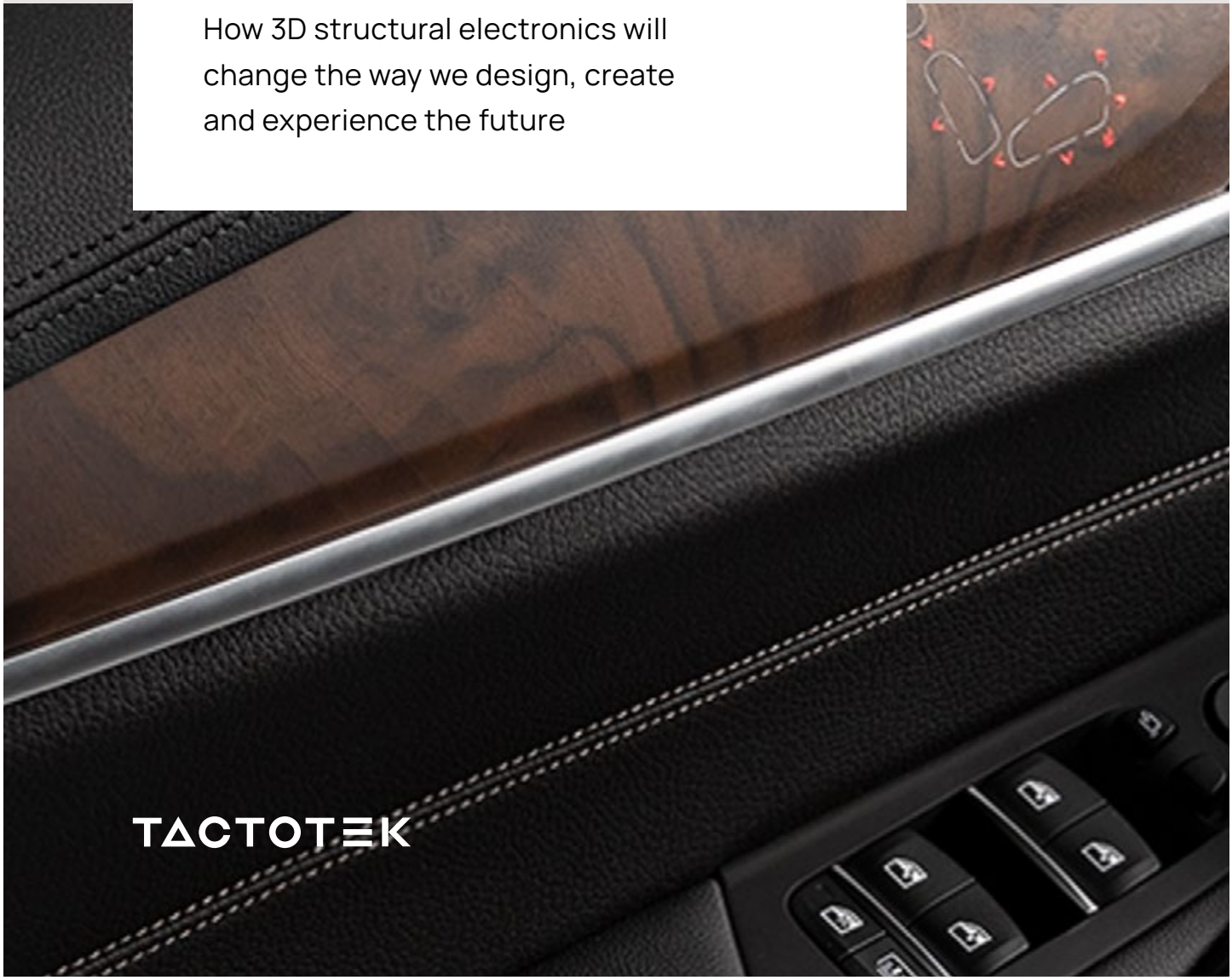
Smarter surfaces for a smarter future

How 3D structural electronics will change the way we design, create and experience the future



Executive summary

The relationship between electronics and the mechanical structures that house them is changing rapidly. There are many factors driving this transition. Significantly, brand owners, manufacturers and suppliers are looking for new opportunities to achieve differentiation in the face of fierce competition. Meanwhile, pressure from governmental organizations, investors and, consumer preferences are driving them to look toward more environmentally friendly business practices.

This white paper examines how smart molded structures are adding functionality to previously inert surfaces and driving new levels of design freedom.

These key trends can be categorized as:

- The increasing digitalization and interconnectivity across all industries and walks of life.
- How manufacturing processes and organizational structures—some of which have been essentially unchanged for decades—need to become more environmentally friendly, efficient and brought into line with technological innovations.
- The pressure to provide brand differentiation in the face of increasing competition.
- Increased consumer expectations for intuitive and impressive user experiences.
- The need to ensure total cost of ownership is managed in light of competitive pressures.

This paper explains why in-mold structural electronic (IMSE®) technology meets these opportunities and is a reliable, market-ready, and smart solution for businesses to embrace. IMSE solutions integrate printed circuitry and discrete electronic components inside 3D injection-molded plastics to create a seamless structure with revolutionary design freedom.

IMSE creates multiple business advantages:

- Making it easier for designers to innovate and create brand differentiation with functional decorative surfaces and more intuitive user interfaces.
- Supporting more environmentally conscious lifecycles, as compared with conventional electronics reference parts (IMSE can reduce plastic use by 70% and cut greenhouse gas emissions by 35%).
- Offering a smarter, more efficient way to manufacture electronics that keeps the total cost of ownership down by minimizing materials, optimizing manufacturing processes, reducing tooling requirements, and realizing high manufacturing yield.

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Introduction

A revolution is quietly taking place in how we interact with the world around us. The distinction between electronics and the mechanics that contain them is vanishing, as old technologies become outdated, and new solutions dazzle. Smart surfaces transform hitherto inanimate structures into intelligent three-dimensional entities that can be touched, sensed, illuminated, and connected to their surrounding environment in ways never before possible.

"The future will not see technology applied onto the surfaces of our buildings, furniture, and vehicles ... but rather the very surfaces that we use to construct these products will be inherently intelligent. ... At their most ambitious, smart surfaces promise dynamic, reconfigurable digital control over surfaces in the physical environment", hackster.io. Key drivers like ambitious sustainability targets and increasing consumer expectations mean that this "smartification" is entering and disrupting previously immovable industries. Look under a new car's hood and you will be greeted by a network of modular electronic parts rather than the grimy individual metal components once adored by hobby mechanics. Meanwhile, there are significant regulatory and legislative directives being manifested with regard to sustainability and an all-encompassing circular economy, all directed towards initiating profound change from all players in the value chain.

In this paper, we examine the trends and challenges faced by the industries which currently stand to benefit most from the innovations delivered by in-mold structural electronics (IMSE®)—in particular, the automotive industry, industrial and home appliances (sometimes referred to as white goods), and consumer goods. The scope for change stretches far beyond isolated applications though—it will be seen in any business environment in which plastic and electronics can come together to form new spatial, experiential, and functional HMI, UX, and UI designs. We are only in the beginning phase of a major disruption, and the only limit is the collective imagination of a new breed of engineers, designers, and visionaries.

An industry-ready solution

In-mold structural electronics provide many of the values common in this necessary upheaval—namely smarter surfaces, greater sustainability, and clean additive manufacturing processes. The automotive industry has undergone changes with regards to electrification that were inconceivable even 15 years ago, bringing an upheaval to organizational structures that have been in place since the turn of the 20th century. Home appliances are no longer mundane necessities we put in an unseen

corner of our house—they now contribute to our home's layout, combining smooth surface styling, illuminated smart human machine interfaces (HMI) and the kind of functionality that smartphone-native end users have come to expect. For many areas of industry, the days of countless individual electrical components being assembled to make up a single electrical device will draw to a close in the not-too-distant future. IMSE technology is no longer a conceptual idea that catches the interest of eagle-eyed engineers. It is a new reality that brands, manufacturers, and sub-suppliers in the automotive industry, aerospace, industrial appliances, smart homes, and consumer electronics have embraced. IMSE simplifies supply chains, material flows, manufacturing processes and transforms end-user experiences.

"Customers are quick to adopt even highly complex and expensive technology if it makes their lives easier."

CHAPTER 2

Key trends in the marketplace

2.1 Staying connected in an information society

Interconnectivity is a trend that infiltrates our lives to make them easier and more productive.

The ways in which vehicles, industrial and home appliances, wearables, and other technological products are being manufactured is changing and will continue to do so for the foreseeable future. The digitalization of our everyday lives continues to gather pace as IoT connectivity and data intelligence become commonplace and end users become more accustomed to the newfound possibilities. As the information society has emerged and become more rooted, smart devices and structures are connecting to larger networks and intelligence units, and communicating, sharing information, and interacting with the surrounding environment. Human-machine interfaces now appear in every facet of our lives—from our dashboards to our front doors, via the keys that open these doors.

Global Smart Surfaces Market to Reach USD 93.4 Billion by the Year 2027

2.2 Maintaining a presence in the circular economy

The move away from fossil-based means of energy and material production is arguably the defining trend of our time, and its effects ripple throughout every aspect of the electronics sector. Regulatory initiatives such as the European Commission's first circular economy action plan, which seeks to close the loop of product life cycles through greater recycling and reuse, mean that manufacturing processes must seek ways in which the yield from, and recycling of, all possible materials is maximized and waste is kept to a minimum. Electrical equipment continues to be one of the fastest growing waste streams (around 2% annually) and less than 40% is currently recycled within the EU. Innovations such as additive manufacturing and the simplification of part structures can play key roles in ensuring that sustainability targets can be met. They help reduce material use and waste streams, although improvements are still needed regarding the use of recycled and recyclable materials. Recycling processes also need to be made more efficient. Before being ultimately recycled, products must be designed with cradle-to-grave operation in mind, ensuring that manufacturing processes, material use, waste reduction, durability, reliability, and maintenance are all as efficient as possible.

