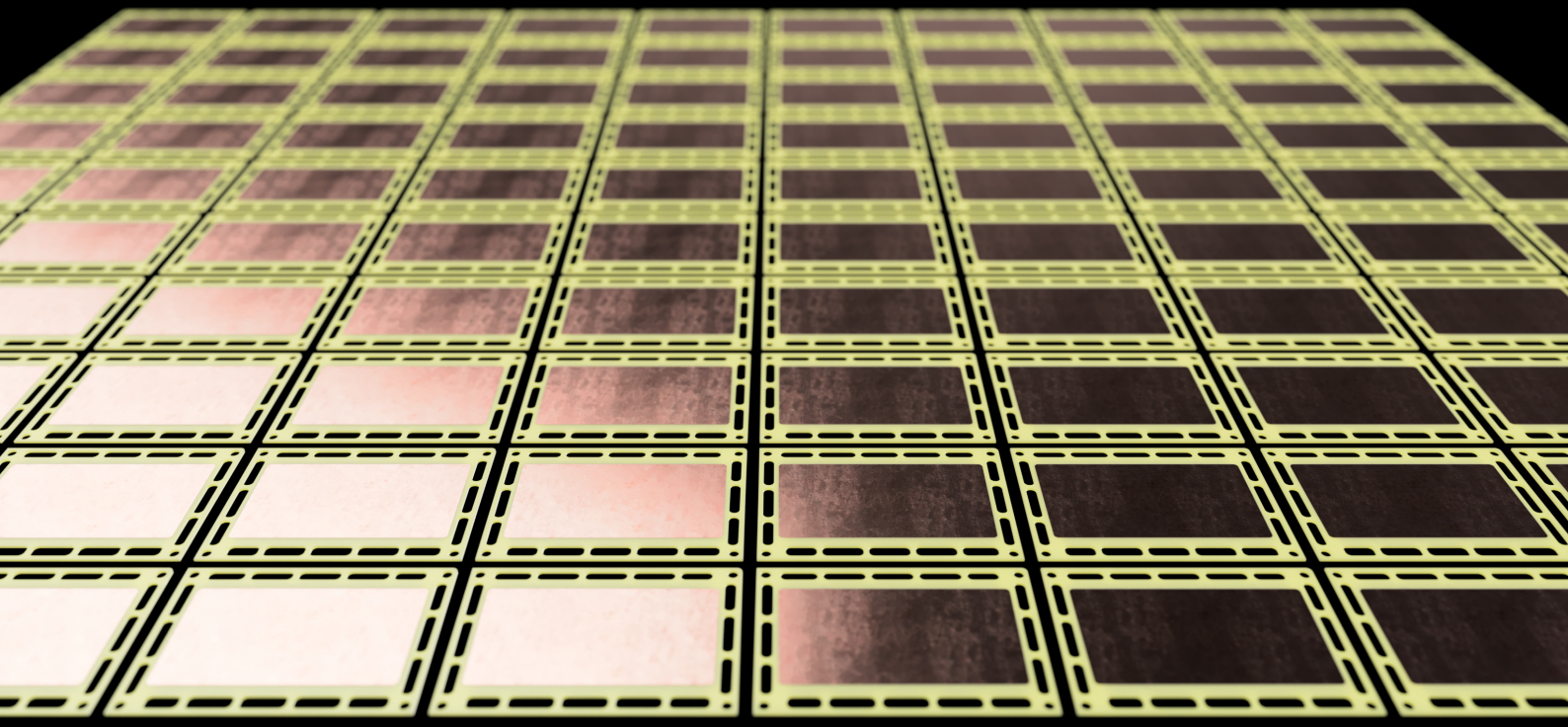
BRAMBLE ENERGY



PCBFC™:

The pathway to the lowest cost fuel cell

2023

Contents

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Dr Vidal Bharath

Chief Commercial Officer

Executive summary

Since the inception of commercial hydrogen fuel cell products, the landscape has been dominated by industry costs as the largest barrier to widespread adoption. Simply put, even in hard to abate sectors such as transportation, until costs are aggressively slashed, they will remain the major barrier to implementation of hydrogen technologies at scale.

