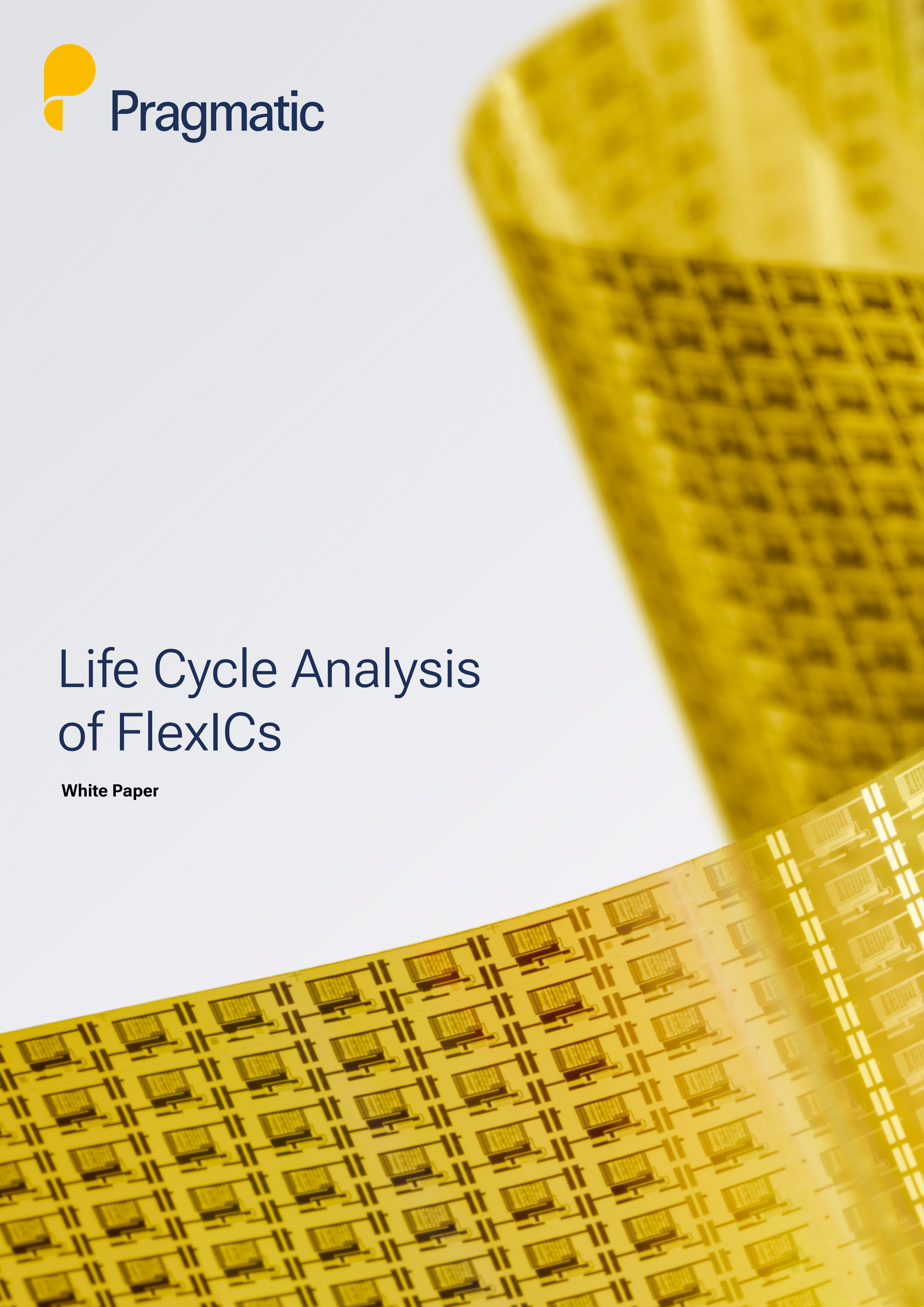
Pragmatic

# Life Cycle Analysis of FlexICs

**White Paper**



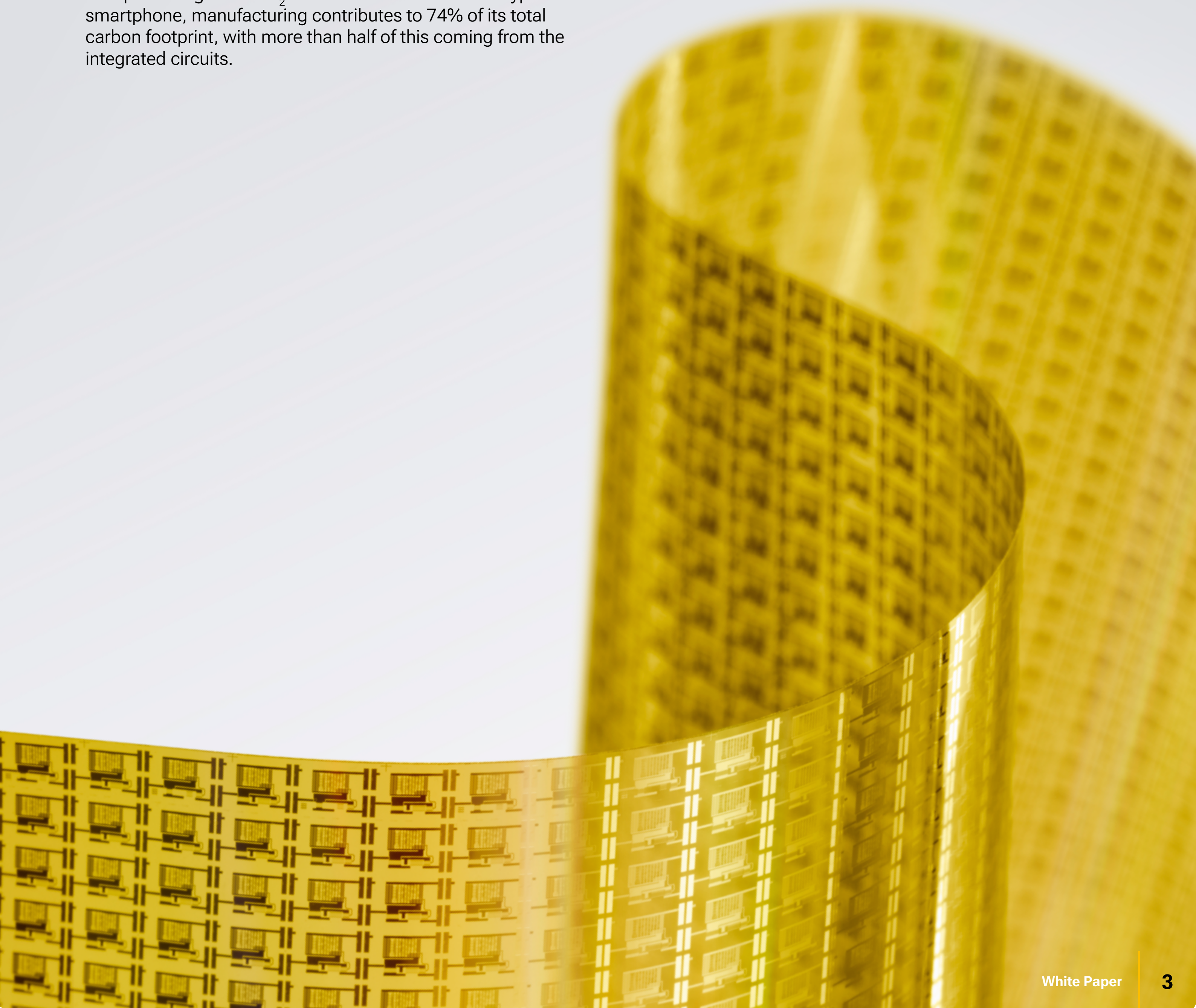
Authors:
Ashiq Ahamed
Cinthya Anand
Joshua Young

# Introduction

Pragmatic Semiconductor is a British semiconductor manufacturing company that develops ultra-low-cost flexible electronics that can help address society's challenges. We provide a unique, flexible platform and rapid turnaround time, with significantly lower footprint and cost than conventional silicon foundries.