The automotive industry has completely changed its approach in the past decade, with a move away from polluting diesel engines to the defining trend of the sector—an accelerating shift to electrical vehicles. A report by PWC states that that 55% of all new car sales in Europe could be fully electrified by 2030. Aside from the more obvious reduction in CO_2 emissions, the electrification of the drivetrain ensures that only very low levels of harmful substances, dust and noise are emitted. In the same way, changes in design and manufacturing processes can reduce plastic consumption to a minimum and ensure material is only used as needed with the help of additive manufacturing.

> "The car of the future is electrified, autonomous, shared, connected and yearly updated"
>
> PWC, Five trends transforming the industry.

2.3 Brand differentiation = customer appeal

"Customers are quick to adopt even highly complex and expensive technology if it makes their lives easier." Ever since smartphones landed in people's hands a little over a decade ago, the average consumer has gained an expectation that the products they use will be intuitive and consistent in design and use pattern. There is now an expectation that our devices co-exist alongside one another to provide users with synergistic functionalities. Meanwhile the increasing use of illumination to provide function and styling to surfaces across markets has allowed smart functionality to infiltrate our homes, automotive interiors and exteriors. This trend appears set to continue in the foreseeable future.

2.4 The evolution of the user experience

As interconnectivity between devices, capacitive touch, LED touchscreens and the like has brought dramatic improvements to the capabilities of electronic devices, customer expectations have increased accordingly. According to a survey from Metova, 90% of US customers claim to have at least one smart home gadget, while around 70% of the same audience own a voice-controlled system, such as Google Home or Amazon Alexa. The notion of getting used to a product via the accompanying instruction manual is a dated concept. Nowadays, if a user has to even refer to a manual, it may be seen as a weakness in the product's user experience. An entirely intuitive user interface is now the expectation rather than the goal. These trends have extended to the automotive industry in which disruptive OEMs and sub-suppliers have transformed user expectations of car interiors—displays have become larger and more abundant, while HMI interfaces have become ever smarter and more functional.

CHAPTER 3

Challenges faced by brands and manufacturers

3.1 Staying ahead of a changing field

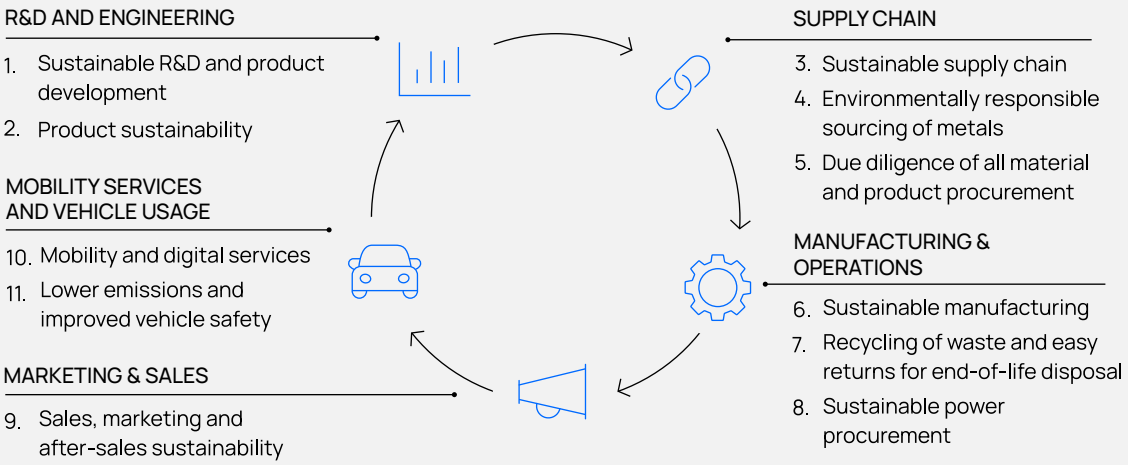
As consumers' expectations grow, innovation is democratized, and competition intensifies, many major industry players are playing catch-up. The only automotive company to appear in the top ten of PwC's Global Innovation 1000 Study (2018) is a relative newcomer, Tesla. Several of the European giants have woken up to the need in recent years, with Volkswagen being the third biggest spender on R&D, behind Apple and Google.

As McKinsey lays out in their publication Automotive revolution – perspective towards 2030, the design of future cars is still very much unclear and there is still no integrated perspective on how the automotive industry will look in 10 to 15 years. As a result, designers and engineers are looking for the right answers without a clear template.

3.2 Sustainable action that makes business sense

As climate change increasingly influences global political discourse, manufacturers have faced growing regulatory and commercial pressure to create products in a manner that minimizes the imprint on our environment. The European Union's Circular Economy Action plan requires industries to change dramatically. A report by CapGemini states that while sustainability is a strategic priority for the automotive industry—62% of automotive organizations claim to have a comprehensive sustainability strategy—implementation seems fragmented with an estimated investment of USD 50 billion required to meet targets. Similarly, while 74% of OEMs have an electric vehicle plan, only 56% of them have made EVs a part of their sustainability strategy.

Sustainability across the automotive value chain



Source: CapGemini, The automotive industry in the era of sustainability.

Electronics has already been earmarked as a focal point for the EU's plan, due to the high-impact nature of the sector. Products that offer good sustainable performance will lead to rewards as the European Commission links high performance levels with incentives. After years of the US dragging its heels, the new administration in the White House has also defined new ambitious goals to reduce emissions and make manufacturing processes more efficient. The focus on electric vehicle manufacturing is clearly laid out, advancing fuel efficiency and emission standards; financing, retooling, and expanding the full domestic manufacturing chain and innovating the next generation of clean technologies.

These kinds of incentives have led to a noticeable shift in attitudes from business, with investors now pushing for sustainability targets to be met. Since 2015, the number of investor events which place sustainability at the center of their discussions has more than doubled. Investors now recognize the clear roadmap laid out by regulators and public-interest groups. It is up to OEMs to react.

The conclusion is that more needs to be done to achieve true sustainability, and new, smarter manufacturing processes need to be adopted quickly.

3.3 A changing landscape of manufacturing

Major manufacturers serve a global audience with broad and diverse product requirements. They often meet the nuances of local demand by creating increasing numbers of variants and product portfolios, which in turn require multiple sourcing streams for materials, tools and manufacturing. As the needs and expectations of end users (and designers) become greater, there is a danger that manufacturing processes spiral out of control, becoming more expensive, taking up more space, and consuming more energy during manufacturing and operation. Therefore, OEMs and manufacturers are constantly looking for new technologies and manufacturing processes that can help minimize the cost and supply chain impacts of creating different versions of products. Targets may include reducing the number of individual mechanical parts, and minimizing costs and waste.

The EU's Circular Economy Action plan has set targets for 'less waste, more value'—a mantra which has repercussions for material sourcing and waste reduction targets. Suppliers will need to adjust to much shorter development cycles and improved recycling methods if they are to adapt to the new business models.

Sustainable action, and the possibilities of digitalization, mean that suppliers are starting to feel the increased scrutiny with regards to manufacturing and sourcing processes. Unforeseen factors, such as the COVID-19 pandemic and the blockage of the Suez Canal, have placed supply chains under great pressure and have accelerated the need for brand owners to further turn their attention towards streamlining their supply chains. As McKinsey points out in its assessment of How the automotive industry is accelerating out of the turn, digitalization is "driving greater transparency in manufacturing." This increased scrutiny makes it imperative that processes are streamlined wherever possible. Outdated and inefficient methods will make way for increased levels of efficiency.

3.4 Total cost of ownership in a period of transition

The momentous nature of the changes affecting many industries demand that budget allocation be aligned accordingly.

In the automotive sector, evidence points to the fact that the current period is a transitional one until electrical vehicles become the standard and production processes and consumer habits are consistent with that transition. Between 2020 and 2025 the industry will have to find ways of compensating for falling margins and rising investment.

Meanwhile the cost of many of the raw materials that go into making the appliances in our homes—such as copper, zinc and aluminum—have increased significantly of late. Ocean freight and global storage are also more costly. Business Today reported in late 2020 that "companies ... cannot absorb the inflation in input costs ... and therefore the companies will have to pass on the price hike to consumers."

With consumers reluctant to spend—let alone spend **more**—on products that are costlier to manufacture, heavy strain is placed on brand owners across many industries to control costs. Many consumers have suffered economically from the global pandemic and its economic repercussions. According to Deloitte's Global Automotive Consumer Study 2021, not only has this left consumers "unwilling to pay even a small premium for connectivity, autonomous or infotainment features", it has led many to reconsider the internal combustion engine as a reliable option (with lower initial cost) in the face of near-term uncertainty. While the widespread adoption of electric vehicles seems ultimately inevitable, end users will not tolerate being saddled with increased prices to cover increased material and manufacturing costs.

The reality is that OEMs are currently investing significant amounts of money in new areas, and costs elsewhere must come down. This makes it imperative that new technologies, including structural electronic solutions, come at a competitive price point that provide a financial incentive rather than a challenge for OEM purchases. Not only do the financial figures across total cost of ownership have to be tantalizingly low, but the perceived level of risk also has to be minimal.

