented reality through their on-site innovation lab. The site also sends top talent to participate in the internal short-term assignments (STAR), where shopfloor associates join the transformation team for three months to be part of a specific digital project, collaborating in the design, development and execution of a solution. They eventually become ambassadors upon returning to operations.<sup>48</sup>

“ Cultivating change agents is critical as they function as conduits between frontline and management.”

Cultivating change agents is critical as they function as conduits between frontline and management in both directions. From leadership to the frontline, they deliver key messages, addressing questions and supporting the education of frontline peers. Conversely, they relay frontline ideas, feedback and sentiment to transformation leadership – shaping the transformation approach to fit local contexts. For Lighthouses, these change agents

participate in and support technology demos, deliver incentives and awards, lead ideation sessions or speak in town halls. They are the glue that makes change stick.

Closely tied to user adoption is model adoption. It is not enough for solutions to work once – they must demonstrate ongoing value to operators, otherwise they will be discarded and become more waste.

### EXAMPLE

#### Schneider Electric

To help younger operators manage a growing portfolio of automation equipment, Schneider Electric in China introduced Gen-AI enabled augmented reality (AR) glasses to seamlessly collect operator feedback. By inputting extensive equipment data and manuals into the model and continuously improving it with maintenance technician-chosen actions, the AR glasses display potential causes and corresponding solutions for fault codes, reducing time for new technicians to master equipment from 18 to nine months. The key was the ability for operators to interact with model recommendations to improve model accuracy and transfer years of knowledge from experienced operators into the underlying model.<sup>49</sup>



3

# Beyond productivity: applying AI across value chains for agility and sustainability

Lighthouses are driving transformational change across entire value chains, yielding benefits for both people and the environment.

“ As industries are moving from a mass production model to one where customization is the norm, driven by diversity of customer preferences, Lighthouses are focusing on agility to gain a competitive edge.

As the movement of goods has become more globalized, supply chains increasingly face myriad challenges, from catastrophic natural disasters and geopolitical tensions to market instability causing resources shortages and inflation. In response, Lighthouses are optimizing their supply chains for greater visibility to anticipate and manage disruption. They are taking a holistic lifecycle look at risk, with targeted solutions to drive resilience in product design, demand planning and logistics.

Moreover, as industries are moving from a mass production model to one where customization is the norm, driven by diversity of customer preferences, Lighthouses are focusing on agility to gain a competitive edge. Sites adopting engineer-to-order (ETO) or configure-to-order (CTO) models must

manage higher levels of complexity to provide customers with flexibility while delivering design and production at speed and scale.

Lighthouses extend a risk view to sustainability and are actively reducing their environmental footprint within sites and value chains. Advances in big data analytics, cloud computing and IoT have inspired new ways of organizing the means of production – such as using heat waste as energy inputs – and are driving step-change improvements in resource efficiency. With supply chain emissions six times greater than scope 1 and 2 emissions,<sup>50</sup> Lighthouses are looking beyond technology to promote circular models and reduce scope 3 emissions, collaborating both upstream with suppliers and downstream with customers to create closed-loop ecosystems.

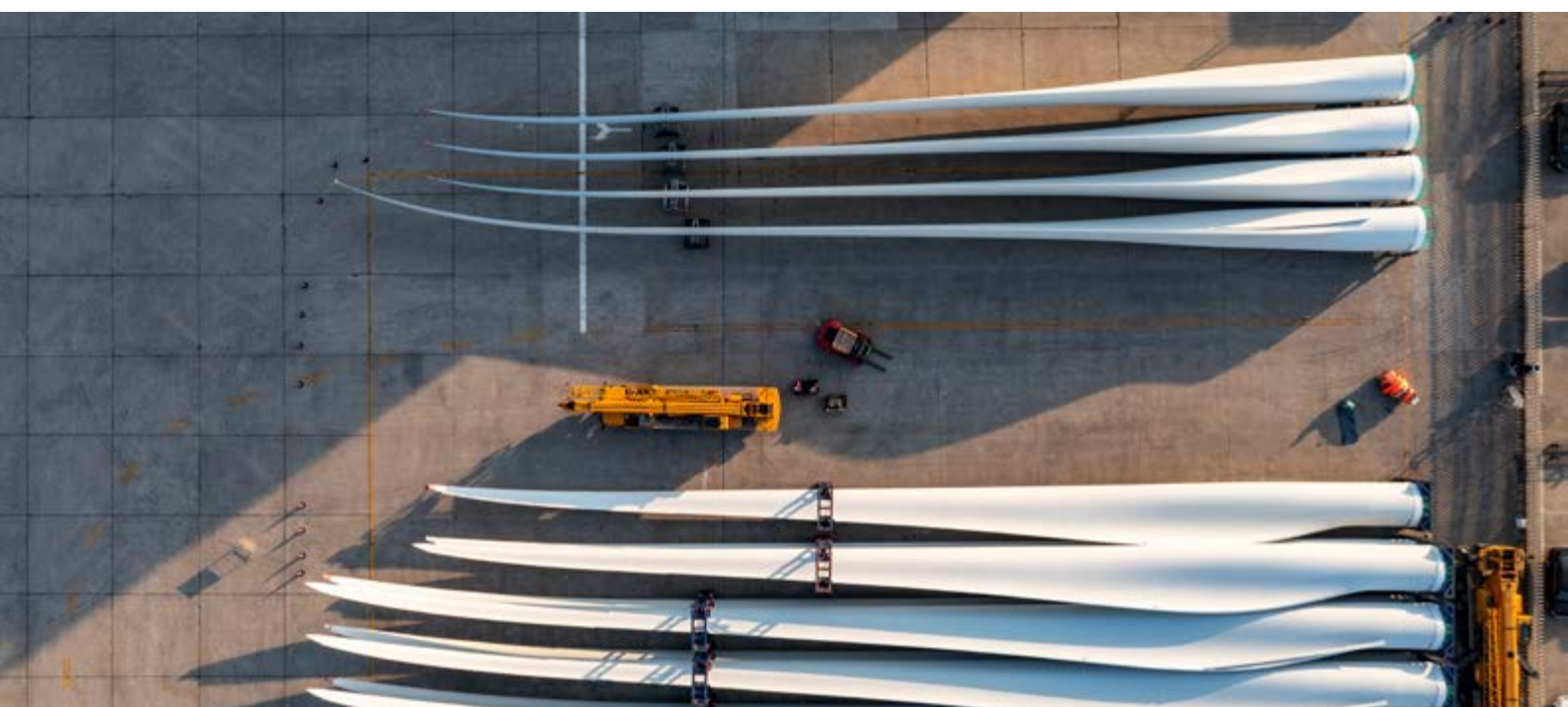
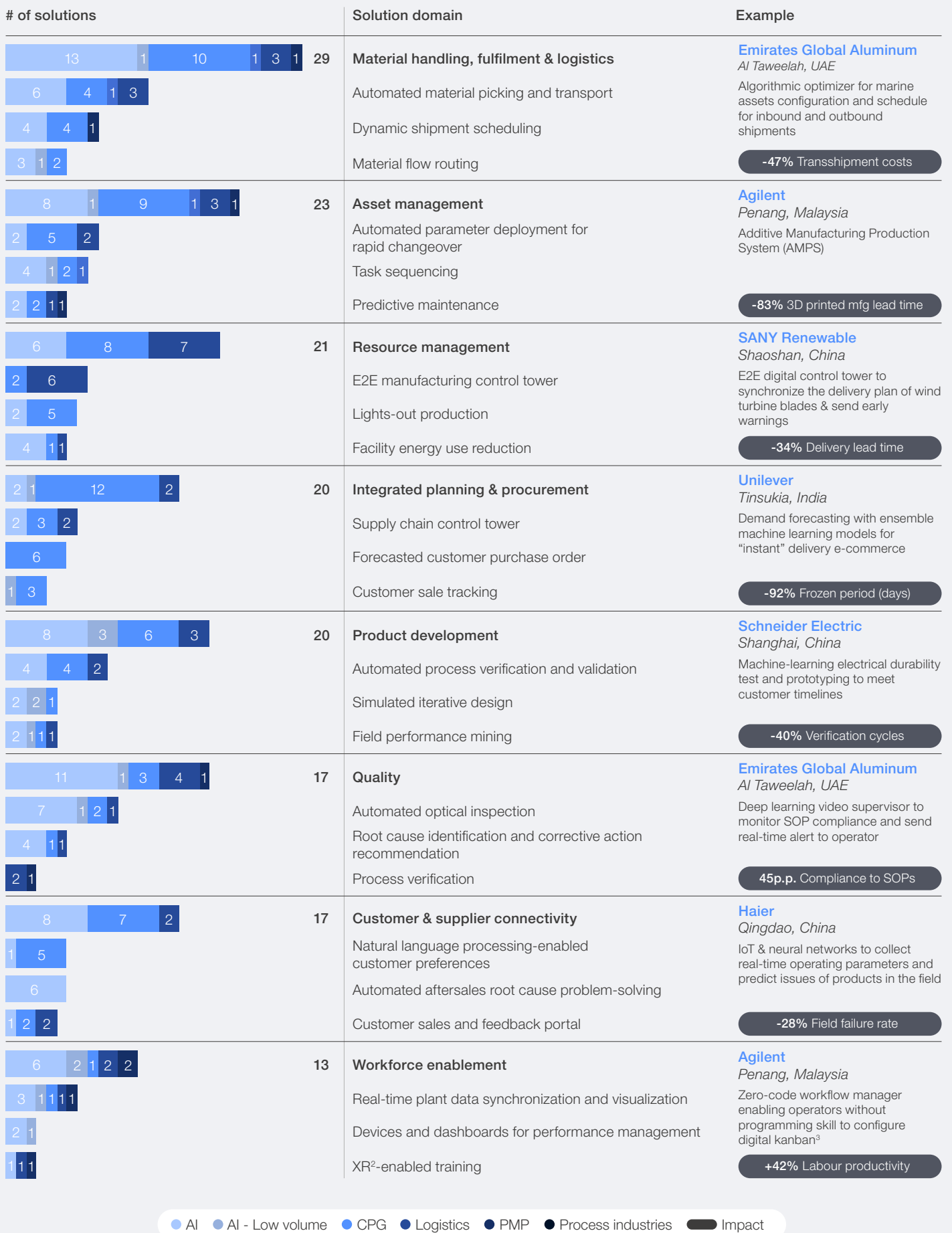


FIGURE 14 | Distribution of Lighthouse solutions across the value chain<sup>1</sup>



1. Excludes Factory and Sustainability solutions. 2. XR: eXtended Reality includes all technologies that enhance or replace real-world experiences, such as augmented reality (AR), virtual reality (VR) and mixed reality (MR). 3. Kanban is visual workflow management method that uses cards and boards to optimize and track work processes. **Source:** Global Lighthouse Network.