Electronics is one of the most polluting industries in the world. Semiconductors have overtaken the automotive sector in overall carbon footprint, with the world's largest chip producer now producing more $CO_2$ than General Motors. For a typical smartphone, manufacturing contributes to 74% of its total carbon footprint, with more than half of this coming from the integrated circuits.

In this whitepaper, we report the life cycle analysis of one of our key electronic products and discuss why low carbon electronics are poised to play a significant role in implementing a ubiquitous Internet of Things. This report illustrates our forecasted environmental footprint and ongoing efforts to minimise this further through advances in intelligent low-carbon manufacturing.



# Impact of semiconductor manufacturing

Semiconductor manufacturing is notoriously resource and energy intensive, from the management of cleanroom facilities to development of sub-fab tools and wafer processing. As the performance and complexity of devices increases, so does the number of process steps and the consumption of water, chemicals, gases, and energy. Alongside direct emissions from their facilities, manufacturers have to consider the impact from their supply-chain, energy generation, disposal of complex waste and technology life cycle.

The total emissions can be broken down into three kinds:

## Scope 1

Direct emissions from the manufacturing facility.

## Scope 2

Emissions from the energy consumed, in the form of electricity and heat, at the facility.

## Scope 3

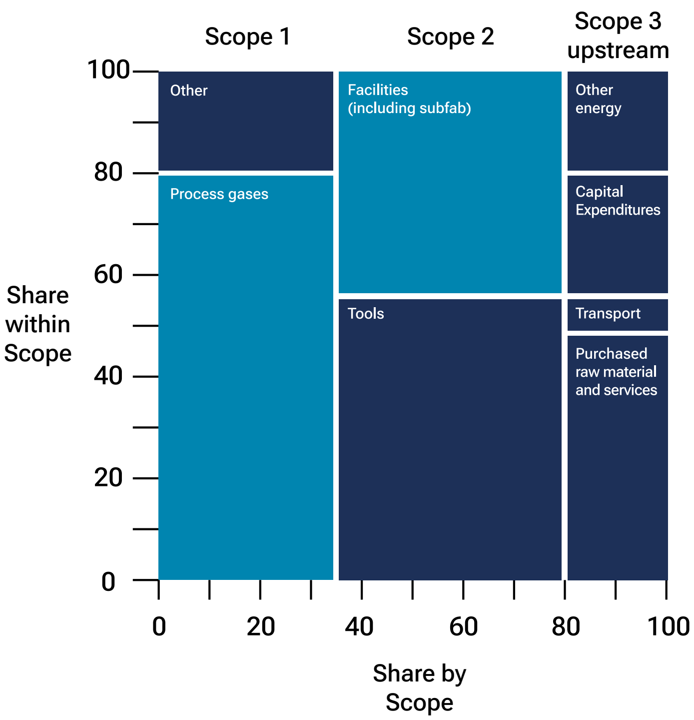
Emissions in the supply chain and raw materials used in the production.

For a typical silicon chip foundry, 80% of emissions come from Scope 1 & 2 (Graphic 1).

**Semiconductor fab emissions primarily come from scope 1 process gases and scope 2 electricity consumption.**

FIGURE 1
$CO_2$-equivalent emissions for typical silicon semiconductor foundries. Source: McKinsey & Company

**$CO_2$-equivalent emissions for typical fab profile[1]** % share




[1] Excluding scope 3 downstream. Emissions averaged across 200-millimeter (mm) and 300-mm semiconductor fabs