Traditional manufacturers and suppliers will need to adjust quickly if they are to survive in the future, as the ICE reaches obsolescence faster than some players have been able to accept. These are decisive years for OEMs and the need to direct investment into the core elements of electrification, such as batteries and microchips, mean that areas such as automotive interiors face budgetary pressure to reduce or at least level off investment.

CHAPTER 4

Introducing IMSE® technology

Introducing IMSE® technology

In-mold structural electronic (IMSE) technology will help transform the way we look at our surrounding man-made environment. It liberates designers, making them free to innovate by adding electronic functions in new form factors. It enables the making of smart surfaces to become commonplace. It also makes those surfaces thinner, lighter, and more durable, while maintaining aesthetic and tactile qualities through plastic, wood, and other materials.

In conventional use cases, such as in-vehicle control panels, a single IMSE part replaces a multi-part traditional electronics structure and eliminates labor-intensive electro-mechanical assembly. It can reduce weight by up to 70% and depth by up to 90%, relative to conventional multi-part assemblies. Because electronics are sealed within injection-molded plastic, they are protected from impact, vibration, moisture and debris.

IMSE integrates **printed circuitry** and discrete **electronic components** inside 3D injection-molded plastics to create a **seamless structure** with a revolutionary **design freedom**. Mass-production manufacturing equipment is used in the process.

IMSE VS. CONVENTIONAL ELECTRONICS

Doing it with IMSE
4mm part thickness ≈90% reduced thickness, 1 molded part + PCBA, 140 gram weight, ≈70% weight reduction, 35% greenhouse gas reduction.

How it was done before
35 mm part thickness , 64 parts + PCBA, 470 gram weight.

Overhead control panel of a car; Conventional electronics vs IMSE.

4.1 Enablers for customer-centric design

IMSE technology is built using a verified materials platform. Customer features and designs are realized using verified materials and electronic components in combination. Core capabilities can be defined according to five building blocks: touch, sense, illumination, connectivity and the look & feel of the product. Each of these can be combined to meet the needs of different use cases across many markets. This means that IMSE technology is able to provide customers with the capabilities and properties that their product needs—and nothing more.

Touch

Individual capacitive sensors or sensor groups that operate as switches and slider controls can be placed on curved surfaces and offer greater control. Sliders can be linear, circular, or other shapes.

Sense

Proximity sensing, often used to activate a part or function from a passive state.

Connect

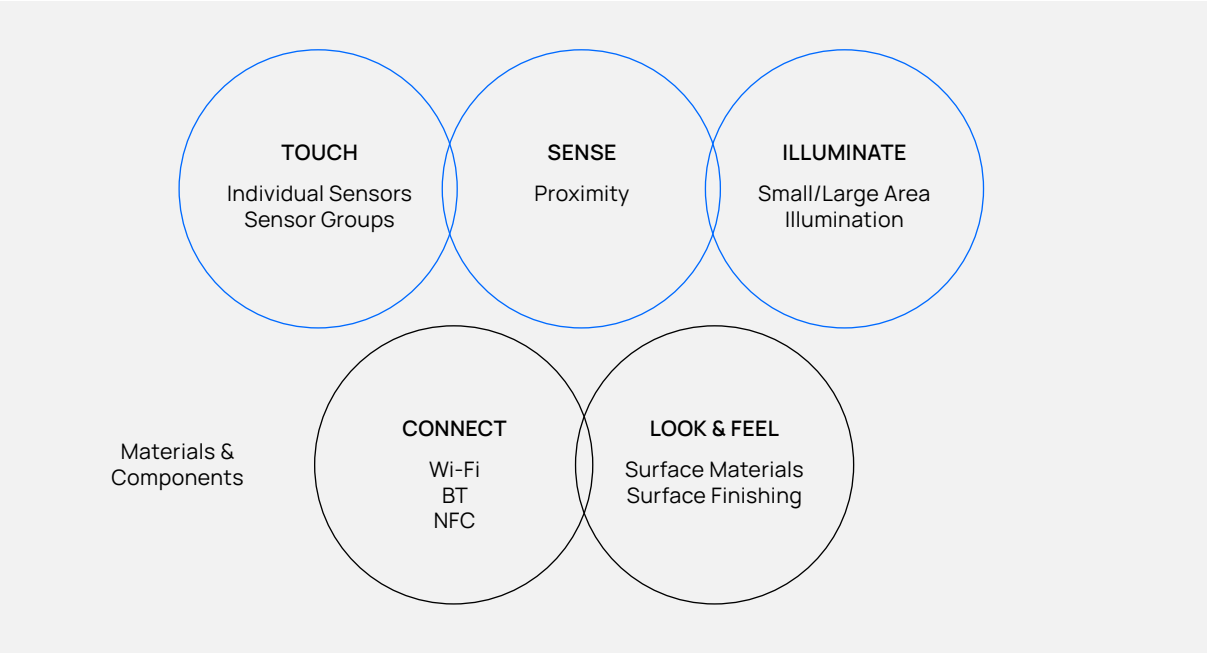
Wireless connectivity using printed antennas within the IMSE part. Many antenna and coil designs, such as Bluetooth, NFC and Wi-Fi, benefit from IMSE since the antennas can be large and in the surface structure of the part.

Illuminate

IMSE enables multiple styles of illumination including single color or RGB in static, and dynamic implementations from LEDs integrated within the 3D IMSE structure. Examples include localized icon backlighting, light lines showing control levels, and large area decorative ambient illumination.

Look & Feel

Designers can implement electrical functions anywhere they choose, and in shapes and styles that support both their design vision and intuitive user interactions. Functionality can even be achieved on natural surfaces such as wood veneer.



4.2 The development process

As with any product, the needs of the end-user are the biggest drivers in specifying the functionality, design, usability, and technical requirements of the solution.

With the list of requirements ready, an IMSE design concept is created by combining verified IMSE materials and electronic components with proven IMSE building blocks, thus enabling rapid turnaround times.

Example of considerations that affect the selection of IMSE materials and building blocks include:

- Operating conditions
- Curvature of the part
- Number of functions and size of the part
- Illumination requirements for styling, icons and indicators, including size, brightness, uniformity, single color or RGB, static or dynamic
- Distance between capacitive sensors and sensor groups
- System connection
- Cost target

IMSE design is a holistic process. Many design disciplines—including mechanics, electronics, plastics, tooling, printing, and illumination—are as seamlessly integrated as the part structure itself. By combining cosmetics, structure and function into a single injection-molded part, we significantly reduce the assembly and integration challenges that are typical of conventional electronics. During the design phase, the IMSE part's behavior for manufacturability and lifetime is simulated, which in turn reduces the time and effort needed to develop parts ready for mass production.

Core IMSE design disciplines include:

- Plastic part mechanics
- IM tooling Design
- Illumination Design
- Electronics, Antenna & Embedded SW Design
- Print & Graphics Design

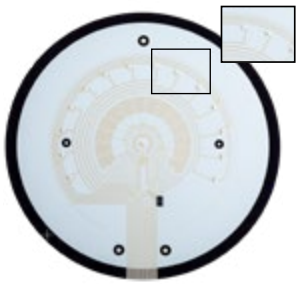
4.3 The manufacturing process

IMSE manufacturing has four main process steps. Manufacturing starts with screen printing. Decoration, if desired, is printed on film insert molding (FIM) material, followed by printing electronics including conductive circuitry, touch electrodes, antennas and proximity sensors. Second, electronic components are mounted on a flat plastic film using standard high-speed pick-and-place (SMT) equipment. Components are attached to the FIM substrate using conductive and structural adhesives. Third, thermoforming transforms the flat electronics film into its 3D shape. TactoTek® design rules and verified material stacks are used to ensure mechanical and electrical system integrity is maintained throughout the forming process. Fourth, the formed electronics film and cosmetic film (or other surface material) are used as an insert for injection molding, resulting in a solid, single-piece structure with electronics encapsulated by injection molded plastics. Typical molding materials include high-pressure, high-temperature plastics such as polycarbonate and thermoplastic polyurethane (PC and TPU). Efficient functional testing after each production process is ensured with IMSE® optimized test systems and equipment.

1

Printing decoration, wiring, touch controls and antennas.

2



Mounting components on **flat** film.

3

Forming 3D shape **with** components.

4

Injection molding final single, seamless part.

MANUFACTURING FLOW > SMART FILM INSERT MOLDING (FIM)

IMSE manufacturing process is realized with standard high-speed equipment.

IMSE Part Structure

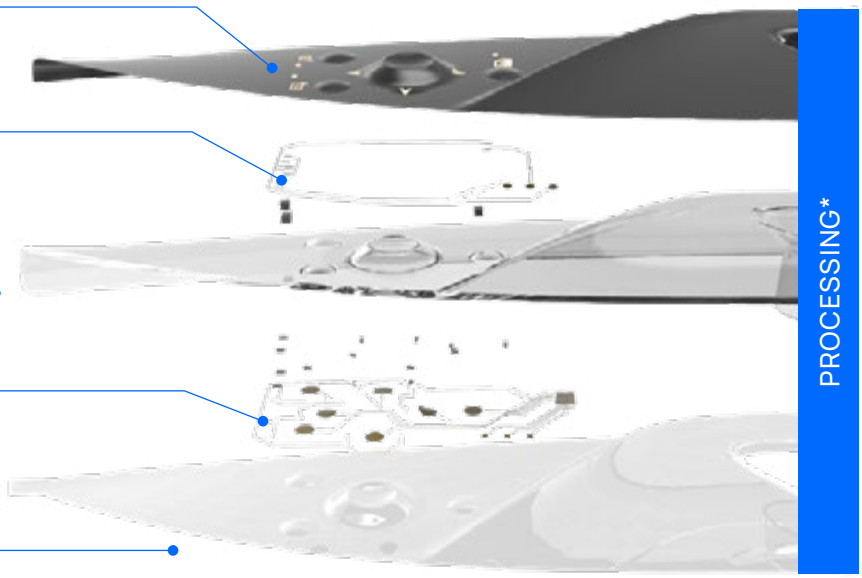
Decorative A Surface
- IML Film or Natural Materials
- Decorative inks

A surface electronics
- Conductive inks
- Dielectric inks
- SMT electronics

Plastic resin
- PC, TPU

B surface electronics
- Conductive inks
- Dielectric inks
- SMT electronics

Functional B Surface
- IML film



*Everything is injection molded to one-piece assembly

DESIGNS MAY BE 1- OR 2-FILM > ELECTRONICS MAY BE ON ONE OR BOTH FILMS

When we consider the structure and details of an IMSE design, we can see clear distinctions relative to conventional electronics and mechanics. The typical full-sized PCB layer structure is missing, while the mechanical structure, cosmetics and key electronic functions are consolidated into one seamless smart structure. Because of this, every design element in IMSE has to be in perfect synergy.