### 3.1 Intelligent product introduction tools to accelerate product development cycles

With an increasing focus on customized products and shorter times between introductions, speed to market is a crucial metric for many Lighthouses. They have achieved step-change improvements in the design-verify-prototype-test cycle.

More recently, they have been deploying advanced solutions against each step – including recommendation engines for material or process parameters, advanced simulation models for product performance and

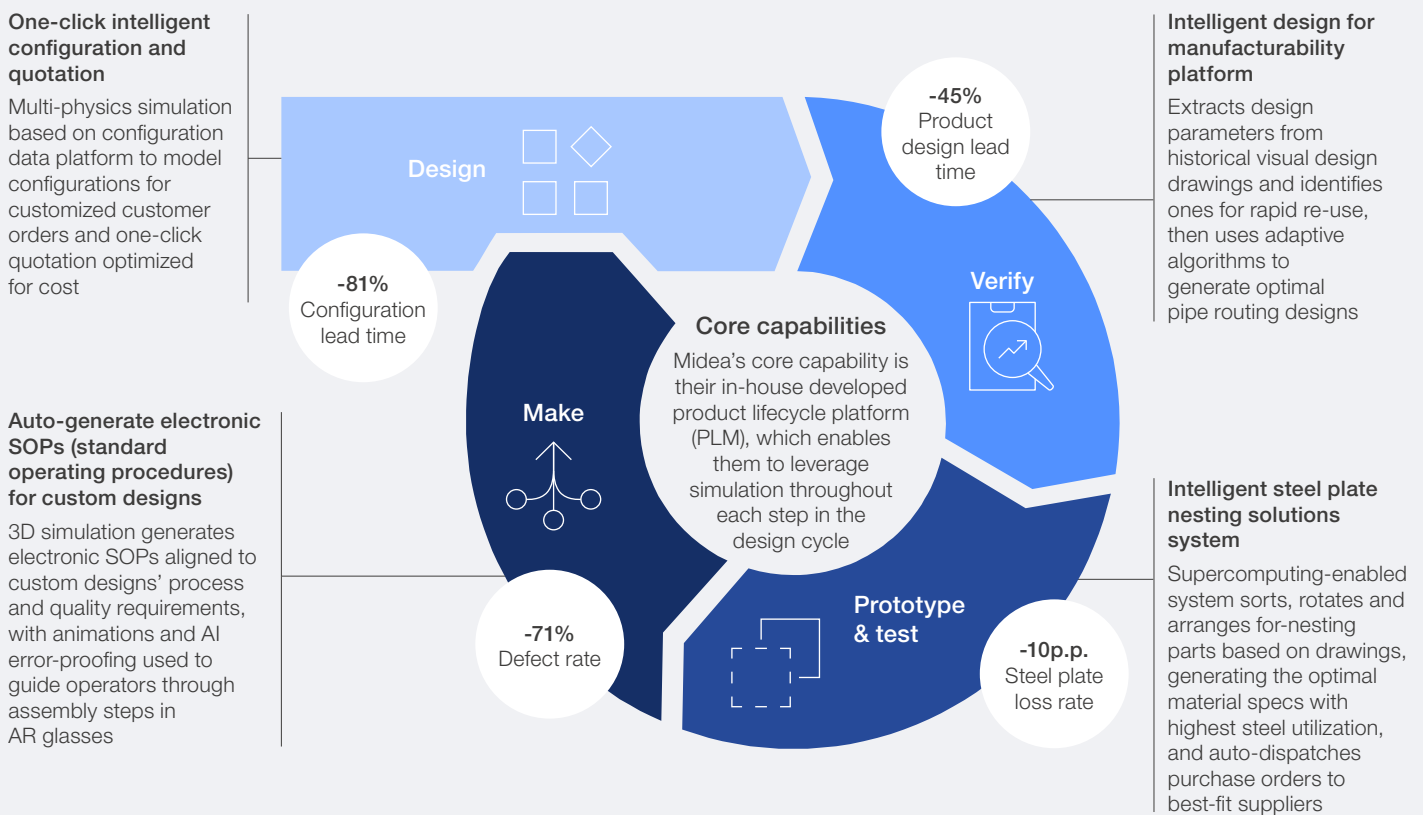
customer market and data intelligence capabilities to forecast demand.

What differentiates today's Lighthouses is their ability to integrate solutions across the product development lifecycle. The core capability, therefore, is not any one of the solutions, but rather the product lifecycle data platforms that integrate and make accessible customer, supplier, product and process data for simulation and forecasting of new products.

#### EXAMPLE Midea

Midea in China exemplifies this mindset. Their product lifecycle management platform has enabled digital tools at each step in the product development process, enabling a full design-verify-prototype-produce cycle to be completed digitally before bidding on new products or investing in any assets. This has the dual effect of improving response times to new orders enabling more opportunities to bid, with higher “first time right” designs and higher fidelity cost estimations improving competitiveness by reducing the cost buffers previously baked into bids (see Figure 15).<sup>51</sup>

FIGURE 15 Midea drives rapid product development by creating full design feedback loops



Source: Global Lighthouse Network.

## Platforms for rapid customization

Sites face growing demands for rapid product customization and must deliver stringent requirements, complex configurations and smaller batch operations. To address this, companies such as Midea and Haier have invested in the

central capabilities and digital tools that re-assign responsibility for product introduction tasks and decisions back to sites, improving agility and responsiveness to emerging opportunities.

### EXAMPLE

#### Haier

To meet demand for air conditioners with climate-specific customizations, Haier in China deployed a product performance prediction model that simulates a design's capacity based on customer specifications. The company then uses a machine learning algorithm to maximize it, reducing design cycle time by 49% and prototype verification cost by 77% per model.<sup>52</sup>

## Simulating cost performance to reduce design risk and improve bid competition

When data platforms are integrated across the end-to-end lifecycle of a product, valuable information can be fed back into early design stages to ensure optimal cost performance. Integrated advanced digital tools, such as automated product

configuration and manufacturability validation platforms, utilize algorithms and historical data within a PLM system to streamline customization, reduce validation time and bid confidently on complex design requests.

### EXAMPLE

#### Midea

Midea in China did this is with a “one-click” product configuration tool that identifies the most cost-effective configuration out of millions of permutations. The site also developed a digital platform that auto-validates the manufacturability of designs with finite simulation algorithms that generate a comprehensive report, reducing design-for-manufacturing-assembly meetings from one day to 10 minutes. This tool relies on embedded design and feature recognition algorithms to relate new simulated designs to historically documented ones, all integrated into Midea's in-house developed PLM platform that makes the full ecosystem of value chain data accessible, accelerating speed to market and cost competitiveness without sacrificing quality.<sup>53</sup>

## 3.2 Driving supply chain agility through intelligent resilience hubs

“ Since 2020, Lighthouses have implemented an average of five resilience-focused use cases, prioritizing supplier and customer connectivity and integrated planning.

The COVID-19 pandemic inspired many to rethink their supply chains, realizing just how ill-prepared their organizations were to absorb costs from record-breaking disruption.<sup>54</sup> However, Lighthouses tell a different story: 85% of them experienced revenue dips of less than 10% even at the height of the pandemic – while only 14% of other manufacturers could say the same.<sup>55</sup> Since 2020, Lighthouses have implemented an average of five resilience-focused use cases, prioritizing supplier and customer connectivity and integrated planning.<sup>56</sup>

More recently, Lighthouses are maturing solutions to manage the complexity of their fragmented and growing operating bases, especially when such value chains are exposed to market volatility. Solutions such as machine-learning “ensemble” models for demand forecasting and GenAI for commodity pricing and procurement stability are often orchestrated by resilience hubs that centralize risk management. They improve transparency across each node – from suppliers to end customers – and drive integrated decision-making for operational continuity and supply chain performance through disruption.

## Resilience hubs for centralized risk management

Hub-and-spoke models centralize core functions and expertise in a “hub” while distributing specific tasks and operations across decentralized units or “spokes.” Lighthouses are increasingly employing these models to streamline risk management and improve responsiveness across their end-to-end value chains.

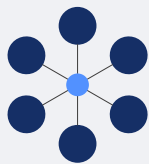
Each of the core function spokes – customers, manufacturing, supply management, logistics, finance etc. – play varying roles within the resilience hub. When spokes lack core response capabilities (such as suppliers and customers who may not be monitoring risk themselves), hub-led models make sense. Alternately, spoke-led approaches enable integration of risk management with other processes and tailored monitoring of specialized risks – most common in logistics, manufacturing, quality and facilities management functions.

## Spoke by spoke: Lighthouse strategies for centralization

Depending on the unique characteristics of their value chains, Lighthouses are deploying digital technologies to build resilience and

transparency across each node. They are using big data and advanced algorithms to improve prediction accuracy in demand and price forecasting and advanced integrations to manage entire risk ecosystems.

- **Supplier management:** Upstream transparency is often enabled by hub-led supplier platforms for improving inbound quality and operational stability.
- **Quality:** Lighthouses utilize a spoke-led approach with suppliers when a decentralized model is needed to leverage localized expertise, allowing suppliers to take ownership of quality while still adhering to standards.
- **Logistics and delivery:** Especially across great distances, Lighthouses tend to take a hub-led approach that assigns single accountability for regional risk response.
- **Inventory and planning:** Lighthouses are leveraging the same integrated data platforms that power product development to power increasingly advanced planning algorithm(s) – plural – to mitigate the impact of disruption.
- **Purchasing and negotiations:** Similar models are being used to predict the future in commodity purchasing.