# Life cycle analysis of FlexICs

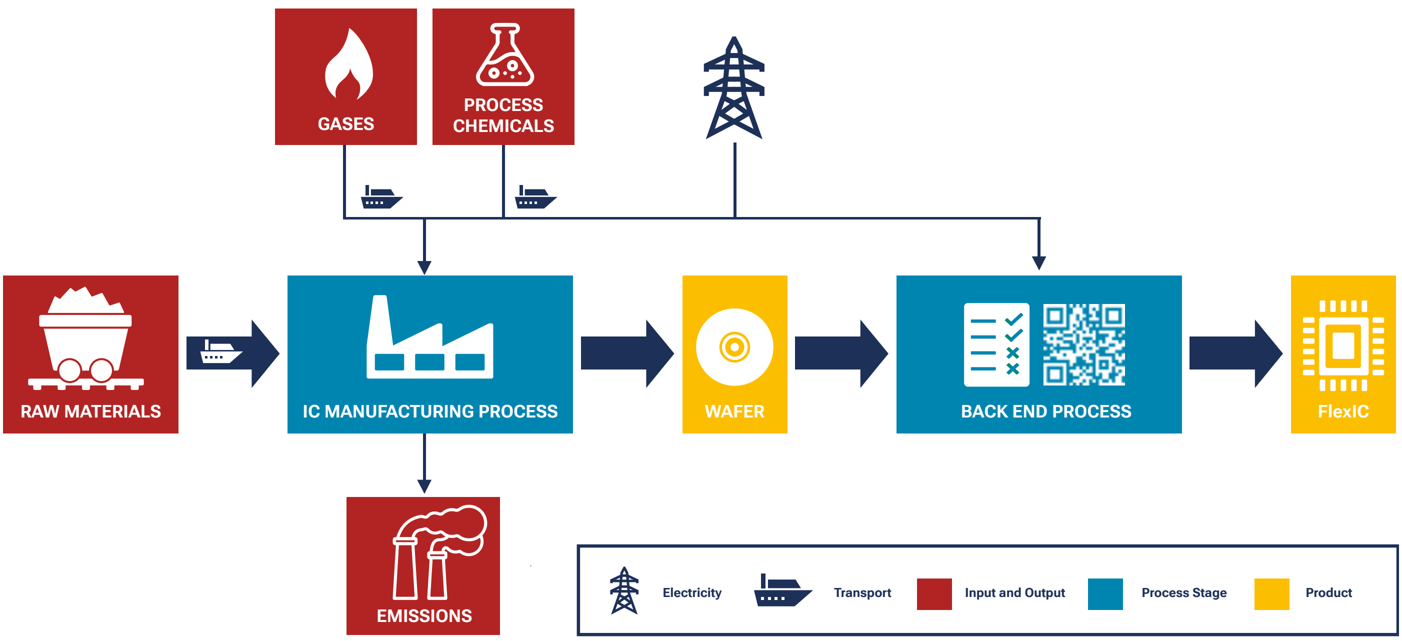
In mid-2021, Pragmatic collaborated with the University of Manchester to conduct a life cycle analysis (LCA) of its manufacturing process. An LCA addresses the potential environmental impacts (e.g., use of resources and the environmental consequences of releases) throughout a product's life cycle[1] and can help companies make environmentally sound decisions in the design, manufacture, and use of a product or system.

In this work, the LCA was conducted to forecast the environmental impacts of the production process of a typical FlexIC, a custom flexible integrated circuit (IC) that is thinner than a human hair (30μm) and can be used for a wide range of applications.

The scope of the LCA covered the entire footprint of the production process (cradle-to-gate analysis) including raw material extraction, supply chain transportation, manufacturing processes, and back-end assembly and testing of the finished product (see Figure 2)[2].

Our results showed the projected environmental footprint of a FlexIC to be less than 0.5 g$CO_2$ equivalent. In comparison, a typical 500 ml bottled carbonated beverage contributes nearly 250 times as much $CO_2$ eq. including ingredients, manufacturing, and packaging in the UK[3]. The most significant contribution came from chemicals used in the manufacturing process, accounting for more than 62%, followed by gases and electricity consumption in the manufacturing processes (see Figure 3).

FIGURE 2: Manufacturing process flow of a standard IC




[1] The LCA was conducted according to ISO 14040:2006 and ISO 14044:2006 guidelines.

[2] The impact assessment method used was based on the Intergovernmental Panel on Climate Change (IPCC) - Global Warming Potential (GWP) 100 years' timeframe.

[3] Amienyo et al., 2013. Life cycle environmental impacts of carbonated soft drinks. Int J Life Cycle Assess 18:77–92.