The US Department of Energy (DoE) has set target costs for the fuel cell industry; an 80 kW fuel cell system, providing sufficient power for a small to medium sized passenger vehicle, at a production volume of 500,000 per annum (roughly 25% of Tesla's 2023 total volume[1]) has a target cost of $30/kW[2].

It is widely recognised that whilst this is the ultimate cost target to achieve competitiveness with incumbent technologies, interim targets must be set and met in the short term. A commonly accepted interim goal is $100/kW at the stack level. With incumbent technology often quoted above $1000/kW, determining a route to achieve $100/kW even conceptually has proven to be somewhat elusive for existing industry players.

Until now. This is fuel cells reinvented.

Bramble Energy's PCB based fuel cell technology aims to solve this problem using a revolutionary approach to the design, materials selection, and manufacturing routes not only for fuel cells, the engines of the hydrogen economy, but also for the production of hydrogen through electrolysis.

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The PCBFC™

Bramble Energy's PCBFC™ utilises existing PCB manufacturers around the world, which can deliver fuel cells of varying shapes and sizes for a range of applications through standardised production methods and materials.

The core substrate of Bramble's PCB fuel cell is a standard PCB laminate, which provides structural integrity and can be considered as a traditional fuel cell's bipolar plate. In fact, the standard PCB materials fulfil all the typical and complex fuel cell functional roles including gasketing, current collection, sealing and more. These standardized materials are widely used across the PCB industry, and this has resulted in access to significant economies of scale, even at the smallest production and prototype volumes.