The essence of IMSE design is to understand and accommodate the behavior of different materials and components when they are combined, stretched to a 3D form, and ultimately injection molded into a single-part assembly. The part is then subjected to rigorous testing to test tolerance to the hardest environmental conditions, thus ensuring performance is at the requisite level during manufacturing and over a lifetime of use in the target environment.

CHAPTER 5

How you can benefit from IMSE® technology

How you can benefit from IMSE® technology

IMSE offers benefits that span many industries including automotive, home appliances, industrial & home automation, aerospace, medical & healthcare, as well as IoT and specialized wearable technology.

IMSE offers several benefits over traditional, multi-layer electronics structures, including:

- Innovative, seamless form factors
- Genuine 3D designs
- Lightweight yet rugged material properties
- Thin and conformal structures that open up design freedom and save space
- Smaller environmental footprint—reduced plastics use and greenhouse gas production
- Fast product updates and variants that enable new cosmetics and functions without tooling changes
- Environmental protection of in-molded electronics
- Easily cleanable surfaces
- Innovative use cases that feature HMI, UX and UI design
- Experimental simulation allows for early exploration of design alternatives
- Innovative and diverse illumination techniques in ultra-thin structures

5.1 Innovative design that leads to brand differentiation

Put simply, IMSE technology makes structural surfaces smart. The smart molded structures are thinner, lighter and more durable than conventional electronics for comparable use cases. When utilized to the full extent, IMSE brings an holistic 3D approach to product design. Previously bulky devices can be reshaped, or integrated into the holistic structure to open up new design languages while reducing the space and weight needed for added functionality.

Creative and intuitive UIs come into play enabling new and unimagined possibilities. Previously inert surfaces become active and engaging, enhancing user experiences and increasing efficiency for the user and the appliance itself.

The interior of a car provides a good illustration of the best features of the technology, such as capacitive touch, functional decorative surfaces, large area lighting surfaces and space-saving design.

DESIGN INNOVATION – IMSE enables live and compelling surface and dynamic ambient illumination.

Active, autonomous and relaxing spaces

IMSE eliminates the limitations that have held designers back with regards to functionality, ergonomics and aesthetics. It streamlines manufacturing and design and enables surfaces in our everyday environments to serve as multi-functional design elements. Vehicles become living areas that serve as extensions of our homes. Home appliances become smarter with more AI functionality. Bulky add-on devices in our homes, such as light switches, will be made redundant, with surfaces acting "as a light switch, an occupancy monitor, a water leak monitor, and more." IMSE can create naturally consistent interaction metaphors across all uses that promote intuitive engagement and operation. Put simply, it provides technology solutions that simplify our lives. These are just a few examples to show how a world in which IMSE is fully integrated will look, act, and work better.

Functional decorative surfaces

The smart structure attributes of IMSE also open up new possibilities with regards to merging surface decoration, illumination, and functionality. Since the technology can integrate circuitry within the mechanical form itself, the entire lighting structure needs to be no more than 2-4mm in thickness—the same as a merely decorative layer that other methods use in similar applications.

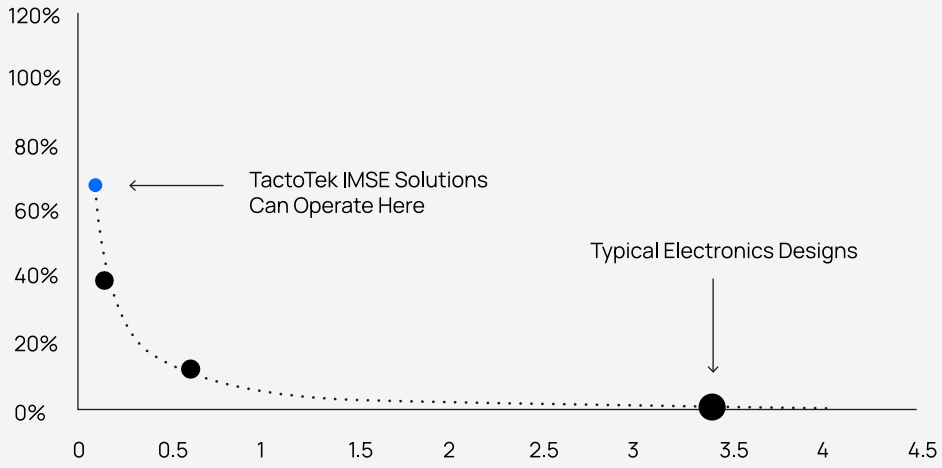
Illumination plays an ever-more present role in HMIs and is often used as a tool to merge function (such as system status and hazard alerts) and aesthetics. IMSE enables easily configurable panel lighting within interiors that can be adjusted to meet passenger preferences. Customization for product facelifts, variants, or localization is possible without the need for costly and laborious circuitry and decorative surface remaking.

Dashboard & Steering Wheels

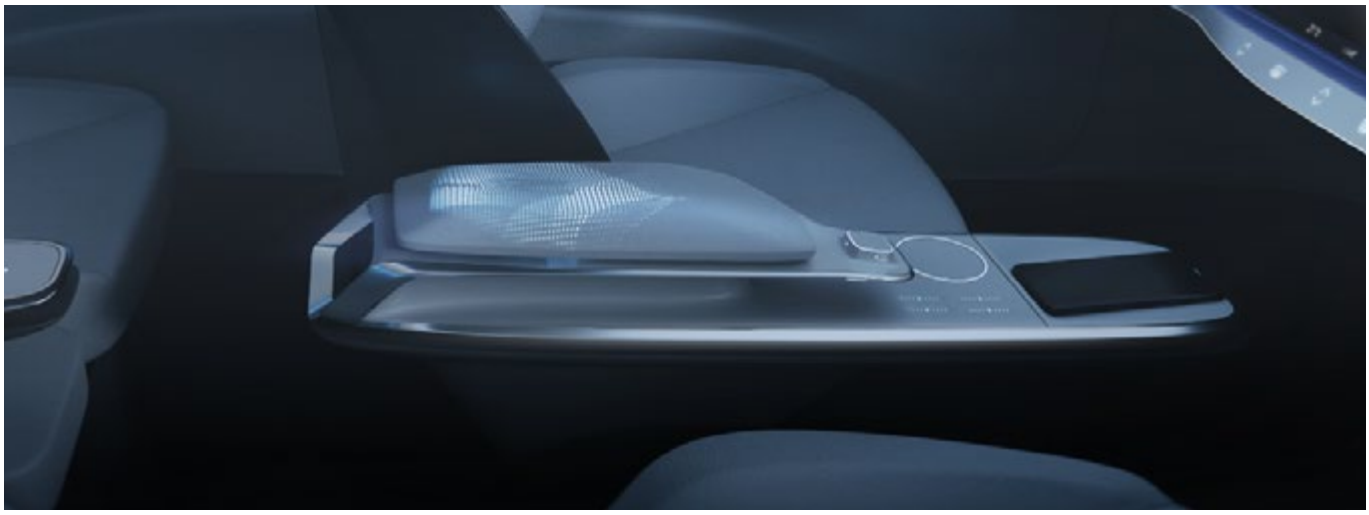
IMSE supports very effective capacitive touch implementation. In some designs, the point of touch is as little as 0.25mm from the touch surface. When the sensor is farther away, the dielectric constant of the plastic materials results in performance equivalent to that with a much smaller air gap. The result is reliable touch controls with a very strong signal to noise ratio.

As you can see from the graph, capacitive performance increases as the sensor gets closer to the point of touch—dramatically so when closer than 1.5mm. Superior touch is experienced in a wide range of scenarios, including full functionality with standard leather gloves.

Capacitance Change vs Thickness
(Finger Press, 8x8mm Pad, 1.5mm FR4 PC8)



Source: Texas instruments, Capacitive Touch Hardware design Guide, SLAA576A.



DESIGN INNOVATION – From control knob to concave contouring for distinctive ergonomics – ease of use without need to look at the UI.

Center consoles

Designers are seeking technology that enables them to replace buttons, and multiple layers involved in the assembly of conventional electro-mechanical switches, with pre-integrated solutions. IMSE adds new possibilities to a designer's palette. It delivers HMIs that support and differentiate brand identity while enabling intuitive and delightful user experiences.

Passenger experience

With IMSE technology, vehicle occupants can expect the interiors of the future to be more spacious, more functional, and more dedicated to the comfort and wellbeing of passengers. Multiple user interfaces can feature on an ergonomically convenient 3D surface, such as a trim part, door handle, steering wheel, or other control point. Such capabilities will improve the intuitiveness of the user experience.