FIGURE 3
Global warming potential (GWP) contribution of the sub-processes and materials to overall footprint of a FlexIC (% share)

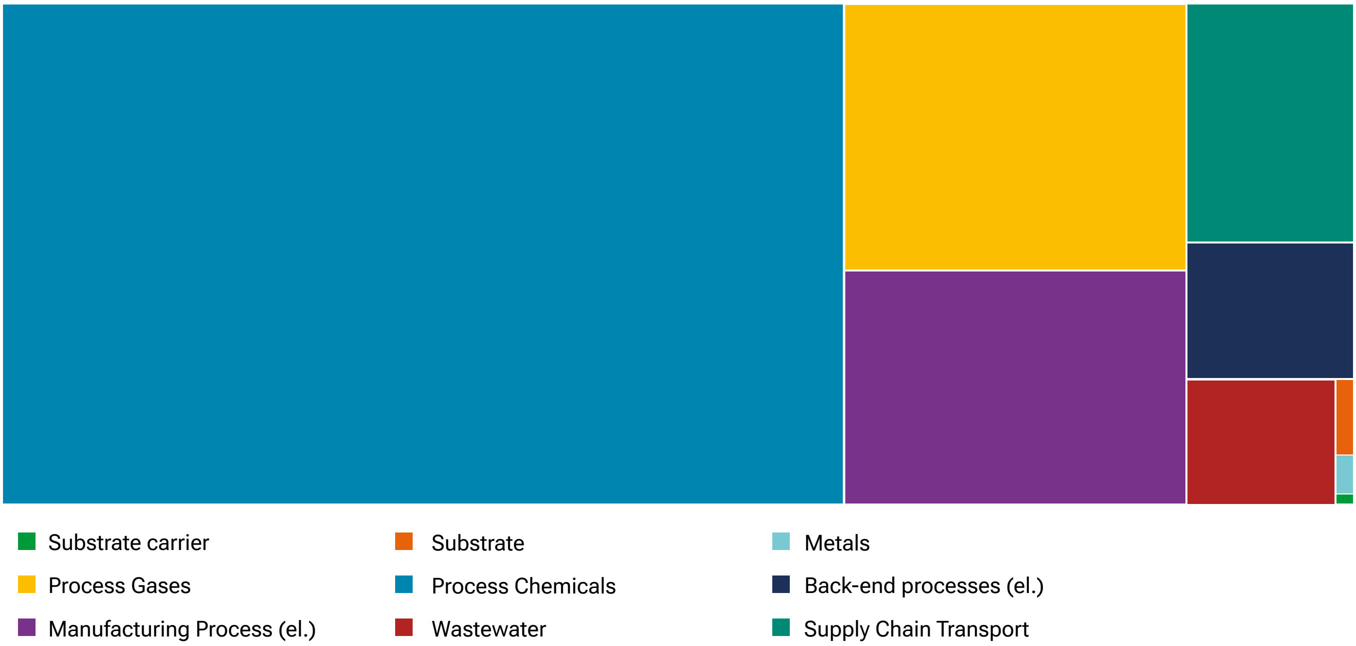



FIGURE 4
The carbon footprint of a typical FlexIC categorised under the Scope 1, 2, and 3 emissions (% share)


## How did we compare?

Carbon footprint of

- FlexIC <0.5 g $C0_2$eq.
- PET bottled carbonated beverage 126 g $CO_2$eq
- Integrated chips in a smartphone 0.9968 kg $C0_2$eq*
- High end smartphone 48 kg $C0_2$eq.
- Cotton jeans 90 kg $CO_2$eq.
- Soap bar 124 g $CO_2$ eq.
- Moulded chocolate 2.8 kg $CO_2$eq. per kg

* This data looks at the production of a smartphone known for its lower carbon footprint; higher-end models can have a significantly bigger impact.

# Greenhouse Gas Emissions: Scope 1, 2 and 3

In this analysis, we have focused on the carbon footprint of an individual FlexIC chip (Figure 4) and therefore, have not included emissions from office spaces, employee transport, and allied activities that are unrelated to the FlexIC production, as this allows us to forecast emissions in a likely future scenario where production is decentralised.

- Conventional wafer fabrication uses highly potent gases such as NF3 that has a global warming potential (GWP) 17,000 times more than $CO_2$
- Our technology uses less potent gases which are easier to dispose through standard recycling processes

## Scope 1

Scope 1 covers direct emissions from the manufacturing facility including gaseous emissions and wastewater.