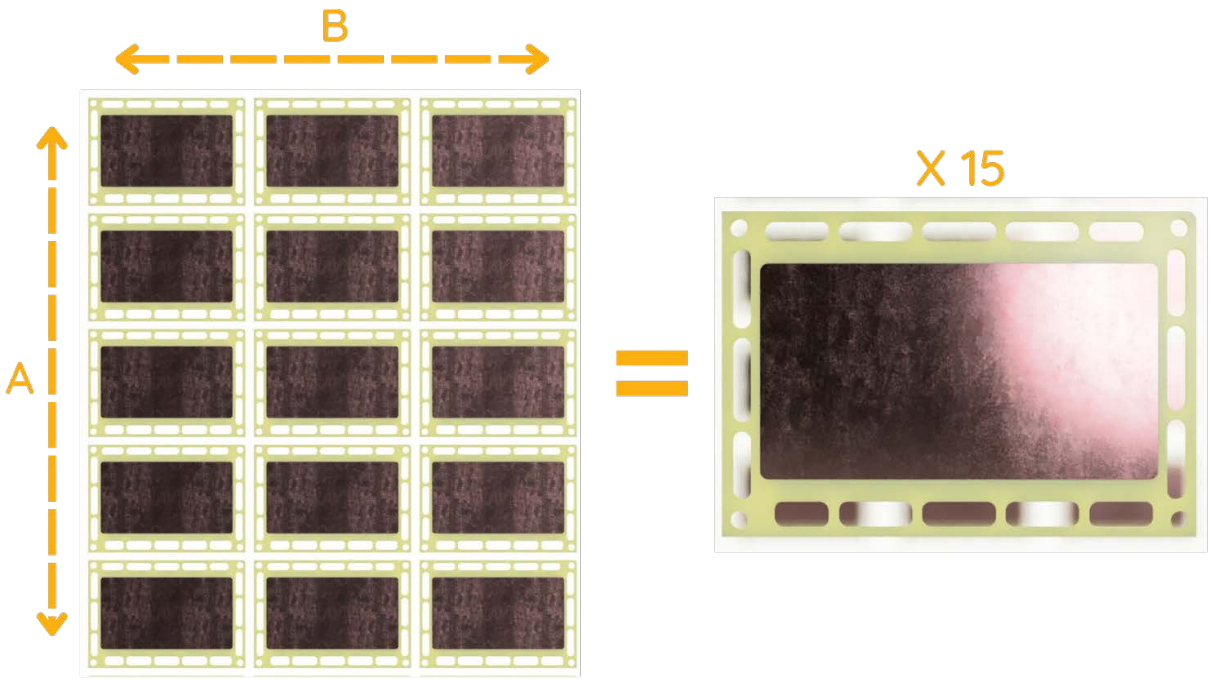

Figure 1. A single PCB panel can be divided into an unlimited number of designs, to produce fuel cells of all shapes and sizes. However, as each panel has an associated cost, maximizing for panel utilization directly results in improved $/kW.

PCB laminates are constructed of conductive and dielectric materials and are produced in standard sheets sizes known as panels. Bramble uses these panels to provide both structural integrity for a gas tight cell and electrical conductivity. A single sheet can produce numerous fuel cell modules (the building blocks of Bramble's fuel cell stacks) depending on form factor (Figure 1). Through designing fuel cell form factors to fit within a panel, Bramble can maximise material utilization and further reduce cost.

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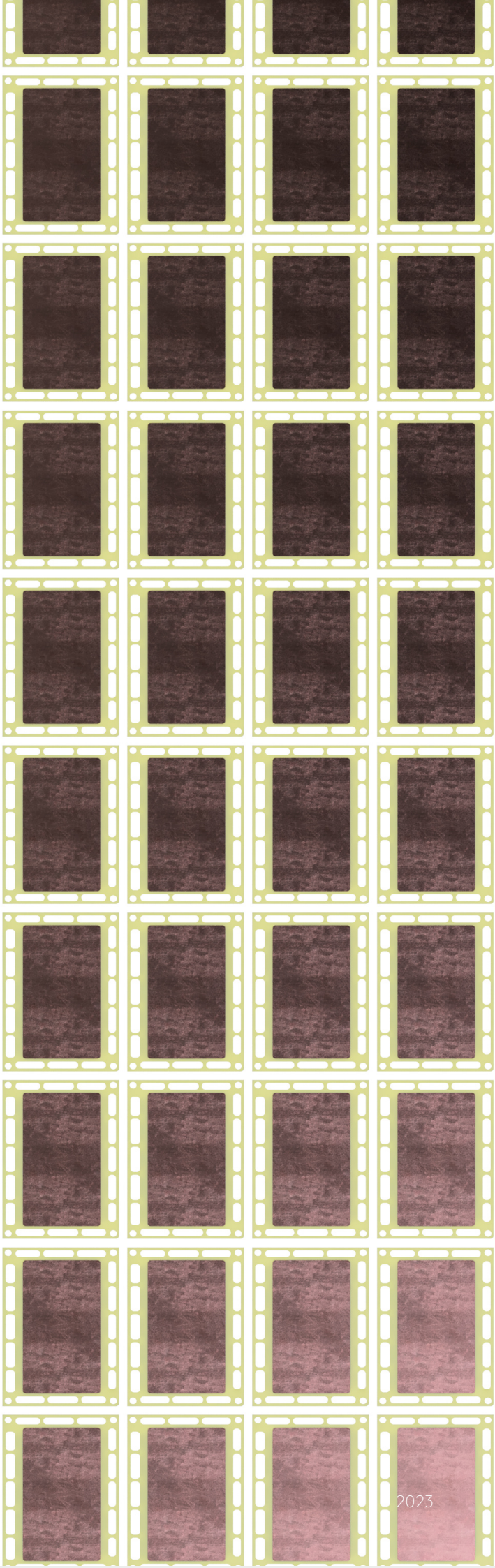
Since its foundation, Bramble Energy has had a simple goal; to decrease the cost of manufacturing hydrogen fuel cells. This target has and continues to define Bramble's business to date. In the past year, Bramble has used its credible, established supply chain to demonstrate how $100/kW for a PEM fuel cell stack could be achieved and at what volume.