DESIGN INNOVATION – Passenger door HMI for media and seat controls (and/or other functions such as climate control). Thin multifunctional applications are able to incorporate features such as door handling, lighting and HMI controls all in a single millimeters-thick structure.

5.2 An environmentally-conscious lifecycle

An independent lifecycle analysis confirms that for a reference part IMSE technology reduces plastics use by up to 70% and produces 35% less greenhouse gas emissions from raw material extraction to ready-made products, from cradle to gate, compared to conventional electronics manufacturing processes.

An IMSE product requires fewer parts and less plastics compared to parts built with conventional methods, leading to multiple benefits including reduced environmental impacts. Human machine interfaces (HMI) made using conventional electronics structures are assemblies that require multiple parts and subassemblies. Each of these parts must be designed, tooled, manufactured, transported and assembled. Many different suppliers are often needed. Injection molds are required to create the necessary cosmetic surfaces, structures, and functions of the solutions. Switches, buttons, cases, and other assemblies all require their own set of tools and subsequently, assembly. With IMSE technology, the number of production tools is reduced dramatically to as little as one-tenth of the number that conventional electronics manufacturing assemblies require. Because IMSE parts are single seamless components, only one injection mold is required. This reduces not only tooling costs, but also the engineering costs, materials costs, and the assembly required to creating a functional product. It also reduces the environmental impact across the entire supply chain.

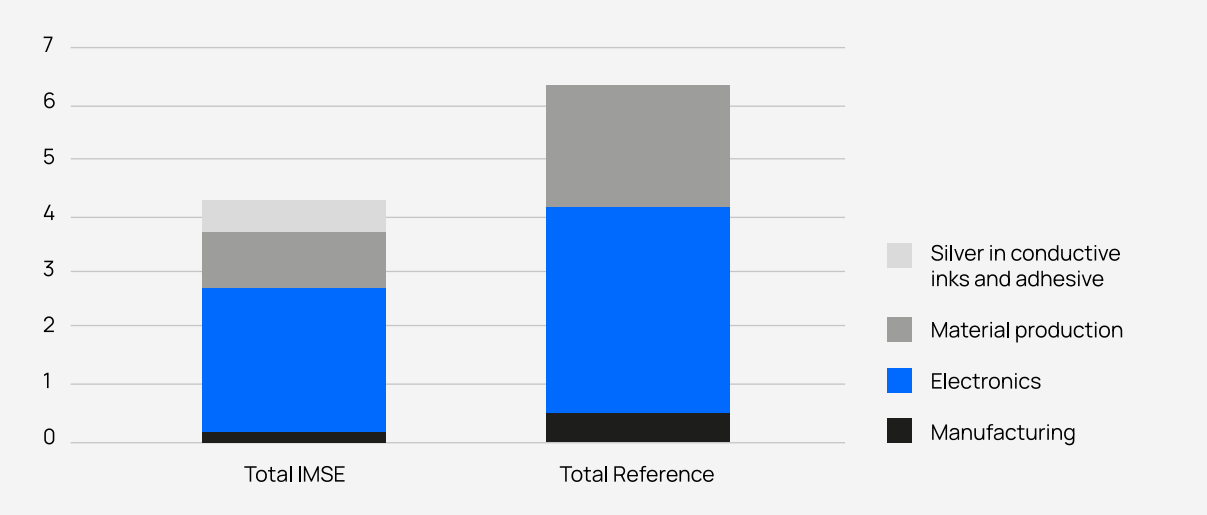
Design and engineering

Before making physical parts, IMSE designs are evaluated and optimized using virtual building and simulations. This practice reduces the number of physical prototypes required from concept to mass production. This streamlines the design process, lowers the number of production experiments, and helps reduce the environmental impact of this first step of the lifecycle.

Manufacturing

The greatest environmental impact when manufacturing plastic parts comes from the injection molding process's electricity consumption. With IMSE technology, the total number of injection molding machines and tools is significantly reduced, resulting in a reduction of the environmental impact. An independent life cycle analysis (see infographic on next page) shows that IMSE technology reduces the CO_2 greenhouse emissions during the manufacturing process by 35% compared to conventional electronics for a reference part. IMSE technology also significantly reduces the amount of toxic waste streams in electronics manufacturing by utilizing clean additive processes. The additive manufacturing technique ensures optimal yield.

CO_2 lifecycle emissions comparison between IMSE part and reference part.
Figures given in kg/CO_2



Source: VTT.

Materials and components

Each IMSE part is a seamless one-piece structure that replaces multi-part assemblies of traditional electronics. Using less plastics also saves weight: IMSE parts are an effective part of lightweighting and typically reduce weight by 50-70%. Less plastics and less weight are especially important in the automotive and aviation industry, where the resulting lightweight parts in vehicles are not only stylish and elegant, but also help reduce CO_2 greenhouse emissions during a lifetime of vehicle operation.

Logistics

By reducing both number of parts and the mass and volume of the resulting products, IMSE technology has a positive environmental impact for the upstream and downstream logistics processes. The required transportation volume for both the manufacturing process, as well as the shipping to end-users or for final assembly at the customer, is significantly reduced. Further, as IMSE technology reduces the amount of different sub-components and parts needed for the final manufactured solution, this translates into supply chain efficiency and a reduced environmental impact due to not having to ship different parts globally.

Recycling

Parties within the IMSE ecosystem are working together to verify sustainable material stacks and have ongoing efforts towards enabling circular material loops. Most of the waste streams generated during the IMSE manufacturing process can be easily recycled and further reused.

Recovering high value materials within an IMSE part is economically efficient using mature recycling and recovery methods. Meanwhile, recycling plastics used in IMSE parts is challenging due to the integration of many different materials within an integrated structure—this is a challenge that many industries are working together to solve.

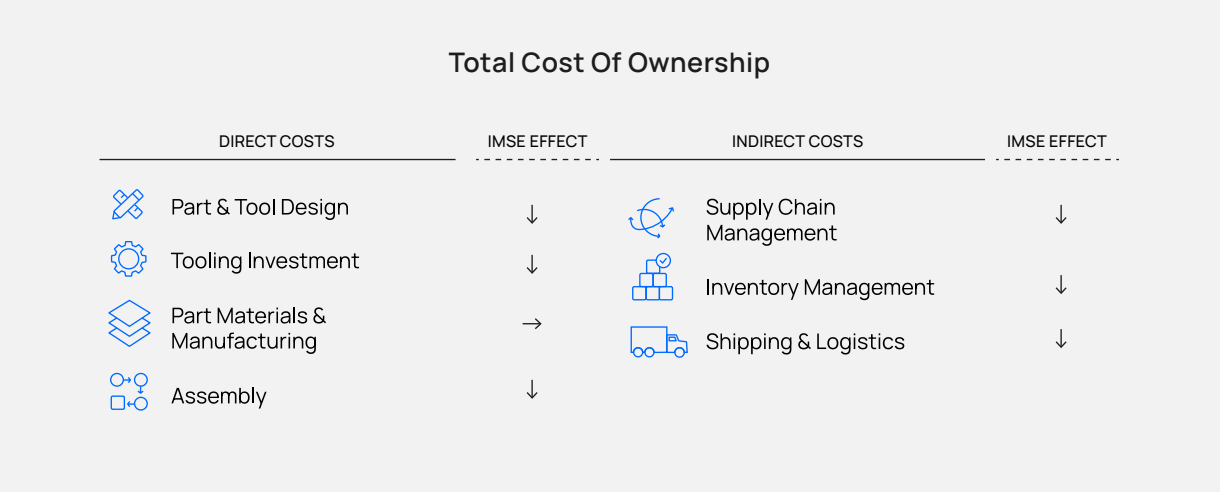
5.3 Keeping down the total cost of ownership

Given the cost pressures laid out previously in this white paper, it is essential that IMSE is cost-competitive relative to other technologies while enabling multiple additional opportunities for innovation and customer value creation. Because IMSE parts integrate electronics within the part structure, they cost more than merely decorative surface parts. However, they are typically very competitive with the total cost of the assemblies that they replace and can reduce total cost of ownership (TCO). IMSE designs minimize or eliminate dedicated external printed circuit boards, light pipe structures, antenna components, and related electro-mechanical assembly. Additional savings come from reduced tooling requirements, assembly costs, inventory carrying costs and supplier consolidation. IMSE delivers significant production cost savings. A study of an automotive dashboard application showed that, when replacing a traditional electronics part with a standard IMSE part, costs can be brought down by 10%. A graph showing the relative cost reduction can be seen on the next page.

It is important to state that true cost savings are best assessed by OEMs and part manufacturers themselves. The sharing and transferring of knowledge and information for ecosystem partners can help to realize the ways in which costs and manufacturing can be streamlined to the fullest extent.