### Safer chemicals and gases

The application of less potent gases in wafer fabrication stages has significantly reduced Scope 1 emissions in FlexIC production. For example, conventional wafer fabrication uses highly potent gases such as $NF_3$ that has a global warming potential (GWP) 17,000 times more than $CO_2$[567]. Subsequently, optimising gases and chemical usage through sensorisation and automation, and constantly evolving towards less potent materials would help lower Scope 1 emissions further.

### Reducing wastewater emissions

Water and chemical use is significantly lower than traditional silicon chip manufacturing and the constant optimisation of processes has contributed to lower Scope 1 wastewater emissions than the industrial norm. This will be further improved upon at our new manufacturing facility at Pragmatic Park by creating a localised wastewater treatment facility so that untreated wastewater will not leave the facility.

## Scope 2

Scope 2 covers emissions from the energy consumed in the form of electricity and heat at the facility.

### Optimised processes

Because Pragmatic uses state-of-the-art equipment and optimised processes based on specific design requirements, it has been possible to bring down cost and energy footprint significantly. A key contributor to this is the 'fit-for-purpose' technology node and the technology's reduced tapeout times.

Electricity consumption in the manufacturing process contributing to the Scope 2 emissions accounted for about 15%. The adoption of latest and advanced energy efficient equipment, constant optimisation of the process, and transitioning to 300mm fab to lower the overall energy consumption per IC resulted in the lower energy footprint for the FlexIC production process.

[4] https://ghgprotocol.org/about-us

[5] https://www.imec-int.com/en/expertise/cmos-advanced/sustainable-semiconductor-technologies-and-systems-ssts/stss-white-paper

[6] https://www.nist.gov/pml/sensor-science/fluid-metrology/database-thermophysical-properties-gases-used-semiconductor-0

[7] https://www.siad.com/products/specialty-pure-and-very-pure-gases/semiconductor-gases

# Scope 3

The greatest contribution to the overall footprint is from the Scope 3 emissions that include the materials and chemicals used in the production process and their supply chain activities. There are numerous materials used in the production of an IC chip, including metals, chemicals, gases, and substrate material. The production and supply chain transportation of all these accounted for the significant portion of the GHG emissions associated with FlexIC production. The current practice includes optimised consumption of the process chemicals and materials, selection of material resources with lower environmental footprint, improved conversion efficiency and thereby, minimising material wastage have favoured in achieving lower overall environmental footprint.

## Decentralised production

One of the reasons why Scope 3 for semiconductor industry is so large is because it is heavily centralised. By moving to decentralised production across the world, there is a possibility to lower the Scope 3 emissions considerably by offsetting the transportation footprint from the supply chain. The quantum of it would depend on the location of the fab and the origin of materials. Furthermore, by shortening customer supply chains, we offer an opportunity for companies (our customers) to curtail their carbon emissions. For example, if a large beverage company had a mini fab beside its bottling factories, that would reduce the emissions associated with transportation.

## Bringing suppliers on board

One of the key actions to reduce Scope 3 emissions is to improve sustainability across the supply chain. We aim to do this in two ways: by encouraging existing suppliers to shift towards sustainable production methods and by adopting suppliers who have already implemented such practices which will have a major impact in minimising our Scope III footprint further.

In summary, the emissions from Pragmatic's manufacturing facility are significantly lower than conventional fabs leading to lower Scope 1 and 2 emissions than Scope 3. We can further reduce existing footprint by incorporating in-house water and wastewater treatment, nitrogen optimisation, VOC (volatile organic components) reduction, and sensorisation of equipment. Eliminating the need for ultra-pure chemicals at every step of the process and extending control over the supply chain will enable us to deliver energy efficient products with minimal environmental impact.

# Why does this matter?

The global semiconductor industry is projected to grow to $680 billion market value in 2023, registering a growth of 5.1%[8]. The industry is at the forefront of enabling the digital transformation and the Internet of Things across the world. Low-carbon electronics will play a critical role in minimising the environmental implications when compared to conventional electronics.