From its inception, manufacturability (form factor flexibility and scale up) has always been at the forefront of Bramble Energy's activities. Bramble's technology is solving the greatest gap that exists with the commercialisation of PEM fuel cell technology; how to scale complex manufacturing whilst also becoming cost competitive with traditional powertrain technologies, as well as our competitors.

Bramble's fuel cells have an inherent cost advantage compared to the competition. This stems from a standardised PCB material set (and the enormous economies of scale inherent within these materials) and pre-existing manufacturing route (no CAPEX investment). With mass production of gigawatts of fuel cells per year already achievable through global PCB manufacturing routes, Bramble has turned its attention to maximising materials usage to further decrease the cost of this green energy technology.

Due to low manufacturing maturity, incumbent fuel cell technologies remain high cost, despite producing increasingly high-powered stacks and systems. Scaling of traditional metal and graphite plate fuel cell technologies requires several CAPEX-intensive steps between manufacture of prototypes and volume production. However, manufacturing fuel cells through the PCB industry allows Bramble and its customers to avoid many of the traditional hurdles and move directly to high-volume production within the same factory as the initial prototype. The PCBFC™ uses the same materials and processes regardless of production volume, always manufacturing in pre-existing facilities with zero CAPEX investment.



The PCB Advantage

Printed circuit boards (PCBs) are all around us. They are often in use in many of our day-to-day tools, whether that's checking the time on your digital watch or reading this article on a laptop, tablet or mobile phone. Consequently, the PCB industry has a global manufacturing base and is worth >$70b annually[3].