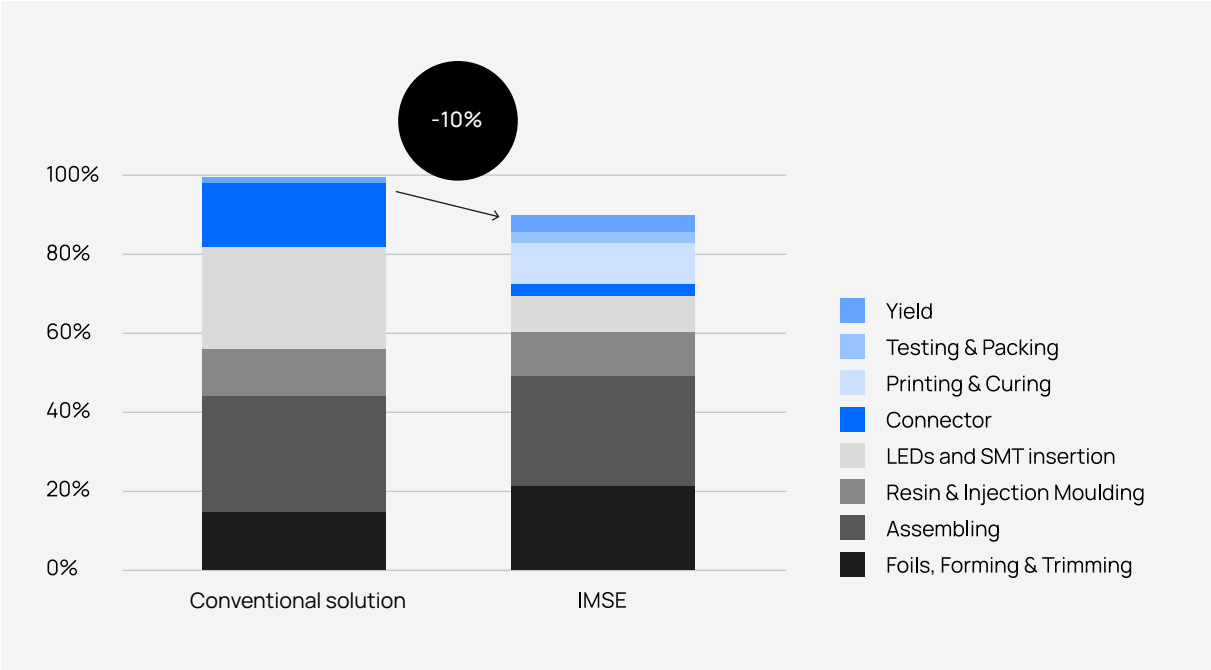
In summary the TCO model incorporates costs for the following items:

- Engineering Design & Testing / Non-Recurring Engineering
- Part Variables (Cost of Materials, Cost of Manufacturing, Cost of Assembly)
- Tooling
- Packaging and freight
- Item handling
- Sourcing
- Warranties
- Royalties



IMSE for total cost efficiency.

TCO comparison for car interior trim part manufacturing: Traditional electronics vs IMSE technology



Source: TactoTek analysis.

5.4 A smarter, more efficient approach to making electronics

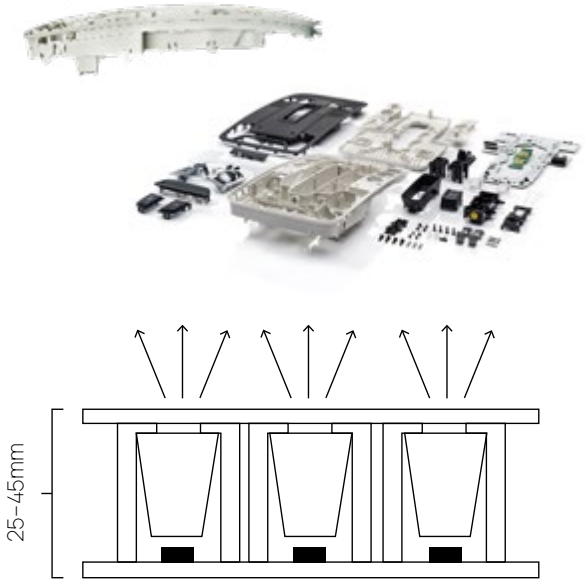
IMSE is a disruptive technology that transforms the manufacturing process, but it does so using well-known materials and mature manufacturing processes that rely on commodity capital equipment in new and innovative ways. Because IMSE designs integrate mechanical structures and electrical functions into a single part, they have unique design requirements that differ from those of traditional electronics. This means that designing functional, reliable and mass-producible IMSE parts requires specialized knowledge across multiple engineering disciplines. This involves design specialists for industrial, graphical, mechanical, electrical, antenna, illumination, production tooling, and embedded software aspects for a part. Ideally, a simulation-based design process is utilized. These measures will ensure that brand owners and their suppliers reap the full benefits of IMSE technology.

IMSE technology replaces the full-size circuit board with electronics and components molded within and printed directly into the surface structure of a part. This process eliminates costly and extensive electro-mechanical assembly and a space-stealing depth requirement. It offers significant benefits for manufacturers of home appliances and other industrial white goods, who often need to sell in multiple segments. Similarly, automotive interiors can benefit from selling the same part for different car models. For example, a premium model may call for more lighting capabilities than an economy model.

Most automotive OEMs and Tier 1 suppliers are actively searching for new styling and smart surface solutions to increase value, minimize assembly, and reduce vehicle weight. To address needs for new technologies and designs, IMSE technology building blocks and enablers can be combined to create a wide variety of solutions for different use cases, manufactured in an efficient and cost-effective manner.

IMSE Illumination Basics

CONVENTIONAL
Conventional electro-mechanical structure carries LEDs on a PCB, and uses mechanical lightguide assemblies to control light.



IMSE
IMSE part structure eliminates the need for separate light guides, and uses printing layers and injection molding resin as method(s) for controlling light.

5.5 Managing yield that matches innovation

Ensuring that high levels of manufacturing efficiency, quality, and performance are maintained is imperative for all brand owners and manufacturers. Innovation cannot add complexity or introduce inefficient manufacturing processes.

Each target market and customer segment has its own specific requirements for product validation, verification, and quality assurance under a variety of operating conditions. To date, the most demanding spectrum of requirements for IMSE comes from the automotive industry. TactoTek has developed IMSE technology to meet these demanding requirements and has built the internal capabilities to verify IMSE technology and product-specific designs against the most demanding of these standards. In addition, the company has IMSE parts evaluated by independent testing laboratories and submits parts for testing directly by OEMs and Tiers. Criteria and conditions for which products may be tested include (but are not limited to) vibration, impact resistance, abrasion, extreme temperatures, high humidity, thermal cycling, and thermal shock.

Tests and experience from manufacturing projects has shown that IMSE is able to withstand the rigors of automotive testing. It is important to note that each new part design may require optimization to meet these demanding requirements. Success depends on quick iteration through simulations, design solutions, and producing parts for testing. When these steps are smoothly carried out, customer requirements can be achieved within the desired timeframe.

Part level: B-Film

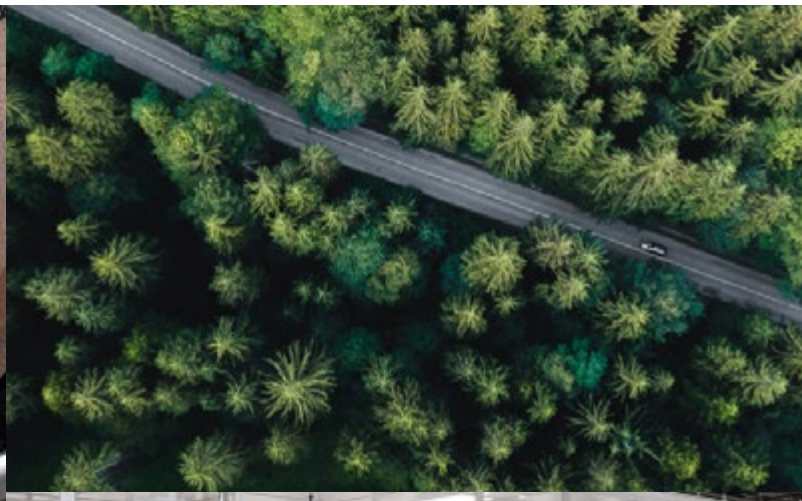
Process phase	Printing	SMD	THERMOFORMING	PRE-ASSEMBLY
Yield	99.6%	98.9%	99.25%	99.1%

Part level: IMSE

Process phase	IM: FUNCTIONALITY	IM: ILLUMINATION	IM: DIMENSIONS	IM: VQ
Yield	99.35%	98.3%	100%	91.7%

A study carried out across a Smart Lock mass manufacturing process at TactoTek, in two separate manufacturing runs with a total of c.6000 parts, provided a rolled throughput yield of 89%. The part in question has a high-gloss finish.

During manufacturing, prior to the visual quality check, the RTY for the same manufacturing runs was 94%.



CHAPTER 6

How TactoTek® can help

6.1 New technology requires a new approach

Innovation requires change. We've spoken about the liberation that IMSE® can bring to design. For this to be achieved, it requires a new way of thinking by brand owners and suppliers, many of whom will have to reconfigure how they work in order to flourish in the new era of smart surfaces.

TactoTek works openly with partners across the value chain to consult, advise, and support brand owners and their suppliers, helping them realize the very best capabilities of this new and exciting technology. Producing smart surfaces frequently requires reconfiguring processes within an existing supply chain, or reaching out to new suppliers. Meanwhile, designers and engineers must collaborate in real time because changes in one aspect of part design are likely to affect the engineering of another aspect of a part. For example, changing the location of a lighting feature or capacitive button will require changes to the electrical layout, and the position of mechanical features and the gating location of the injection molding tool must also be considered.

TactoTek uses methods for simulating IMSE-enabled designs that reduce the number of physical prototypes required from concept to mass production and follow the principles of the EU Ecodesign directive. Simulations not only streamline the design process—they also reduce the environmental impact in this first step of the lifecycle, because the number of individual tools, as well as mechanical and electrical sub-assemblies, are significantly reduced relative to conventional electronics.

6.2 The IMSE® Market Ecosystem

The IMSE ecosystem spans suppliers of materials and electronics that comprise of IMSE parts, contract design and manufacturing entities, and IMSE testing equipment providers, before reaching the brand owners. IDTechEx expects the structural electronics market to reach a value of over USD 200 billion by 2030.