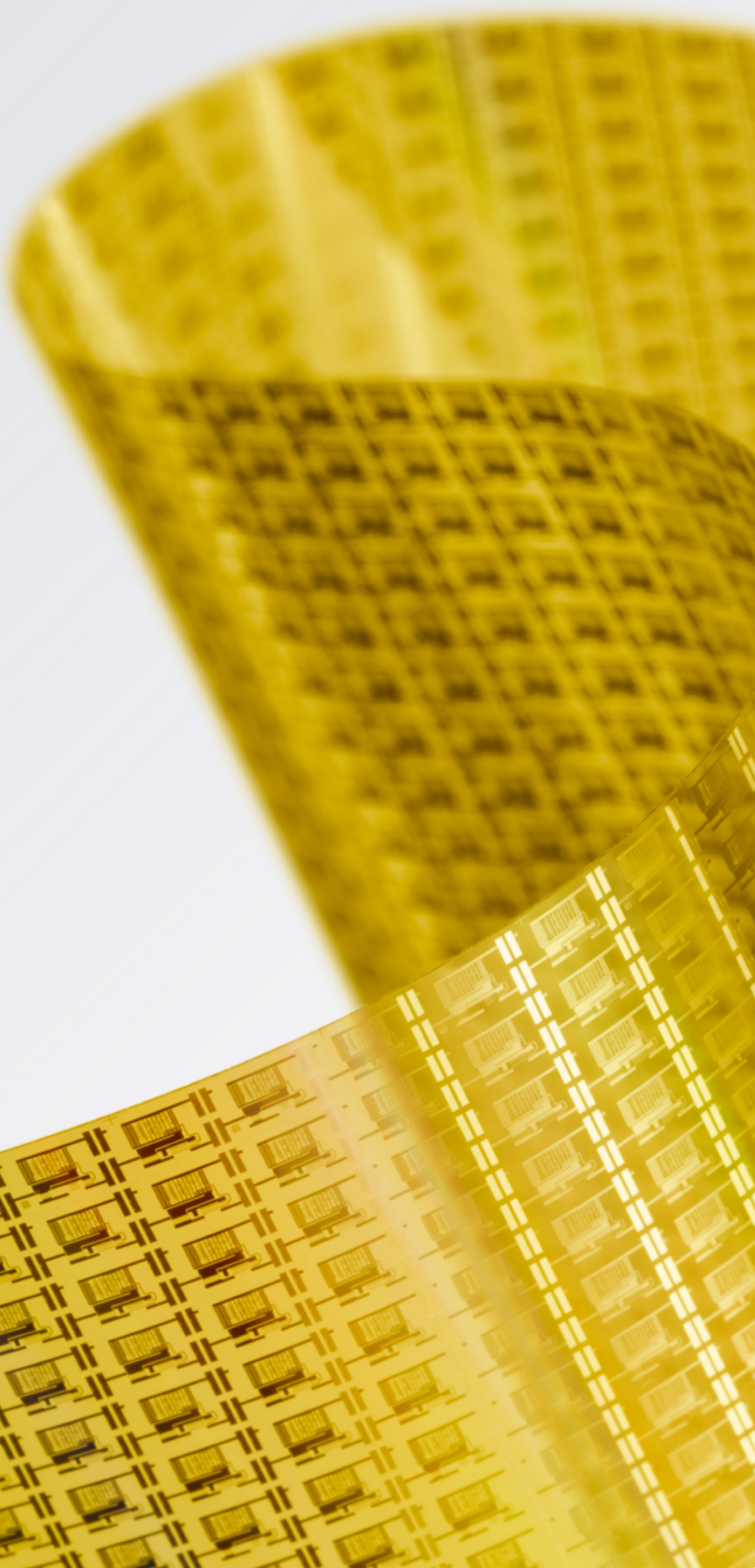
Achieving net zero targets will need complex solutions that take into consideration the entire footprint of a product from production to end of life. For instance, early trials have shown that enabling digital IDs in everyday items can improve recyclability rates by a factor that enables a net positive outcome.