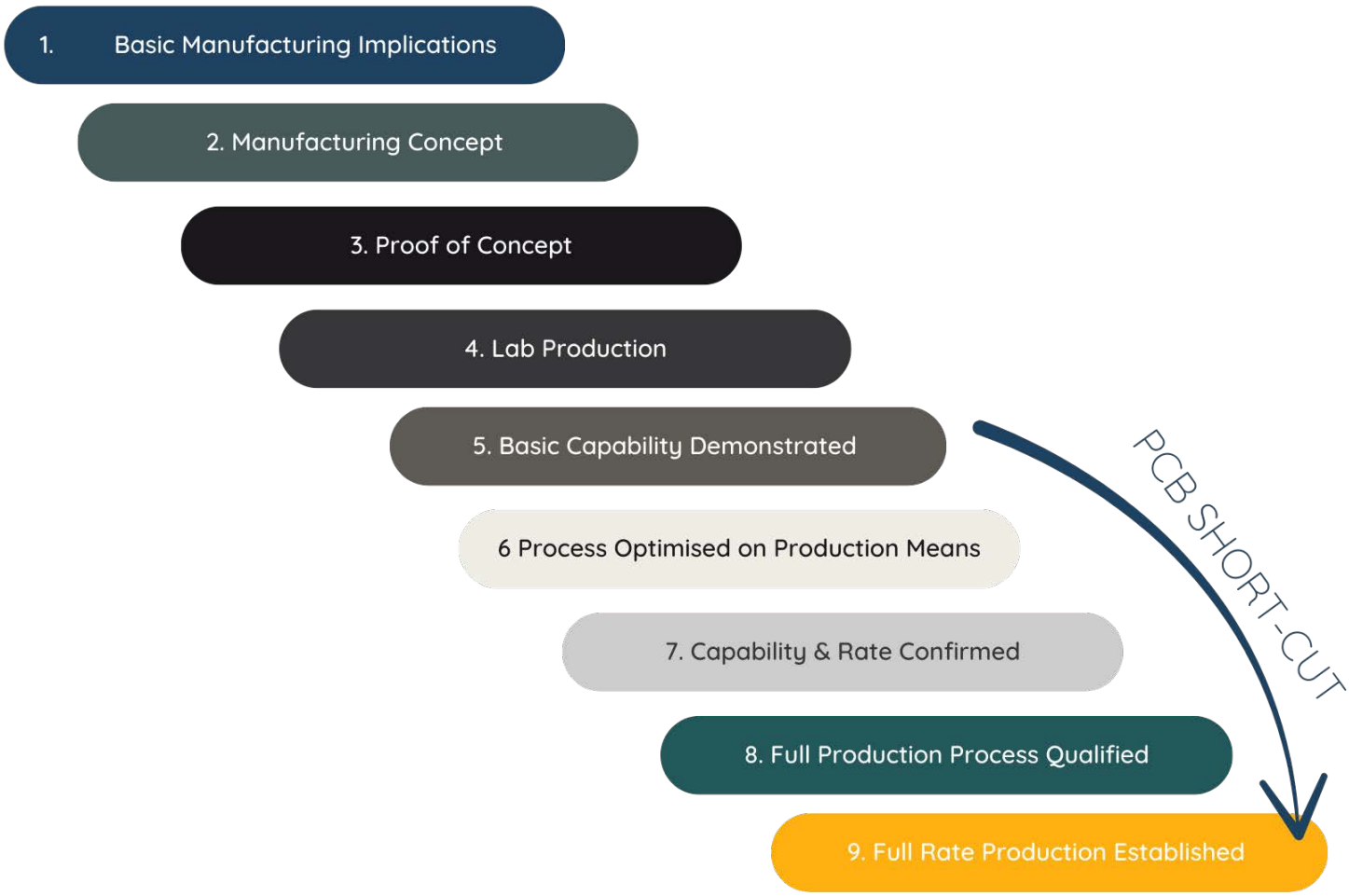


Figure 2. Manufacturing fuel cells through the PCB industry allows Bramble to skip past capital-intensive manufacturing readiness levels and move directly to high-volume production from prototype.

Figure 3.

PCB factories are available worldwide, and adhere to manufacturing standards such as ISO9001, BS EN9100 and IPC-6012. The throughput of a UK prototyping PCB facility is in the region of 250 panels per day. Large offshore facilities will typically handle 25,000 panels per day, and high-volume facilities also work with larger panel sizes, which are more cost-effective and allow further freedom of design. A standard UK panel represents c.2 kW of power, increasing to c.5 kW in larger panel sizes.

What makes Bramble Energy's technology so applicable in a world that needs fuel cells for so many different applications is its ability to be manufactured at almost any PCB factory in the world.

Having the world's only digitally tooled fuel cell, means Bramble Energy can design and produce fuel cells of varying sizes, both in terms of form factor and power output. This means it can service a multitude of customers, for a range of applications in a number of industries and sectors. Producing fuel cells using this method also gives rise to one of Bramble's greatest strengths,. The ability to empower our customers to control their own fuel cell supply chain. Bramble operates a licence model to its customers for its PCB technology; through joint development agreements (JDAs) Bramble develops products and technology that actually uniquely solves customers' needs.

Following a JDA, license agreements are established with customers to allow them to manufacture the product using PCB factories within their existing supply chain. Often this means they can continue to rely on well- established, trusted relationships with their existing PCB suppliers and even access further cost-down activity through increased buying power and volume.

To understand the true impact of Bramble's PCB-X™ platform technology, the structure of a traditional PEM fuel cell should be compared to the PCBFC™.