### Spoke-led

**Best for:** Spokes with strong risk management capabilities locally are spoke-led; centralized support and standards by Hub



### Hub-led

**Best for:** Spokes with nascent risk management capabilities but potential for cross-site data integration with Hub

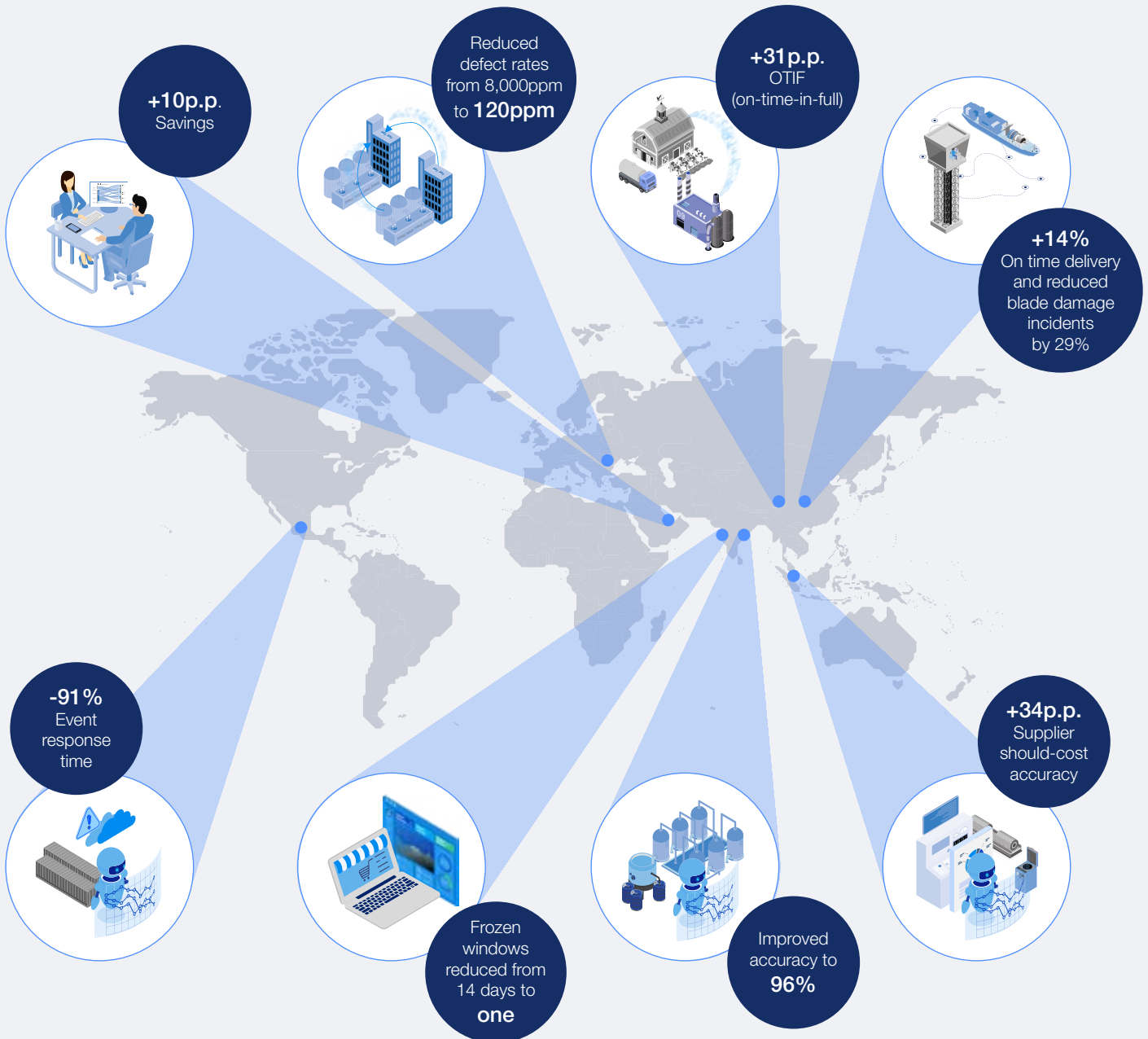


**Emirates Global Aluminium** in United Arab Emirates uses an LLM to simulate negotiation positions and enable frontline category managers to achieve higher savings compared to published market rates.

**Beko** in Turkey established a supplier collaboration platform to deploy their smart moulds for plastic injection directly at the supplier side, while feeding the data back to Beko's site. This allowed the company to implement process controls based on lot-specific process parameters from the supplier, while also reducing the cost to the suppliers – a win-win collaboration.

**Mengniu Dairy** in China improved on-time-in-full (OTIF) from suppliers by implementing an APS-driven supply chain optimizer which integrates data from supplier dairy farms to address demand volatility in raw milk supply.

**SANY Renewable** in China deployed a digital control tower for wind turbine blade delivery, with an early warning platform that enables specialized in-field logistics teams to plan for high-risk situations such as hazardous roads and adverse weather and auto-generates work tickets with image-recognition to notify repair teams of detected abnormalities and required repairs.



**Schneider Electric** in Mexico monitors the risk and safety of billions of dollars' worth of transported goods and more than 25,000 employees in the region. It uses AI models to monitor for risks such as stolen cargo or weather hazards and auto-generates analysis reports.

**Unilever** in India utilizes an “ensemble” approach to enhance demand prediction despite facing an unpredictable surge in “instant delivery” e-commerce channels, by deploying 10+ AI-based machine-learning models based on sales channel, customer and product category data and over 100+ demand drivers and business scenarios.

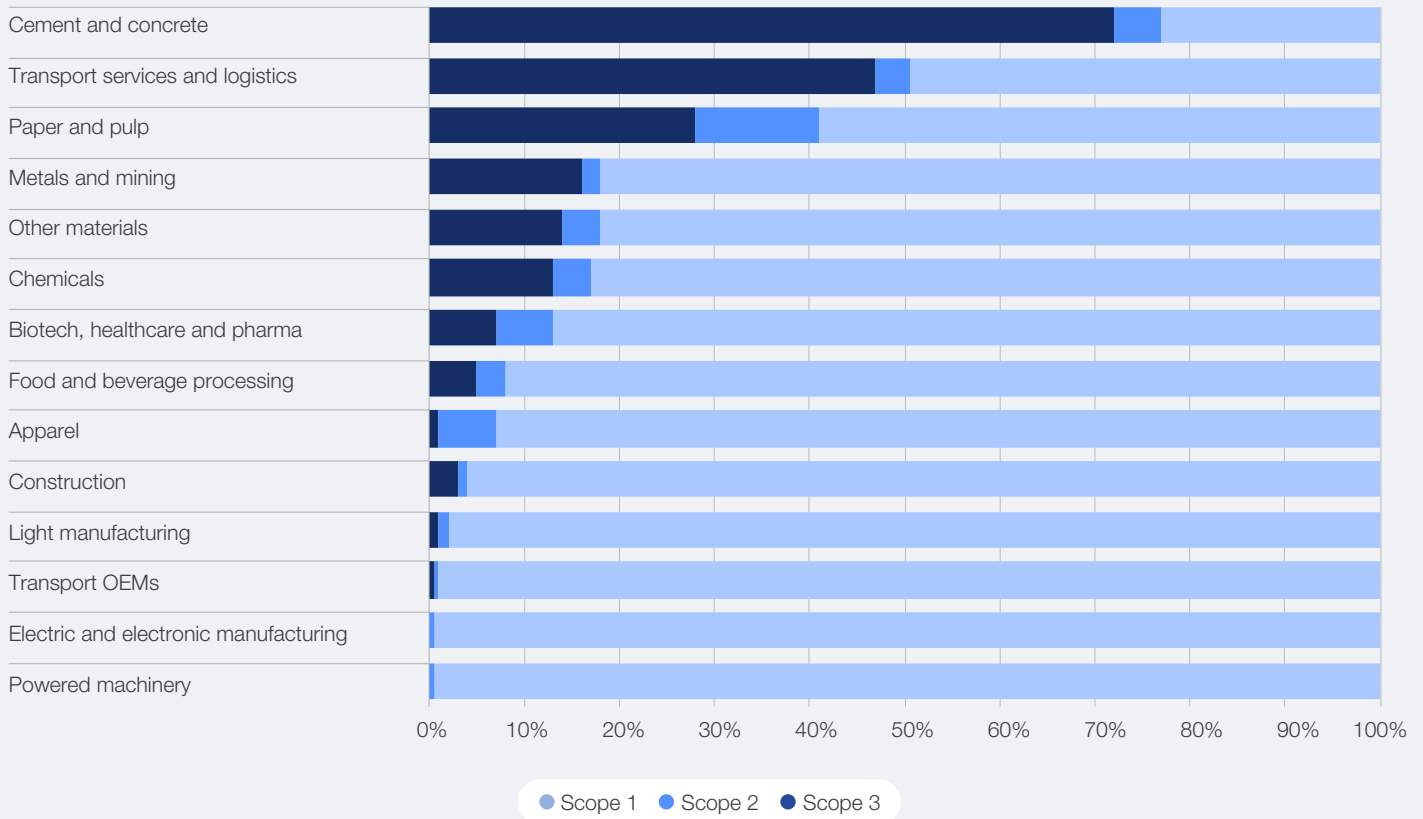
**Jubilant** in India combined three algorithmic models to predict prices of acetic acid by incorporating data from global price indices and chemical production.

**Agilent** in Malaysia built a predictive cost-modelling tool that forecasts material price based on AI-driven news sentiment analysis.

Source: Global Lighthouse Network.

### 3.3 Moving from linear to circular for value chain sustainability

FIGURE 17 Why the value chain matters – scope 3 emissions for selected industries



Source: World Economic Forum.<sup>57</sup>

“ Despite 77% of the top industrial emitters pledging to achieve net zero by 2050 or sooner, just 3% have fully outlined the strategies and actions necessary to meet these ambitious goals.