The dynamic of working relationships may vary; sometimes OEMs dictate part design, while others may rely on their Tier 1 sub-suppliers for design. Typically, an OEM will design some parts themselves or via a design contractor, while sourcing other parts from manufacturing tier customers. OEMs often rely on specialty design firms with whom they have close relationships and stylists—such as TactoTek partner Lightworks GmbH—for illumination.

It is in the interest of materials and component vendors to help build the IMSE market, which is why many work in partnership with TactoTek to develop the market and optimize their products to support the simplified manufacturing techniques and processing that IMSE offers. IMSE technology only uses REACH, RoHS and Conflict Mineral compliant materials and components for verified material stacks and structures.

For manufacturers to prosper from IMSE technology adoption, it is vital to get a full understanding of the technology and how it can fit into their own operational and customer relationship structures. Some work directly with TactoTek to develop new designs and present solutions to OEM customers, while others are identified by OEMs as prospective TactoTek-licensed mass production suppliers after TactoTek has worked directly with OEMs to develop a prototype. The OEMs who will benefit most from IMSE are the ones who can themselves understand how the technology works.

Market Ecosystem

Illustrative only, not a comprehensive list of ecosystem partners.

IMSE BUILDER®

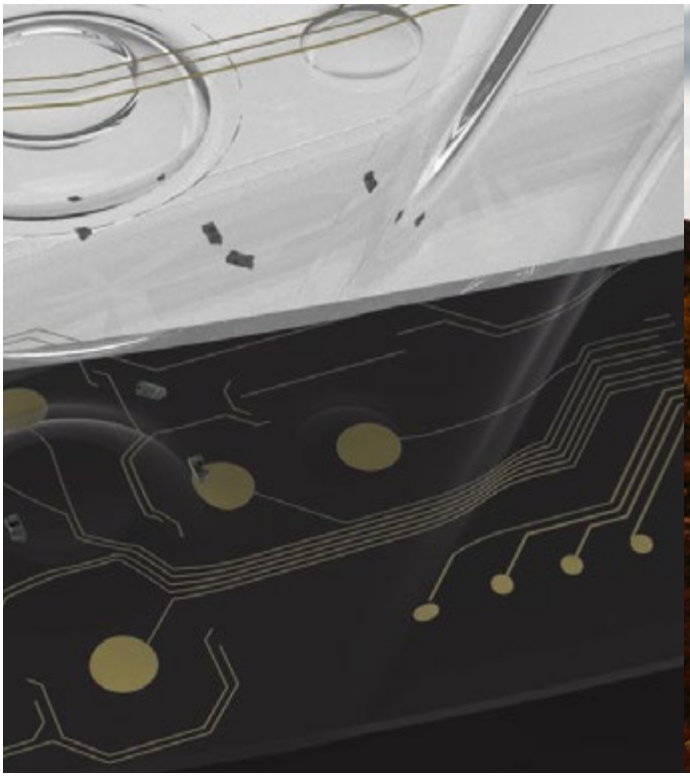
Become a certified IMSE parts manufacturer with IMSE Builder—a comprehensive package of intellectual property and know-how that is used to manufacture IMSE parts. The package includes detailed IMSE manufacturing and testing guidelines combined with specific material- and process-related details. IMSE Builder includes hands-on training at TactoTek's production facility to ensure successful transfer of skills and know-how required for efficient, high yield IMSE manufacturing.

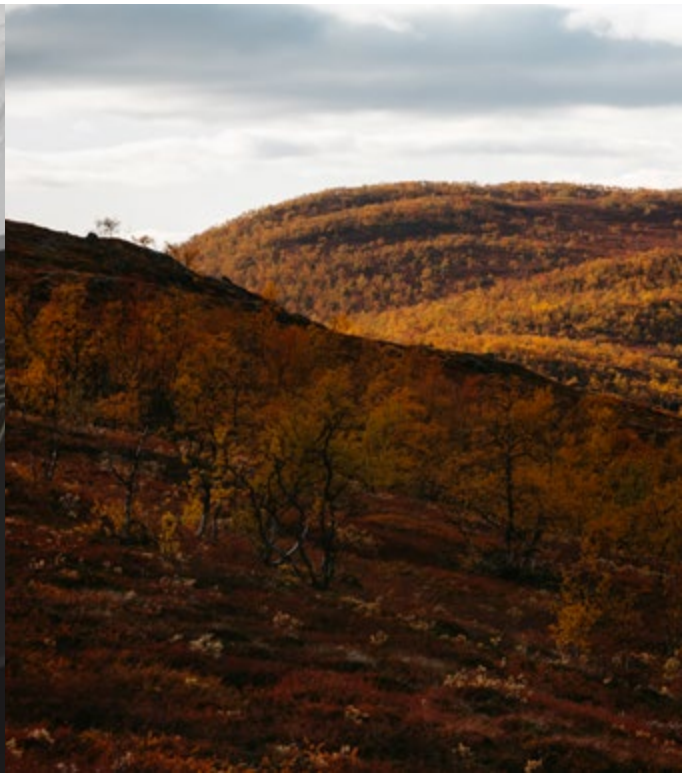
IMSE DESIGNER®

Your team will master IMSE design with IMSE Designer, a comprehensive package of intellectual property and know-how for designing IMSE parts. Hands-on training and detailed design instructions answer the essentials of IMSE design, including design process flow, optimizing electronics layout, creating multi-layered structures to optimize lighting performance. Applied examples show how theory becomes practice. Our experts will support and guide you along the way of mastering IMSE design.

TACTOTEK® DESIGN & MANUFACTURING

TactoTek works with you to realize your design using IMSE technology and then TactoTek manufactures your IMSE parts. TactoTek design and manufacturing services range from early concept design to full product development and production. Our vertically integrated IMSE manufacturing facility is ISO 9001 certified and includes an ISO 7 clean room to ensure quality and consistency.





6.3 IMSE innovation in action

■ IMSE in the automotive market

Automotive designs represent compelling canvases for IMSE technology. The industry is undergoing a dramatic change, and designers are looking to differentiate their designs using the kinds of 3D structures for which IMSE excels. This could mean creating a car interior that begins to resemble both a living area, replete with comfort, more space, and illuminated interactive panels in the most ergonomic positions. Alternative interpretations include a modern cockpit experience with vast swathes of the panelling being illuminated or interactive in some other way. Designers' visions are revealing breath-taking possibilities with IMSE technology.

Integrating IMSE designs into automotive interior and exterior parts enables cantilevered parts, 3D styling and space-saving lightweight robustness.

Case: The Overhead Control Panel

- Electronic functionality on 3D contours
- Thin and light-weight
- Versatile illumination features

Following many customer requests and proof-of-concept builds, TactoTek developed its own Overhead Control Panel technology demonstrator with several capacitive touch buttons, a multi-function slider, multiple styles of illumination, including illuminated icons, task lighting, and Bluetooth connectivity with an in-mold printed antenna. Some of the key product qualities and features include:

- 3.5mm thickness
- Illuminated icons
- One color and RGB illumination features
- Capacitive touch buttons
- Illuminated light stripes
- Courtesy lights
- BT antenna

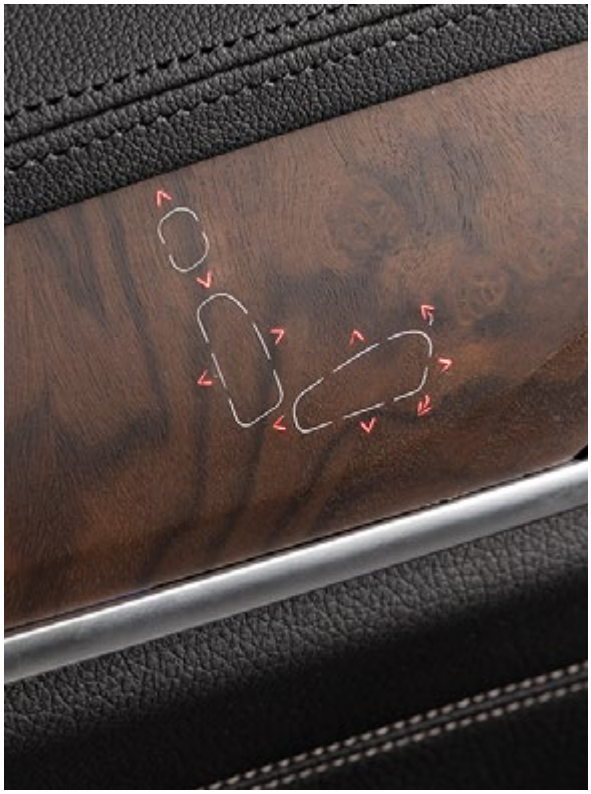
The conventional equivalent is what we see in high-end vehicles today (particularly in SUVs and trucks, from most manufacturers). It is a bulky structure of 64 individual mechanical parts (excluding mounted components). It requires more than 30 different assembly steps in production. The assembled unit is 45mm thick and weighs as much as 1.4 kg.

By way of comparison, the IMSE unit has similar functionality, but comes in a totally different form factor. Using just one injection-molded part that includes both mechanics and electronics, a "smart surface," and a small printed circuit board assembly, the part thickness is just 3.5mm, and it weighs in at only 200g. Additionally, the process requires only a single injection molding tool, reducing tooling and design costs and no assembly.