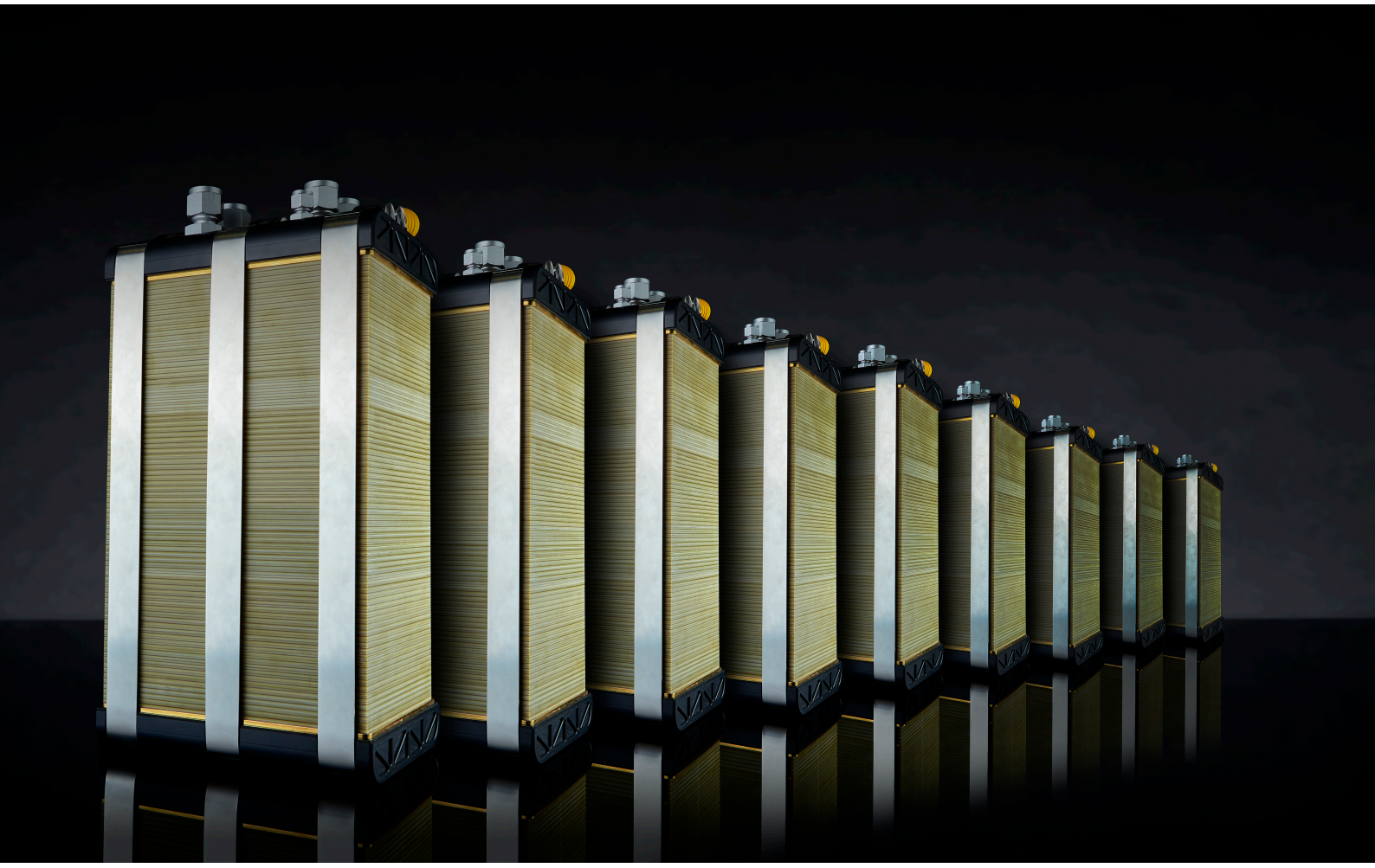
At the heart of a fuel cell engine is the Membrane Electrode Assembly (MEA). This is the heart of the engine and transforms the fuel into power through an electrochemical reaction. The MEAs used by Bramble come from established suppliers and are common, high-volume components within the hydrogen industry. Bramble uses several variants from different suppliers depending upon the customer requirements for a specific application.

The stack enables the MEA to function efficiently and keeps it well fed with reactants, hydrated and at the optimum temperature. This is where Bramble's PCB-X™ platform innovates to simplify components and structures by using globally standardised PCB industry techniques and materials to develop low-cost, scalable fuel cells that are globally accessible. The stack contributes the most significant cost of scaling fuel cell engines and it is here that Bramble Energy's effort has been focussed.