In an era where industrial activities contribute to 30% of global greenhouse gas (GHG) emissions, the urgency to bridge the gap between sustainability commitment and action has never been more important.<sup>58</sup> Despite 77% of the top industrial emitters pledging to achieve net zero by 2050 or sooner, just 3% have fully outlined the strategies and actions necessary to meet these ambitious goals.<sup>59</sup>

The top few emitting sectors contribute the lion’s share of total scopes 1 and 2 emissions. For all others, the need to focus on value chains for scope 3 emissions is critical, as these sources often make up the majority of an organization’s total carbon footprint. In consumer goods, for instance, up to 90% of emissions can be attributed to scope 3 sources, including upstream activities such as raw material extraction and downstream activities such as product use and disposal.<sup>60</sup>

Over the past few years, most Sustainability Lighthouses have focused on scopes 1 and 2 emissions, targeting eco-efficiency through facilities, asset and process optimizations on site. More










recently, reflecting an industry-wide push to reduce scope 3, some Lighthouses are introducing more circular approaches, beginning with on-site circular processes such as closed-loop water and waste systems. From there, they are looking beyond technology, such as through collaborations with suppliers and customers, to start closing loops across the value chain and progress towards net zero goals.

#### Reducing site emissions and resource consumption with controls for local circularity

Together, integrated IT/OT architectures, accurate carbon accounting and real-time process control provide Lighthouses the foundations to close loops on site and reduce scope 1 and 2 emissions. With integrated facilities and production systems capable of nano-second real-time control, they are achieving optimizations from new recycled packaging to facilitating the transfer of heat and energy, traditionally a leading source of loss.

FIGURE 18 | Sustainability levers across Lighthouse value chains

Examples of linear and circular solutions from the 2024 Lighthouse cohort

Linear	Solution domain	Examples	Lighthouse companies	
<p>Make Take Waste</p> <p>↑</p> <p>↓</p> <p>Reduce Reuse Recycle Recover</p> <p>Circular</p>	<b>Facilities optimization</b>	Reduce electricity/water consumption per unit of output, reduce total site gas consumption	 <b>Dicastal</b>	<b>-71%</b> Scope 1 & 2 emissions
	<b>Process optimization</b>	Process re-design for resource efficiency, improve process yield/material recovery, reduce scrap	 <b>JUBILANT INGREVIA</b>	<b>-20%</b> Energy consumption
	<b>Asset optimization</b>	Repair or refurbish equipment to reduce leakage, extend useful life	 <b>SIEMENS</b>	<b>-58%</b> Scope 3 emissions
		Retrofit equipment/fleet, replace with lower carbon alternatives, convert from scope 1 to scope 2	 <b>TSINGTAO</b>	<b>-31%</b> Scope 3 emissions
	<b>Carbon capture (CCUS<sup>1</sup>, DAC<sup>2</sup>)</b>	Convert to feedstock, long-term storage		Emerging
	<b>Green energy procurement (LCFFES<sup>3</sup>)</b>	Switch to low-carbon fuels/renewables, on-prem or supplied by grid	 <b>Midea</b>	<b>+20%</b> Green energy utilization rate
	<b>Design &amp; specification optimization</b>	Switch to low-carbon feedstock, use high-performance or lightweight materials, improve recycle allowance, improve disassembly and recyclability, improve durability, re-think value proposition	 <b>ferrovial</b>	<b>-72%</b> Volume of concrete and steel
	<b>Sustainable sourcing &amp; procurement</b>	Sourcing recyclates to replace virgin input, sustainable secondary packaging solutions, collaborative procurement to amplify demand	 <b>Unilever</b>	<b>-21%</b> Plastic consumption
	<b>Supplier emissions management</b>	Partner on upstream scope 3 emissions reporting; hold suppliers accountable	 <b>FI</b>	<b>-39%</b> Scope 3 emissions
	<b>Planning &amp; logistics optimization</b>	Improve forecast accuracy to minimize overproduction, streamline transportation flows	 <b>Midea</b>	<b>-35%</b> Scope 3 emissions (transportation)
	<b>Re-manufacturing components</b>	Disassembly and reassembly of defective product component parts	 <b>Schneider Electric</b>	<b>-70%</b> Scope 3 emissions (cradle to gate)
	<b>Closed-loop processes</b>	On-site recycling, re-use of process by-products, scrap, excess heat, or water as inputs	 <b>NOVELIS</b>	<b>-47%</b> Primary material consumption
<b>Circular business models</b>	Product-as-a-service/subscription models, incentivize/offer repair of sold products, take-back-scheme/ refurbishment of products	 <b>Schneider Electric</b>	<b>-38%</b> Raw material consumption	
<b>Closed-loop systems and networks</b>	Partnerships with aluminium/steel scrap recyclers, reverse logistics, offtakers for process waste/scrap	 <b>FI</b>	<b>+50%</b> Input material recycled content	

A combination of solutions is needed to reach net zero

**Scope 1**  
Direct emissions from owned or controlled sources

**Scope 2**  
Indirect emissions from the generation of purchased electricity and other energy sources

**Scope 3**  
All other indirect emissions that occur in a company's value chain

1. Carbon capture, utilization and storage 2. Direct air capture 3. Low carbon fuels, feedstock and energy sources.

Source: Global Lighthouse Network.

Lighthouses such as **Jubilant** in India and **Tsingtao Brewery** in China continue to push the boundaries of eco-efficiency, with integrated facilities and production systems enabling “true” real-time control to reduce waste and maximize the value of resources, such as through the transfer of heat and energy, achieving results such as 20% steam consumption reduction and 100% scope 2 effluent emissions reduction.<sup>61</sup> Meanwhile, **Schneider Electric** in Mexico builds on mature capabilities in automation and advanced process control to deploy closed-loop processes on site – cutting water consumption in half by optimizing process parameters in a water re-circulation and treatment tank using reverse osmosis.<sup>62</sup> Others, such as **Unilever** in India, layer in simulation capabilities, with a digital twin that predicts “first time right” process parameters for sustainable packaging designs and process parameters to optimize recycled packaging use in mass production.<sup>63</sup>

Within their four walls, Lighthouses are extending well-established monitoring and production control capabilities to close loops on site and reduce environmental impact. However, they still have a long way to go to reach net zero, inviting new types of innovation – particularly across value chains.

### Reducing value chain carbon footprints through transparency and collaboration

Recent experiences with supply chain disruptions and demands for lifecycle sustainability have motivated leaders to take a hard look at their product portfolios and value chain stewardship.

Today, Lighthouses have upgraded toolkits for green product design, especially for scope 3 emissions reduction, with advanced models for product’s lifecycle footprint. To optimize the efficiency of its washing machines, Midea in China integrated AI-enabled carbon lifecycle

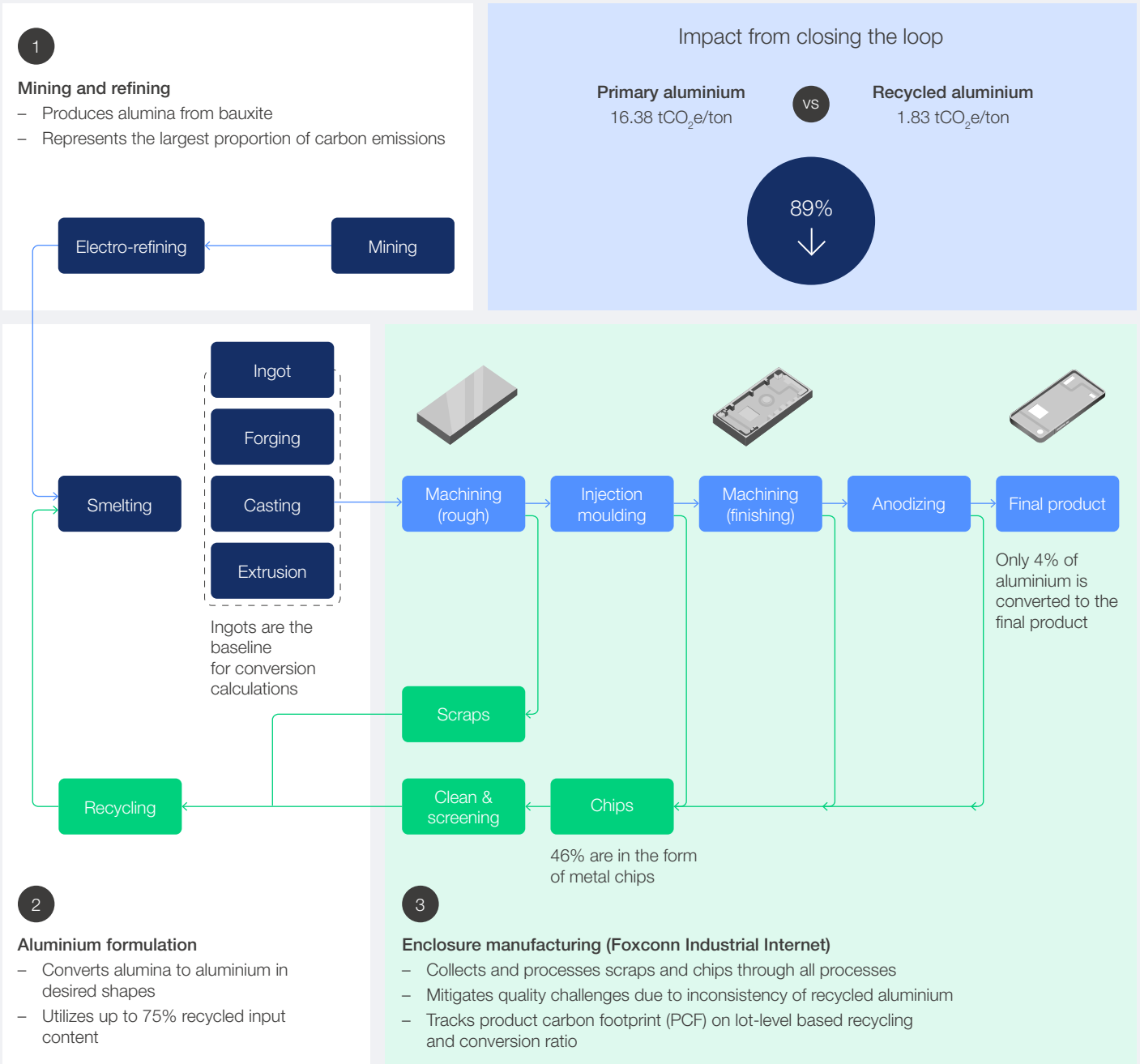
allocation analysis into its design simulation platforms to simplify product structure and reduce or identify alternative materials, achieving a 28% reduction in scope 3 emissions from purchased goods and materials and a 33% reduction in the use of sold products.<sup>64</sup>

With more than 50% of a company’s carbon emissions originating from the supply chain,<sup>65</sup> new partnerships with suppliers and end-customers are required to establish stable and resilient resource loops to increase recycled content. For example, Foxconn Industrial Internet in China has collaborated with its customers and suppliers in the metal alloy value chain on a lifecycle tracking system that ensures lot-level visibility of the scrap produced by its machining suppliers. This data informs the process parameters that Foxconn Industrial Internet uses to maximize use of this scrap content and maintain stable quality – a particular challenge with metal alloys. Overall, the site reduced scope 3 emissions by 39% and now replaces over 50% of input material with recycled content.<sup>66</sup>



FIGURE 19 | Closing the loop for scope 3 emissions reduction at Foxconn Industrial Internet

Illustration of Foxconn Industrial Internet's closed loop for metal alloys



Source: Foxconn Industrial Internet.