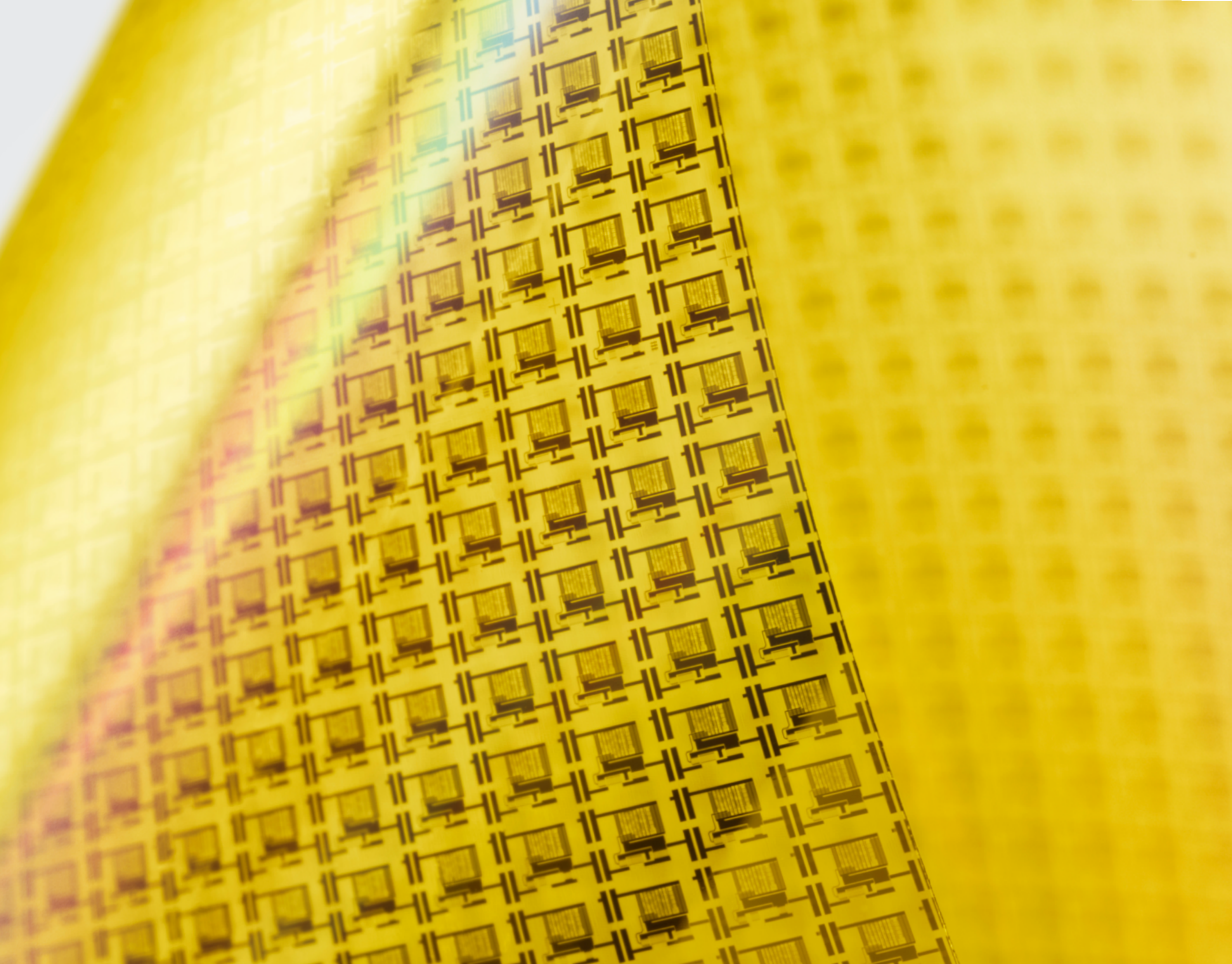
Taking the example of the FlexIC chip, a typical 500 mL PET bottled carbonated beverage contributes to about 126 g $CO_2$eq. from its ingredients, manufacturing, and packaging in the UK (cradle-to-gate LCA). Adding a FlexIC chip will increase the overall footprint by an insignificant amount but can make a major impact on recyclability down the line, by allowing retailers to track the quality and provenance of the bottle through its entire life cycle. It also helps to provide information about the grade of material and other additives used to retain the highest recyclate quality.

## Find out more

Visit our website www.pragmaticsemi.com to learn more about how we are enabling sustainability in semiconductor manufacturing. Contact us at info@pragmaticsemi.com for more information.

[8] ESIA_WSTS_SpringForecast2022.pdf (eusemiconductors.eu)





Learn more about Pragmatic

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