As with internal combustion, a fuel cell engine requires Balance of Plant (BoP) components. These include compressors, valves, sensors, pumps and radiators to name but a few. Bramble Energy's unique material choices have allowed access to unparalleled BoP (often referred to as the system) advantages, the most significant of which are to minimise the integration complexity between hybrid components. This is achieved by matching voltage-current profiles of the stack to DC/DC converters for example or by removing the need for deionised water coolant systems given that the cooling pathways do not make contact with the electrical pathways in the stack.

The Cost Advantage

To truly understand its cost down activity, Bramble has recently undergone an extensive analysis to determine its cost base at increasing production scales. Using an existing PCB supply chain, Bramble analysed through to quotation PCBFC™ volume capacity potential in the MW and GW per annum to determine the true cost potential of the technology.



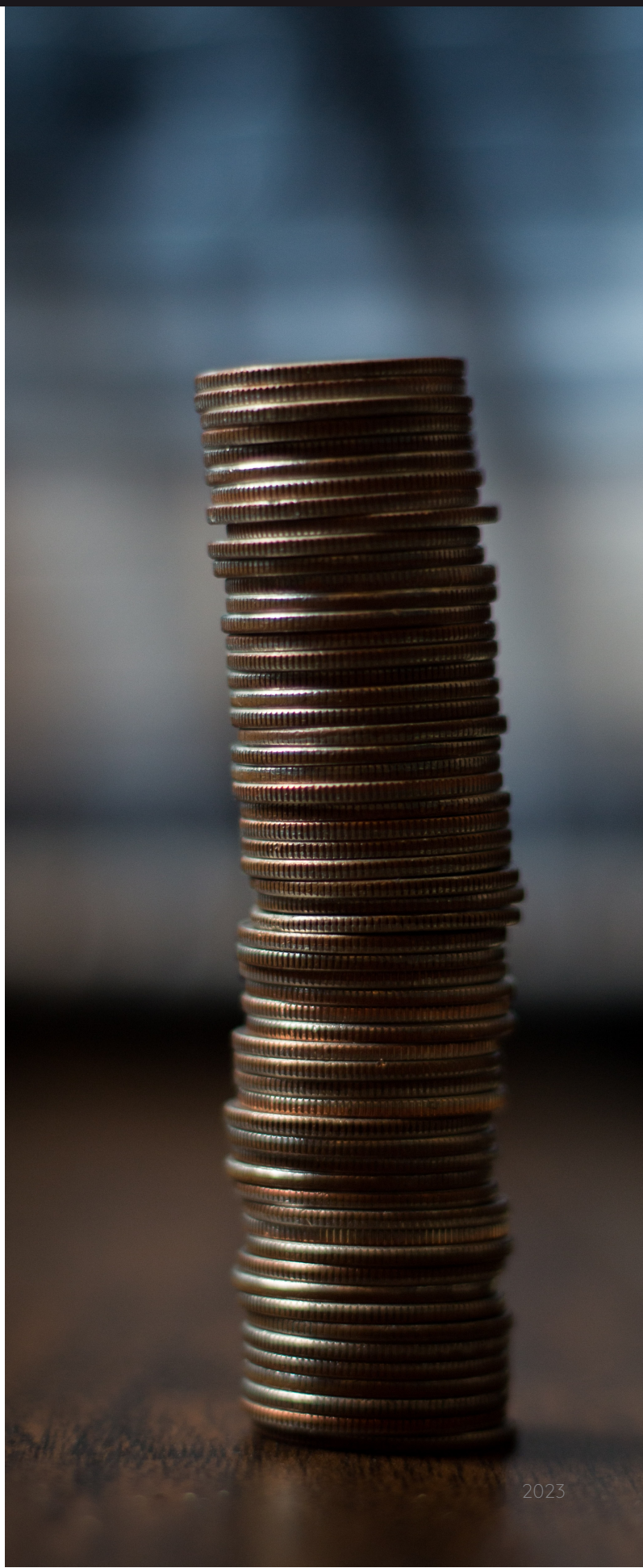
The first analysis of volume production yields a PCB cost (all elements of the repeating unit, not including the MEA), for a volume of 1000 panels per month, equating to c.100 MW per year of production of $106/kW. For context, this quoted volume represents only 0.15% volume of the DoE target (or 0.04% of Tesla's 2023 volume).