# Conclusion

To unlock sustainable, inclusive performance through AI and other technologies, millions of fast followers must look to the examples set by Lighthouses to transform their own sites and value chains.

The Global Lighthouse Network began with a revolutionary vision for the future of production – 189 Lighthouses later, there is indisputable proof of what is possible: advanced digital technologies – when coupled with a holistic operational mindset focused on people and planet – can drive remarkable impacts in productivity, stability and sustainability at scale. Lighthouses have delivered the tools to surpass pilot purgatory and achieve multiples of two or three times return on investment, with transformations happening in as little as 10-20 months.<sup>67</sup>

As Lighthouses continue to innovate, the next imperative for the Fourth Industrial Revolution is to empower the fast followers: those millions of production sites that must quickly, efficiently and effectively catch up with the leaders. These followers are essential to drive more sustainable, inclusive and efficient industry. That remains the central mission of the GLN.

This mission is as crucial as ever, because many organizations both big and small are failing to unlock sustainable, inclusive performance through AI and other technologies. Industry at large must advance alongside its leaders. The global transformation of production will require the inspiration and participation of millions of production sites, not just hundreds.

And so from revolution comes evolution. The Global Lighthouse Network is excited to elevate fast followers, the next shining beacons in the transformation of industry. Companies in the production ecosystem across the world – of every size and in every sector, industry and geography – can look to current Lighthouses and future fast followers for the lessons and inspiration on how to use data and AI to achieve a more inclusive, resilient and sustainable future. With the support of the World Economic Forum's platform, advisors and partners, these companies are well-equipped to navigate the way ahead.



# Appendix: Lighthouse change stories, solutions and impact

## Factory Lighthouses

### Wave 12

Site	Change story	Top five use cases	Impact
<b>AstraZeneca</b> Södertälje, Sweden	To boost capacity and accelerate product launches, AstraZeneca Södertälje implemented 50+ 4IR solutions, including machine learning and optimization algorithms. These efforts, coupled with the upskilling of 3,000 employees, resulted in a 56% increase in labour productivity and a 67% reduction in development lead times for new products	Machine Learning (ML) demand forecasting engine	↓ 23% Inventory level
		Mathematical optimization for batch scheduling and production planning	↑ 26% Productivity
		Advanced process control for new product development and launch	↓ 98% Continuous manufacturing cycle time
		Process digital twins for batch manufacturing optimization	↓ 17% Batch manufacturing cycle time
		Forecasting for the clinical phase of NPI	↓ 39% Overproduction rate
<b>AstraZeneca</b> Wuxi, People's Republic of China	Responding to domestic price cuts and increased demand volatility, AstraZeneca Wuxi deployed 34 4IR use cases, including AI and algorithms, to enhance manufacturing synchronization and efficiency. The site achieved a 55% increase in output, a 44% reduction in manufacturing lead time, an 80% reduction in non-perfect batches and a 54% improvement in labour productivity.	Synchronized factory flow enabled by batch priority optimization	↓ 48% Process lead time
		IoT enabled end-to-end touchless material flow and traceability	↓ 99% Material dispensing lead-time
		Deep learning enabled high-speed computer vision for in-process quality control	↓ 99.4% Rework hours
		IoT based smart andon improves manpower and equipment utilization	↓ 31% Unplanned down time
		ML-enabled forecast engine & inventory control tower	↓ 42% Raw material Inventory days
<b>Beko</b> Ankara, Türkiye	To meet the rising demand for high-quality dishwashers, Beko Dishwasher Plant underwent a 4IR transformation by integrating 35+ in-house solutions with its IoT platform, FLOW. This led to a 46% reduction in time-to-market, a 29.2% drop in field failure rates, and a 26.1% decrease in conversion costs. Additionally, over 1,000 employees were upskilled in 4IR technologies.	ML-powered smart metal sheet forming	↓ 12.5% Material cost
		Advanced cleaning cycle design	↓ 50% Time to market
		AI-enhanced clinching process	↓ 66% Defect rate
		End-to-end autonomous intra-logistic system	↓ 5% Conversion cost
		Supplier collaboration for the advanced plastic injection	↓ 98.5% Defect rate

Site	Change story	Top five use cases	Impact
<b>The Coca-Cola Company</b> Tuas Bay, Singapore	Confronted with rising volume and product portfolio complexity, the site implemented ML-powered demand forecasting, robotics and advanced scheduling algorithms. This led to a 28% throughput increase, a 70% boost in labour productivity, an 80% reduction in shortages, and a 31% improvement in on-time deliveries while cutting scope 2 emissions by 34%.	ML demand forecasting and integrated digital tools	↑ 47% 3-month demand forecast accuracy
		Advanced algorithms for production scheduling	↑ 28% Throughput
		ML-powered vision system for complex object pick-and-place	↑ 76% Labour productivity
		AGV simulation tool for optimized material handling	↑ 92% AGV throughput
		Cognitive maintenance AI advisor	↑ 21% Maintenance productivity
<b>Continental Automotive</b> Brandys nad Labem, Czech Republic	Continental Automotive's largest electronics plant in Brandys reimaged its processes to meet demand and shifting consumer preferences. By implementing over 30 digital solutions, the plant achieved a 35% efficiency boost, 15% better space utilization, and a 10% reduction in field incidents, all while enhancing employee satisfaction and setting new standards in high-tech production for its upcoming "Digital Mega Factory."	Digital twin-powered virtual commissioning	↓ 75% Equipment commissioning time
		Digital simulations – layout optimization	↓ 35% Throughput
		'Lights-out' warehouse with intelligent sorting	↓ 37% Warehouse space
		Failure simulation on new products with E2E production data	↓ 49% Scrap cost
		Brand-agnostic AMR control platform	↑ 33% AMR productivity
<b>Roche</b> Basel, Switzerland	Roche's Basel Drug Substance site, a key player in the company's goal to launch 20 new transformative medicines by 2030, produces a wide range of treatments, including chemically synthesized small molecules. To enhance efficiency, the site deployed digital and AI solutions that cut yield variability by 60%, halved technology transfer time, and reduced scope 1 and 2 emissions by 31%, reinforcing its critical role in Roche's global network.	Predictive modelling of product health end-to-end	↑ 10% Yield per batch
		AI-driven quality analytics portal	↓ 40% Recurring deviations
		Human-centric no-code innovation hub for augmented operators	↓ 39% Human error related deviations
		Intelligent authoring: digitally native report creation	↑ 27% Health authority reports submitted
		Autonomous recipe management	↓ 50% Tech transfer duration
<b>Foxconn Industrial Internet</b> B c Giang, Viet Nam	In its global expansion for supply chain resilience, Foxconn Industrial Internet Viet Nam overcame initial challenges such as heavy reliance on imported materials and the opportunity to develop local talent. By implementing 40+ 4IR use cases, including advanced planning and AI-driven automation, the site improved labour productivity by 190%, achieved 99.5% on-time delivery and cut manufacturing costs by 45%.	AI-enabled order forecasting and supply chain planning	↑ 8.3p.p. On time in full (OTIF)
		Vision inertial positioning for flexible and rapid pick & place	↑ 113% Units per hour
		Real-time shop floor compliance management with 360° AI vision	↓ 88% Indirect labour (compliance)
		AR-enabled multilingual remote guidance	↓ 80% Mean time to repair (MTTR)
		LLM-enabled machine failure log analysis and anomaly handling	↓ 90% Unplanned downtime

Site	Change story	Top five use cases	Impact
<b>GE HealthCare</b> Beijing, People's Republic of China	Serving 160 countries, GE HealthCare Beijing tackled complex manufacturing and quality demands by implementing 45 digital solutions across 26 production lines. By deploying AI for defect detection and deep learning, the site reduced cycle times by 66%, slashed scrap by 66% and lowered customer complaints by 73%.	Cloud based real-time production scheduling	↑ 40% On time shipment (urgent demand)
		Automated and closed-loop testing line on edge	↓ 66% Production cycle time
		Deep learning enabled unit sorting & sequencing	↓ 70% Testing cycle time
		AI-enabled CT raw material early defect detection	↓ 66% Scrap per unit
		AI-based vision systems for inspection	↓ 73% Customer complaint
<b>Jubilant Ingrevia Limited</b> Bharuch, India	Jubilant Ingrevia deployed 4IR technologies in global brownfield specialty chemical manufacturing and reskilling over 2000 employees. Through 30+ integrated use cases leveraging artificial and machine learning, IoT-based digital twin and predictive platforms, Jubilant Ingrevia's site reduced the overall process variability by 60% and almost doubled production volume.	ML-enabled raw material price prediction model	↓ 4.6% Material cost
		AI/ML-enabled yield optimization	↑ 1.3% Yield
		Advanced analytics enabled optimization of reactor	↑ 2% OEE (Availability)
		Advanced analytics led steam consumption optimization	↓ 20% Scope 1 emissions
		Predictive maintenance for critical equipment	↓ 85% Unplanned maintenance hours
<b>Mengniu Dairy</b> Ningxia, People's Republic of China	To meet rising consumer demand for fresher, more nutritious dairy products, Mengniu Dairy's Ningxia factory implemented over 30 advanced 4IR use cases, from intelligent decision-making to flexible automation. These initiatives, covering milk processing, packaging and testing, led to a 55% reduction in delivery lead time, a 60% decrease in quality defects and a 32% reduction in operational costs, significantly enhancing both efficiency and product quality.	AI-driven optimization of raw milk supply	↑ 67% Raw milk turnover
		AI-enabled process monitoring, optimization and controls	↓ 42% Raw milk waste
		One-stop smart laboratory	↓ 30% Test lead time
		Package volume precise control based on e-SPC	↓ 67% Package volume fluctuation
		Big data model monitoring package integrity	↓ 88% Package integrity inspection frequency
<b>Hisensehitachi</b> Qingdao, People's Republic of China	To meet global market demands, Hisensehitachi's Qingdao site implemented 40+ 4IR use cases, boosting product development speed by 37%, increasing labour productivity by 49% and reducing manufacturing costs by 35%.	Accelerated product development through integrated simulation	↓ 37% Product development cycle
		High precision flexible automation with computer vision	↑ 49% Throughput
		AI-enabled integrated supply chain planning	↓ 38% Prediction error
		GenAI-enabled performance management of shopfloor and operations	↓ 33% Production loss from equipment
		Skill development with gamified training and mixed reality simulations	↓ 43% Training cycle

Site	Change story	Top five use cases	Impact
<b>Sanmen Nuclear Power</b> Taizhou, People's Republic of China	Committed to zero accidents, Sanmen Nuclear Power deployed 40+ 4IR cases, including AI and robotics, to improve operational safety. These efforts maintained a 0% safety accident rate, increased capacity factor by 1.5%, and cut major overhaul periods by 46% while improving labour productivity by 18%.	AI-enabled reliability management for nuclear critical equipment	↓ 50% Total troubleshooting time
		Advanced analysis and optimization of nuclear reactor core power	↓ 70.18% Time to full power
		High-risk area inspection utilizing AI robots	↓ 60% Inspection time
		Advanced analysis and management of unit operation risk	↑ 55% Safety systems test performed during normal operation
		Deep simulation-enabled training for nuclear power personnel	↑ 1.46% Average capacity factor of unit
<b>SANY Renewable Energy</b> Shaoshan, People's Republic of China	Facing various challenges in producing and transporting large wind turbine blades, SANY deployed 29 4IR use cases, including AI and intelligent automation. This resulted in a 20% reduction in defects, a 33% boost in productivity and a 34% cut in delivery time, demonstrating digital technology's transformative impact on clean energy.	Smart real-time quality management platform	↓ 19.9% Quality defects per unit area
		Workforce task optimization based on UWB and AI analysis	↑ 31.9% Labour productivity
		Innovative flexible blade grinding	↓ 73.8% Grinding lead time
		Digital control tower for blade delivery	↓ 28.6% Blade damage rate during transportation
		AI-based blade operation failure prediction and root cause analysis	↓ 50% Field failure rate
<b>Schneider Electric</b> Monterrey, Mexico	To meet the growing demand for complex products, Schneider Electric's Monterrey facility integrated digital technologies such as ML-driven forecasting and autonomous robots. These enhancements led to sustained annual growth, a 20% reduction in defects and a 30% reduction in water consumption.	ML-enabled forecasting and supplier integration	↓ 49.6% Customer lead time
		AMRs and drones for material handling	↑ 115% Cycle count efficiency
		Deep learning vision systems for inspection and quality robustness	↓ 70% Manual inspections controls
		Connected facilities for process water management	↓ 54% Water consumption
		AI-enabled regional risk monitoring, analysis, and alert system	↓ 77% Theft incidents
<b>Siemens</b> Erlangen, Germany	Siemens Erlangen developed its Green Lean Digital strategy to lead in mid-volume, high-mix manufacturing. With over 100 AI algorithms and extensive use of digital twins, powered by a flexible and modular IT architecture, the site improved labour productivity by 69%, cut time to market by 40% and reduced energy usage by 42%.	AI-enabled closed-loop electrical testing	↓ 51% False positive rate
		E2E advanced analytics platform for greenfield semiconductor manufacturing operations	↑ 19% Production yield
		Product digital twin to train AI models for visual inspection/ perception-based robotics	↓ 50% Field failure rate
		AI-enabled automated outbound logistics	↑ 5x Labour productivity in affected logistics area
		Additive manufacturing network platform for spare parts	↓ 80% Spare parts lead time

Site	Change story	Top five use cases	Impact
<b>Taiyuan Heavy Industry Railway Transit Equipment</b> Taiyuan, People's Republic of China	To meet stringent safety and quality standards for high-speed railways, TZ implemented 40+ 4IR use cases enhancing quality and productivity through the use of AI and flexible automation. These advances led to a 33% reduction in defect rates, a 29% decrease in unit costs and a 33% increase in throughput.	AI-enabled material composition recommendation	↓ 66% Defect rate
		Real-time forging quality prediction and control with multi-modal AI	↓ 41% Scrap rate
		Digital twin-enabled furnace and billet temperature control	↓ 35% Temperature difference
		Rapid CNC programming and process parameter design	↓ 26% Cycle time
		Intelligent predictive maintenance and repair solutions	↓ 28% Equipment failure rate
<b>Zhengzhou Coal Mining Machinery</b> Zhengzhou, People's Republic of China	To meet the demand for fully customized hydraulic supports and faster delivery, Zhengzhou Coal Mining implemented 48 4IR use cases, including IoT, machine learning and adaptive automation. These innovations transformed the site into a smart factory capable of high-flexibility, high-efficiency production, cutting lead times by 66%, boosting output per worker by 205% and reducing defect rates by 73%.	One-click customized product selection enabled by neural network	↓ 30% R&D FTE
		Adaptive bevel cutting enabled by 3D point-cloud registration	↓ 90% Defect rate (bevel cutting)
		Heavy-duty logistics dispatch and execution enabled by advanced analytics	↓ 72% WIP inventory cost
		Flexible loading and welding for irregularly shaped heavy parts	↑ 30% OEE
		Loss capture and closing-loop based on automatic process-level order costing	↓ 64% Labour cost per ton produced

## Wave 13

Site	Change story	Top five use cases	Impact
<b>Agilent Technologies</b> Shanghai, People's Republic of China	To meet growing customer demands for higher lab productivity – more applications in a single instrument – the site leveraged 4IR technologies to overcome product customization and lead time challenges. By merging digital and engineering expertise, the site implemented 50 use cases focusing on in-house development of tailored and cost-effective AI solutions. This digitized engineering know-how enhanced adaptability, precision and speed across its design-to-production cycle, improving productivity by 56% and lead time by 31% with customer satisfaction on delivery exceeding 96%.	AI-assisted design of highly-customized GC	↓ 75% Customized order design cycle
		AI-driven planning intelligence for make-to-order (MTO)	↓ 31% Order-to-ship lead time
		GenAI virtual engineers to boost productivity	↓ 68% Line ticket closure cycle
		Low-cost automation toolkit for customized products	↑ 56% Labour productivity
		AI-powered helium gas reduction	↓ 82% Helium consumption

Site	Change story	Top five use cases	Impact
<b>Beijing Shougang Cold Rolling</b> Beijing, People's Republic of China	To meet the challenge of stricter quality standards for high-end automotive manufacturing and increasingly diverse stock-keeping units (SKUs), the site deployed 67 4IR use cases, 61% of which utilized AI. This enhanced end-to-end process accuracy, resolved customer quality challenges and eliminated key quality and throughput constraints. As a result, high-end sales increased by 36%, customer complaints decreased by 55%, product defects dropped by 35% and production line efficiency improved by 21.2%.	Knowledge graph-enabled AI expert system for customer stamping quality improvement	↑ 248% Number of customers' stamping parts
		ML-enabled process settings optimization	↓ 35.1% Product defect rate
		AI neural networks-enabled galvanizing process real-time close loop control	↓ 46.4% Thickness defect rate
		Advanced analytics-based production line efficiency improvement	↑ 18.7% OEE
		Intelligent production planning & scheduling based on advanced algorithms	↑ 24.4% Production line utilization
<b>CEAT Limited</b> Sriperumbudur, India	To support global expansion, CEAT needed to manage three times more SKUs, faster order fulfilment, coupled with new product launches at twice the speed with productivity improvement in assembly process. To achieve this, CEAT deployed over 30 digital solutions, including operational research models for reducing turnaround time, advanced analytics for predictive control and ML-based design. These solutions improved labour productivity by 25%, reduced dispatch turnaround time by 54%, accelerated product ramp-up by 30% and cut scope 1 and 2 emissions by 47%.	Advance analytics-controlled cycle time (CT) optimizer for batch mixing	↓ 18% Cycle time
		ML-based die design for improved ramp-up time	↓ 78% New product ramp-up time
		Operations research (OR) model for export container plan optimization and TAT2 reduction	↑ 288% Dispatch throughput
		Analytics-driven operator performance monitoring & skill enhancement linked to VR training system	↑ 29% Labour productivity
		Vision system-driven zero-touch automation system for dispatch	↓ 57% Truck turnaround time for dispatch
<b>CITIC Dicastal</b> Ameer Seflia, Morocco	"Lightweighting" trends are reshaping the automotive sector, by driving intense competition for high-quality auto parts with smaller environmental footprints. In response, CITIC Dicastal Morocco deployed over 40 digital use cases for high-precision, flexible production and efficient use of materials. The site deployed advanced algorithms for casting and machining, an AI-generated content-enhanced vision inspection system, and a process control to manage natural gas quality volatility in furnaces – a local challenge. This led to a 17% improvement in overall equipment effectiveness, a 27% increase in labour productivity, a 31.1% reduction in defects and a 53% reduction in scope 1 and 2 emissions.	Multi-task ML algorithms for intelligent casting	↓ 19.6% Defect rate
		Advanced sensors and deep learning algorithms for precise control of product weight	↓ 40.1% Weight accuracy ± % tolerance
		AIGC-enhanced industrial inspection robots for complex parts	↓ 98.1% Escape rate of critical defects
		Predictive maintenance of mold enabled by knowledge graphs elevates life-cycle performance	↑ 5.7% Mold OEE
		Advanced process control in furnaces to manage variable energy sources for carbon reduction	↓ 37.1% Natural gas consumption