What makes our cost analysis even more meaningful is that the quoted volumes are not for a single product. It is based on panel throughput within a factory, i.e. it can provide fuel cell modules and stacks of variable sizes and form factors for multiple product applications. Furthermore, the quoted prices include PCB factory margins. For entities with significant buying power such as Bramble's mobility OEM and Tier 1 manufacturer customers, these margins will only continue to improve, by controlling their own PCB supply chains for the manufacture of Bramble's PCB-X™ platform technology.

By recognizing where the cost contributors are in the processing and design of the PCBFC™, Bramble has continued to innovate and develop a new stack architecture with a clear path to an additional reduction in cost of c.40% from the existing PCBFC™ technology.

The latest evolution in structure that has enabled this further significant cost reduction is currently in early phase testing and validation through our UK supply chain. Short stack testing of this technology will be conducted in Q4 2023 after further core module optimisation; with full stack testing expected in Q2 2024.

With further manufacturing volume increases, achieving economies of scale in terms of purchasing power and optimisation of process flows moves Bramble's technology towards a PCB cost at only c.100's MW of cumulative production of $60/kW at 1.5 Wcm-2 power rating.



The Next Steps

Bramble Energy's purpose is to finally bring a cost competitive fuel cell stack technology to the industry. Whilst strides have been made to reduce stack costs compared to incumbent technologies, more can still be achieved.

Bramble Energy will continue to take advantage of advances in electrochemical materials to further extract power density from active area thus delivering improvements in $/kW.

Bramble's PCBFC™ next generation technology is in progress and there is further planning to optimise process efficiencies that are being evaluated to support cost down activities.

Bramble has developed a new generation of hydrogen fuel cells that are accessible to all markets. Low-cost materials and manufacturing routes make implementation of zero-emission technology viable for even the most cost-sensitive markets. What's more, Bramble's partners can access our innovative technology at scale, to be implemented within their applications whilst ensuring significant de-risking through the license model.

Recently completed cost analysis conducted by Bramble with manufacturing partners has shown that the PCB fuel cell can achieve $106/kW today, at a fraction of the volume quoted by industry cost targets. As production volumes continue to scale, there is significant headroom for costs to continue to fall by a further 40%, making the PCBFC™ the most cost effective fuel cell technology available.

About Bramble Energy

Bramble Energy is powering Net Zero, solving key challenges in the production of hydrogen fuel cells including lead times, up-front investment, manufacturing cost and scalability.

We are fast becoming the leading hydrogen fuel cell provider for a cleaner and more sustainable world. Our fuel cell stacks come in any size, any shape, and are completely scalable to your energy requirements. From mobility to construction to industrial use cases, our customisable designs enable it all.

Through revolutionary fuel cell design and manufacturing techniques, we have developed the unique printed circuit board (PCB) fuel cell – the PCBFC™. A patent protected fuel cell that can be manufactured in almost all printed circuit board (PCB) factories worldwide.

We also manufacture modular electrolysers to produce clean, green hydrogen. Our solution focuses on two key pillars, making our hydrogen production reliable and affordable; with this we intend to empower the global uptake of the hydrogen economy and ultimately an energy secure world dominated by truly renewable energy regardless of geographical constraint.

We're ready to bring the lowest cost fuel to market with our PCB-X™. Platform technology unlocking a diverse range of use cases and breaking down traditional barriers to fuel cell production.

For more information about us and our ambition visit www.brambleenergy.com.

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