Site	Change story	Top five use cases	Impact
<b>Haitian Flavouring &amp; Food</b> Foshan, People's Republic of China	<p>To maintain its cost advantage and produce soy sauces with consistent flavour, Haitian implemented digital transformation to address rising consumer demands for diverse products and manage increasingly complex orders. The site deployed over 50 digital use cases, nearly half of which were powered by AI, to optimize operations. Despite a 54% increase in SKUs and a 64% rise in small-batch orders, these efforts reduced raw material waste by 33.6%, cut product defect rates by 39.1% and shortened order lead times by 38.7%.</p>	ML-enabled enabled raw material yield optimization	↓ 23.2% Raw material waste
		Smart nose-enabled soy sauce aroma quality improvement	↓ 25.3% Sensory defect rate
		Digital process quality assurance with near-infrared spectroscopy	↓ 95.9% Average changeover time
		Neural network based closed loop adjustment for precise filling	↓ 49.4% Volume deviation
		APS with genetic algorithm to enable high-mix low-volume production	↓ 38.7% Order lead time
<b>Guizhou Tyre</b> Guiyang, People's Republic of China	<p>Guizhou Tyre faced the challenge of meeting highly customized orders (over 60% of all orders) for heavy load operations, which required strict design, verification and reliability standards. To speed up product design and ensure consistent and stable output, the site implemented over 40 4IR solutions to improve agility and productivity in manufacturing. These solutions, which included AI-enabled design, advanced data analytics and flexible automation, resulted in a 57% reduction in defects, a 68% increase in labour productivity and a 34% reduction in inventory levels.</p>	AI-enabled performance simulation and formulation recommendation	↓ 66% Customized product design cycle
		One-click extrusion changeover and parameter adjustment	↑ 11% OEE
		Vision-based high-resolution X-ray inspection for tyres	↓ 99% Defect leakage
		LLM-powered digital assistant for maintenance and quality control	↓ 35% Defect rate
		AI-enabled demand forecasting and S&OP coordination	↑ 33% Forecast accuracy
<b>Aramco</b> North Ghawar, Saudi Arabia	<p>North Ghawar Oil Producing Complex's history began with the start of Saudi oil production in 1938, and today manages assets dispersed over a 12,500 km<sup>2</sup> area. To meet increasing demand while reducing both operational costs and emissions, the complex launched a 4IR strategy. It pioneered oil producing intelligence, boosted existing asset reliability and upskilled young talent by leveraging over 65 solutions, including advanced analytics, AI-powered digital twins and Aramco large language model (LLM) GenAI. As a result, oil production increased by 8.44% while scope 1 and 2 emissions reduced by 8.21% per barrel of oil equivalent.</p>	Prescriptive analytics at the edge for autonomous well operation to maximize oil production and optimize manpower	↑ 8.44% Throughput
		Digital twin integrated planner to schedule multi-facility production with ML-based power optimization	↓ 17.8% Energy intensity
		ML-based flaring prevention model to minimize process upsets towards net-zero GHG ambition	↓ 35% Flare-causing process upsets
		AI-based asset failure prediction with LLM capability to extend asset life & expedite recovery	↑ 77% OEE
		Facility operator co-pilot powered by GenAI to empower crew and assure throughput availability	↓ 75% Training cost

Site	Change story	Top five use cases	Impact
<b>United Microelectronics Corporation (UMC)</b> Tainan	<p>To enhance profitability in a rapidly changing chip market, UMC focuses on production of specialized semiconductors, which have higher value but also greater process complexity. UMC's largest production and R&amp;D site in Tainan adopted agile strategies to deploy over 48 4IR use cases, such as a ML model to shorten design kit delivery time by 57% and an AI defect analysis system helping rise yields to 97%. This led to higher customer engagement with specialized product ratio up to 53% from 13%, contributing to a 75% gross margin gain.</p>	ML-driven product design kit creation	↓ 57.1% Specialized design kits delivery time
		Intelligence-joint photomask manufacturing platform	↓ 52.7% Photomask manufacturing lead time
		Auto ML-enabled automation for cycle time reduction	↓ 87% Specialized products cycle time at bottleneck tool
		Intelligent defect root cause analysis system	↑ 23% Specialized product yield
		Intelligent-based transportation system	↑ 47% Man-machine ratio
<b>Valeo Interior Controls</b> Shenzhen, People's Republic of China	<p>To maintain leadership in the autonomous driving market and assure product quality, flexible production and optimal costs, Valeo's Shenzhen factory implemented 42 4IR use cases, including AI-powered solutions and 14 advanced algorithms such as genAI-enabled troubleshooting and fully automated "lights-off" workshops. These innovations reduced finished goods defect rates by 45.9%, cut lead times by 34.5%, increased productivity by 60.2% and lowered unit energy consumption by 27.1%, ensuring high-quality, cost-efficient production.</p>	AI-enabled quality self-control lights-off workshop	↓ 86.2% Defect rate
		AI-enabled closed-loop AOXI (Optical & X-Ray) quality assurance	↓ 93.0% Market failure rate
		Multi-AA enabled changeover optimization	↑ 52.6% Lead time
		AI-enabled breakdown troubleshooting management	↑ 9.2% OEE
		AI-enabled dynamic cooling system optimization	↓ 26.1% Cooling equipment energy consumption

# End-to-End (E2E) Value Chain Lighthouses

## Wave 12

### Supply Chain & Logistics

Site	Change story	Top five use cases	Impact
<b>Haier</b> Qingdao, People's Republic of China	To meet surging global demand and address delays in R&D, delivery and after-sales service, Haier Jiaozhou optimized its entire value chain with big data, advanced algorithms and generative AI. Supplying 90% of its products globally, the site achieved a 49% reduction in design cycle time, a 19% decrease in order delivery time, and a 28% drop in overseas failure rates.	Cooling system design optimization based on performance prediction model	↓ 49% Cooling system design cycle
		Advanced algorithm-enabled dynamic scheduling of overseas orders	↓ 19% Overseas orders delivery cycle
		Self-tuning of vacuuming standard based on vacuum level prediction model	↑ 25% Evacuation efficiency
		ML-enabled expert system on global cloud laboratory	↓ 75% Quality defect diagnostic cycle
		AI-enabled overseas air conditioner predictive diagnostics and repair advice	↓ 33% Mean time to repair (MTTR)
<b>Schneider Electric</b> Shanghai, People's Republic of China	Faced with a surge in global orders and a fourfold increase in SKUs from new energy markets, Schneider Electric Shanghai responded by boosting automation by 20% and integrating advanced technologies like ML-enabled prototyping, smart planning and GenAI-driven maintenance. These efforts led to a 63% improvement in speed-to-market, a 67% reduction in make-to-order lead time and an 82% increase in labour productivity.	ML-enabled digital prototyping	↓ 67% Verification lead time
		End-to-end supply chain intelligent planning and scheduling	↑ 8% 2nd time on-time delivery
		Supplier quality connectivity empowered by advanced analytics	↓ 84% Defect rate
		Modular automation production lines empowered by digital twin	↓ 64% Industrialization lead time
		Augmented maintenance workforce using GenAI	↓ 33% Mean time to repair (MTTR)

# Wave 13

## Supply Chain & Logistics

Site	Change story	Top five use cases	Impact
<b>Agilent Technologies</b> Penang, Malaysia	Faced with rising demand, material price volatility and a rapidly expanding portfolio (including four mergers and acquisitions and 2,500 new SKUs since 2018), Agilent's Penang site embraced digital transformation to enhance its high-mix, low-volume manufacturing processes. Deploying over 40 solutions, such as AI in supply chains, 3D printing and zero-code workflows, the site achieved a 40% productivity improvement, a 32% reduction in manufacturing costs and a 48% cut in delivery lead time. Its "Everyone-Can-Digital" initiative upskilled 88% of its workforce, leading to a "Great Place to Work" designation for four consecutive years and reducing attrition to 3.5% compared to the 9.4% industry average.	Best-fit adaptive ML demand forecasting system	↑ 49% 3-months forecast accuracy
		AI-powered procurement simulation platform	↓ 26% Material cost
		Predictive inventory replenishment with advanced algorithms	↓ 55% Deferred revenue
		Additive manufacturing (AM) production system with AI vision system	↓ 75% 3D printed manufacturing lead time
		Zero-code workflow manager for shopfloor automation	↓ 26% Production cycle time
<b>Emirates Global Aluminium (EGA)</b> Al Taweelah, UAE	Operating one of the world's largest aluminium smelters, in an industry marked by raw material and freight cost volatility, EGA undertook a 4IR transformation to further increase its cost competitiveness, agility and flexibility. In three years, the site implemented over 80 use cases and upskilled over 20% of its workforce, injecting advanced AI into a traditional and labour-intensive industry. The site used deep learning computer vision and LLM to optimize frontline operations, reducing operational downtimes by 50% and non-productive time by 18% – raising overall equipment effectiveness by 12%.	Deep learning video supervisor to monitor SOP compliance and send real-time alert to operator	↑ 90% SOP compliance
		AI equipment failure prediction with GenAI to explain root cause to operator	↓ 22% Mean time to repair (MTTR) of cell failure
		Deep learning for online inspection of electrode quality	↑ 97p.p. Visual inspection rate
		One click optimization for inbound and outbound shipments	↓ 51% Demurrage costs
		Category management with GenAI to facilitate negotiation	↑ 19% Savings vs published market rates
<b>Unilever</b> Tinsukia, India	To adapt to the surge in "instant delivery e-commerce" via shorter runs and wider product variety, Unilever Tinsukia, operating in a remote region with limited resources, implemented over 50 digital use cases improving end-to-end supply chain agility through ML-driven planning, AI-enabled changeovers and a green digital twin. This helped reduce planning frozen periods from 14 days to one day, enabling a threefold increase in unique SKUs and cutting the time for sustainable packaging trials by 84%. Additionally, the site supported local community development by fostering digital skills through an Industrial Training Institute and a digital-Braille lab, strengthening its social impact alongside its digital transformation.	AI-enabled one-click rapid changeovers and stabilization for premium packs	↓ 85% Average changeover time
		Green digital twin for accelerating sustainable packaging product launches	↓ 84% Trial stabilization period
		AI powered smart workforce allocation for labour productivity	↑ 3.9X Labour productivity
		GenAI-enabled consumer centric statistical process control	↑ 2.3X Market share growth
		AI-enabled integrated planning ecosystem for instant delivery e-commerce	↑ 35% Forecast accuracy

Site	Change story	Top five use cases	Impact
<b>Midea</b> Chongqing, People's Republic of China	Facing a surge in customized orders – from 31% to 87% – from 42 industries, Midea Chongqing deployed 79 digital use cases powered by machine learning, augmented reality and simulation. This enabled a “Batch Size 1” make-to-order delivery model, optimizing product configuration, intelligent design, agile production and adaptive quality assurance. These measures reduced configuration lead times by 81%, design lead times by 45% and after-sales failure rates by 31% while accommodating a 180% increase in custom orders.	One-click intelligent configuration and quotation based on multi-physics simulation	↓ 81% Configuration lead time
		Intelligent customized component design powered by self-developed PLM and heuristic algorithms	↑ 49% Design reuse rate
		Flexible machining enabled by advanced scheduling and dynamic dispatch	↑ 32% OEE
		AR and AI-enabled intelligent operator guidance and error proofing in assembly	↓ 53% Qualification period for new operators
		ML-enabled dynamic optimization and proactive defect alerts in pressure vessel welding	↓ 71% Defect rate

## Sustainability Lighthouses

### Wave 12

#### Previously awarded Factory or E2E Lighthouses

Site	Change story	Top five use cases	Impact
<b>Foxconn Industrial Internet</b> Shenzhen, People's Republic of China	To meet the consumer electronics industry's commitment to carbon neutrality, Foxconn Industrial Internet utilized AI, Internet of Things (IoT) and other 4IR technologies to optimize recycling, track carbon footprints and innovate for sustainability. This led to a 42% reduction in scope 3 emissions, a 24% cut in scope 1 and 2 emissions, and increased recycled material content to 55%-75%.	Recycling and utilization improvement of metal chips in the value chain	↓ 39% Scope 3 emissions
		Process modelling and IoT-enabled carbon footprint optimization	↓ 44% Carbon footprint
		Sustainable anodizing with AI-powered controls and circularity	↓ 72% Scope 3 emissions
<b>Midea</b> Hefei, People's Republic of China	As a top global washing machine producer and sustainability leader, Midea Hefei implemented 24 4IR use cases to reduce emissions and optimize energy use. The site cut scope 1 and 2 emissions by 36.4% and scope 3 emissions by 26.0%. Solar power now provides 31% of energy, 40% of water is recycled, and waste was reduced by 22.1%.	Advanced analytics for smart energy forecasting, consumption and dynamic balancing	↑ 19.0% Green energy utilization rate
		Green product design with AI-enabled carbon lifecycle footprint analysis and digital simulation	↓ 24.3% Power consumption per cycle
		AI enhanced logistics network and route optimization for fuel reduction	↓ 29.2% Fuel consumption

Site	Change story	Top five use cases	Impact
<b>Tsingtao Brewery</b> Qingdao, People's Republic of China	Industrial beer brewing is traditionally high-energy and carbon intensive. Tsingtao Brewery leveraged advanced algorithms and IoT to deploy 25 use cases aimed at reducing energy and carbon intensity in beer production. The factory achieved a 25% reduction in unit energy consumption, a 57% decrease in scope 1 and 2 emissions, and a 13% cut in scope 3 emissions.	Advanced analytics enabled heat recycling for steam optimization	↓ 100% External steam consumption
		CO <sub>2</sub> recycling based on soft measurement of fermentation products concentration	↓ 43.2% CO <sub>2</sub> purchased per kL of beer
		Filling parameter recommendation of optimal CO <sub>2</sub> dosage based on particle swarm optimization	↓ 36.96% CO <sub>2</sub> consumption

## Wave 13

### Previously awarded Factory or E2E Lighthouses

Site	Change story	Top five use cases	Impact
<b>Schneider Electric</b> Wuxi, People's Republic of China	Schneider Electric's Wuxi campus, an electronics manufacturing centre, reached net-zero scope 1 and 2 emissions in 2022, eight years ahead of its 2030 target. Sustainability initiatives included AI-powered eco-design, a closed-loop carbon-dioxide tracking platform with suppliers, and machine learning models to optimize energy efficiency and the development of circular economy solutions with customers. This led to a 90% reduction in scope 1 and 2 emissions, a 65% reduction in scope 3 emissions and a 15% reduction in water use.	HVAC intelligent system enhanced energy & water efficiency	↓ 35% Energy consumption
		End-to-end circular offer facilitating resource efficiency and decarbonization	↓ 38% Raw material required
		AI-enabled digital simulation for thermal process energy efficiency	↓ 25% Energy consumption

### Sites new to the Global Lighthouse Network

Site	Change story	Top five use cases	Impact
<b>Ferrovial</b> London, UK	The Kilo Apron Development Substructure is Heathrow Airport's largest and most complex civil project of the last 10 years. To prioritize sustainability, since 2017 the project incorporated various innovative technologies and techniques, including drones, hydro-treated vegetable oil (HVO), hybrid excavators, low-carbon concrete, design for manufacture and assembly, and three-dimensional building information modelling. This helped achieved a 67% reduction in scope 1 and 2 emissions and a 63% reduction in scope 3 emissions.	Achieving zero construction and demolition waste	↑ 100% Material recovered
		Maximizing design to value	↓ 58% Design for manufacturability (DfMA) - scope 3 emissions
		Closing the water loop	↓ 71% Total mains water used

Site	Change story	Top five use cases	Impact
<b>Novelis</b> Uhrichsville, United States	Novelis' recycling facility achieved 97% recycled aluminium content, significantly reducing its reliance on energy-intensive primary production. This was achieved through advanced scrap segregation, procurement strategies and digital tools, earning GreenCircle certification. Scope 3 emissions from bauxite mining and primary aluminium production make up 85% of Novelis carbon footprint. With a greenhouse gas intensity of only 1.1 metric tons of carbon dioxide per metric ton of aluminium – far below the industry average of 5.8 metric tons – the site contributes 25% of Novelis' North American sales and advances its goal of achieving carbon neutrality by 2050.	Maximizing circularity through strong sortation & segregation procedures	↓ 47% Primary material consumption
		Increase recycled content through flexible equipment design	↓ 5% Total scrap processed
		Maximizing recycled content through data analytics	↓ 53% Scope 3 emissions
<b>Nucor</b> Sedalia, United States	The steel industry contributes 7%-8% of global carbon dioxide emissions. In January 2020, Nucor launched a \$250 million electric arc furnace mill in Sedalia, Missouri, achieving zero scope 2 emissions via a 75-megawatt power purchase agreement with Utility Energy. Additionally, scope 1 emissions were reduced by nearly 60% through the pre-heating of scrap steel with waste heat and an innovative micro mill technology.	Reducing scope 1 emissions through waste heat recovery for scrap preheating	↓ 65% Natural gas per ton of steel produced
		Zero scope 2 emissions through power purchase agreement (PPA)	↓ 100% Scope 2 emissions per ton of steel produced
		Eliminating need for reheating through micro mill technology	↓ 90% Natural gas per ton of steel produced
<b>Siemens</b> Fürth, Germany	Siemens Fürth aims to achieve net zero by 2026, four years ahead of the company's corporate target. Based on the foundation of extensive energy metering and a cross-department sustainability team, the site deployed multiple solutions including an on-site repair centre for product lifetime extension, electromagnetic filtering for power quality enhancement and end-to-end product carbon footprint management. This has led to energy savings of 12% in absolute terms and 64% per volume, even as overall throughput increased by 145%.	Holistic energy management and optimization (building & production)	↓ 8% Energy consumption
		Energy saving through power quality conditioning (EP-X filter)	↓ 3.8% Energy consumption
		Product lifetime extension services	↑ 58.4% Avoided emissions

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# Endnotes

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- 19 Definitions:
- Conversion costs: the combined costs of direct labour and manufacturing overhead incurred to transform raw materials into finished products.
  - Cycle times: the total duration required to complete one full production process or operation from start to finish.
  - Defect rates: the proportion of products or services that fail to meet quality standards or specifications, expressed as a percentage of the total output.
- 20 Based on analysis of GLN site visit report data (2024 Cohort).
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27	Based on analysis of GLN site visit report data (2020-2024 Cohorts).
28	Based on GLN site visit report, September 2024.
29	Definition and reference:
	<ul style="list-style-type: none"> <li>– Center of Excellence (CoE) is a dedicated entity that provides leadership, best practices, research, support and training for digital initiatives, aiming to drive innovation and ensure the successful implementation and adoption across the network.</li> <li>– McKinsey &amp; Company (2024, December 6). <i>From AI to Impact: Capabilities powering Lighthouses' 4IR adoption</i>." <a href="https://www.mckinsey.com/capabilities/operations/our-insights/from-ai-to-impact-capabilities-powering-lighthouses-4ir-adoption">https://www.mckinsey.com/capabilities/operations/our-insights/from-ai-to-impact-capabilities-powering-lighthouses-4ir-adoption</a>.</li> </ul>
30	Based on GLN site visit report, November 2024.
31	Definition and reference:
	<ul style="list-style-type: none"> <li>– Artificial intelligence/machine learning operations (AI/ML Ops) refers to the practices, tools and frameworks used to manage the end-to-end lifecycle of machine learning models in production. It is an extension of DevOps principles tailored specifically for AI and ML workflows, aiming to bridge the gap between data science and IT operations to ensure that ML models are deployed, monitored and maintained effectively in production environments.</li> <li>– Software Engineering Institute. (2020, January 21). <i>Introduction to MLOps: Bridging Machine Learning and Operations</i>. <a href="https://insights.sei.cmu.edu/blog/introduction-to-mlops-bridging-machine-learning-and-operations/">https://insights.sei.cmu.edu/blog/introduction-to-mlops-bridging-machine-learning-and-operations/</a>.</li> </ul>
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35	See endnote #29.
36	Definitions:
	<ul style="list-style-type: none"> <li>– Manufacturing execution systems (MES): software that monitors and controls manufacturing processes, ensuring efficient production and compliance with quality standards.</li> <li>– Prototyping: the process of creating an early model of a product to test and refine its design before full-scale production.</li> <li>– Batch release: the approval process for ensuring that a manufactured batch meets quality and regulatory standards before it is distributed or sold.</li> </ul>
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