Case: Wooden Door Trim

- Sophisticated wood veneer finish
- Illuminated seat controls with capacitive touch
- Thin structure
- Done in cooperation with TactoTek's partner Novem

Most IMSE designs include high quality plastic surfaces, although the construction of IMSE parts also enables the use of natural materials, including wood veneer. In this example, touch controls and illumination have been integrated into a door trim with a natural wood surface. Illuminated indicators and capacitive touch buttons can be utilized in areas completely new for designers and end users alike.



Case: Center Console

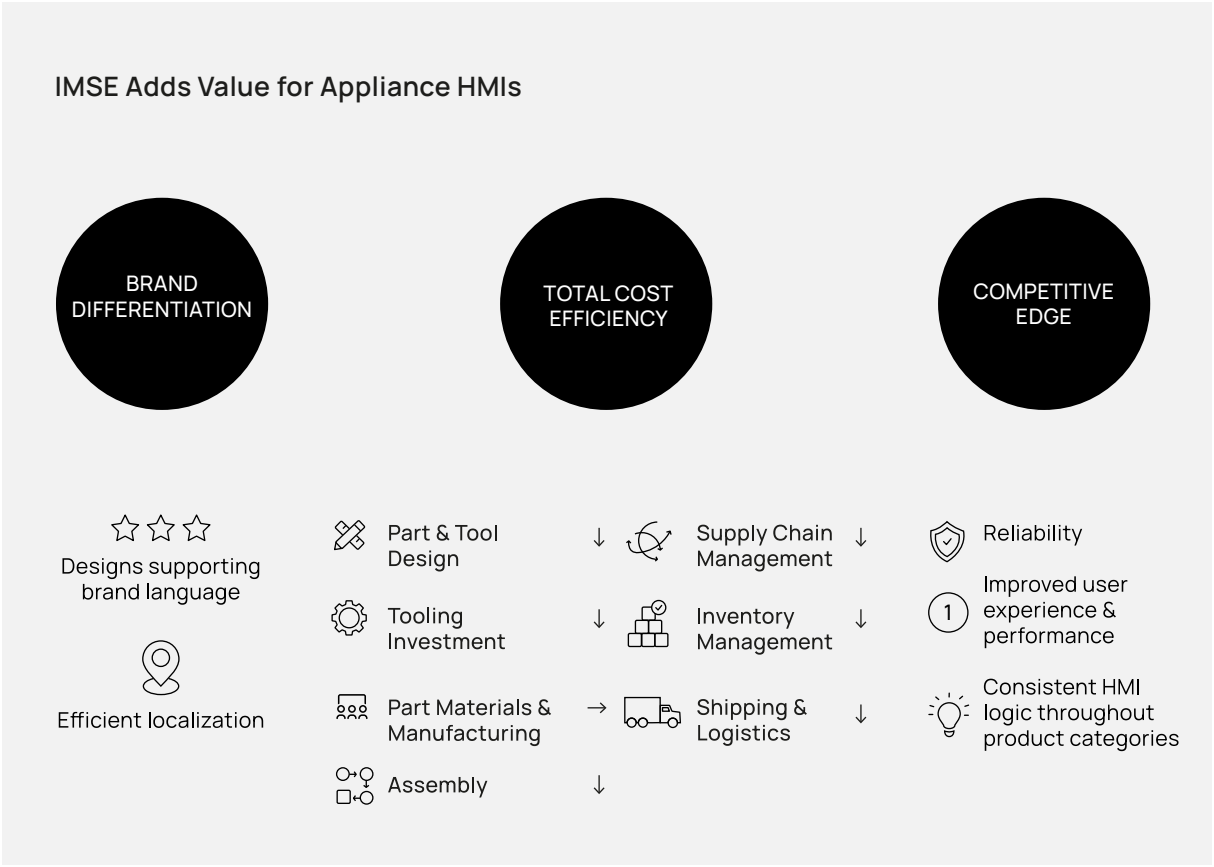
- Interactive center console armrest
- Beautifully illuminated capacitive buttons and slider wheel
- Variety of surface materials and treatments available
- Project done in cooperation with TactoTek's partner Novem

This armrest utilizes IMSE to incorporate illuminated capacitive buttons and a slider wheel. It is available in a selection of different surface materials and treatments, such as wood veneer and PUR coating.

Smart home and appliance markets

Smart home appliance technology is becoming pervasive at the middle and high ends of the market. There is an increase in the adoption of advanced products such as fire safety controls, HVAC systems, building security systems, and video surveillance. Manufacturers of these advanced products further seek for modern technologies such as IMSE to differentiate with design, lower costs, and enhanced performance.

Home products use illumination to provide important messaging—such as conveying application status—in a stylish manner. Just as a vehicle may use lighting along the panelling of a door to signify another vehicle in range, a coffee machine may use it to show that it is running low on beans. More pressingly, a fire detector may blink to indicate the first signs of smoke (such as when burning toast). The examples below are real cases, but the opportunities to bring stylish smart surfaces into the home environment go far beyond them.



IMSE® value add for home appliance brands.

Case: Keyless Entry System - Smart Lock Cover

- Thin and robust surface providing both structure and functionality
- Capacitive touch control, connectivity and illumination
- Award-winning innovative design

In this smart lock cover developed for PassiveBolt's Shepherd Lock, a keyless entry system is a simple add-on that allows homeowners to keep their existing lockset and keys, while converting it into a touch- and smart phone-activated device. Employing their smart phone as a sort of "key fob," users can lock and unlock their door both inside and outside with a touch. IMSE technology allows a smart surface that provides both structural and electronic functionality with a beautiful cosmetic surface. The IMSE part contains printed electronics for circuitry, capacitive touch capabilities, contact pads for external connectivity, and LED illumination to indicate lock status. It involves a mechatronic module that works based on simple touch—no fingerprints or biometrics needed. A combination of sensors and artificial intelligence actively monitor the lock and sends an alert to the homeowner via a secure mobile app if the lock is tampered with. The product won a CES 2020 Innovation Award in the Smart Home category.

Case: Refrigerator HMI Panel

- Seamless, moisture- and debris-resistant structure
- Easy to clean HMI panel
- Hidden-till-lit symbols for sleek design

This HMI is seamlessly integrated into the refrigerator door panel and has been designed for two potential applications; either as a replacement for a conventional HMI panel above the ice dispenser on a combined refrigerator-freezer, or to open up new functionality in the location freed up by IMSE capabilities. The conventional design kept the surface of the part flat to make it a drop-in replacement for the original design, but the part has both overall curvature and 3D functions in the form of recessed capacitive slider and a raised power switch. Symbols are hidden-till-lit, which means that they are not visible when the HMI is in sleep mode. IMSE adds the feature of a large illuminated area as a user alert. This HMI panel demonstrates a dual use for a single tool set—the same geometry but with very different functions realized through IMSE printing processes. Such applications could include a proximity sensor to awaken the HMI, a power on/off function, temperature adjustment for both refrigerator and freezer, and a visual alarm in case the temperature is too low or the door has been left open.

Case: Coffee Machine Control Panel

- Thin and durable HMI panel
- Seamless and easy to clean structure
- Informative illuminated icons

The coffee control panel is something that can be adapted to any number of home appliances—dishwasher, washing machine, microwaves—and utilizes IMSE's strengths of capacitive touch buttons, illuminated icons, ambient lighting, and thin 3D structure. It shares the building blocks of many automotive applications.

Case: Suunto Smart Connector

- Fully encapsulated smart connector
- Lightweight
- Extreme durability

TactoTek also has worked with Movesense, an open development platform for motion sensing and biometrics that was created by Finnish sports watch expert Suunto. Movesense's easy tools allow one to build their own wearable device quickly and cost-efficiently, to enable the tracking of sports, health, equipment, or machinery. Working together, the parties found a way to integrate electronic functionality into fabrics. Typically the challenge with truly wearable electronics—not the wrist device—is the wear and tear they undergo. Clothing, especially in sports, is often worn in extreme conditions, and has to be washed often.

TactoTek was able to make a smart connector using its own wash-and-go material stack for Suunto Movesense. This smart connector is fully encapsulated and can be integrated into clothing, shoes, or any wearable equipment likely to be worn when exercising. It is attached to the sensor part and provides important contextual information on the location of the sensor that results in higher data fidelity. Because the smart connector uses silver inks with high elongation values, it can withstand more than 10,000 twist and bends, and more than 50 washing cycles in a washing machine.

Case: Headphones

- 3D shape
- Thin structure
- User intuitive design

High end headphones are just one category of consumer electronics that can benefit from IMSE. Here is an example of a headset with capacitive touch buttons and slider, along with an illuminated indicator. As in other segments, light, thin, environmentally sealed solutions are valuable for this market segment.

CHAPTER 7

A new era

7. How IMSE® went from a concept to a proven market-ready technology

In this paper, we have looked at how IMSE® technology provides 3D structural electronics that can help realize:

- Innovative, brand-differentiating design
- More sustainable product life cycles
- Smarter, more efficient manufacturing processes
- Reduced total cost of ownership
- High manufacturing yield

IMSE brings electronic functionality to light, thin, 3D structures in an economical and more sustainable manner. In doing so, it gives designers the ability to shape how we interact with our environment and makes those experiences intuitive and rewarding. The distinction between mechanics and electronics has become blurred, with mechanics, cosmetics, and electronic functions molded into single units. Everyday objects such as light switches and mechanical buttons used to control the air conditioning in our cars will become historical artifacts and reimagined as new intelligent and three-dimensional forms that can be touched, sensed, illuminated, and connected. Expectations of user experiences will be heightened, just as they were by the advent of the smartphone in the mid-2000s.

Neither brand owners nor manufacturers can afford to be left behind. It is time for decision makers to commit and take active steps toward a new era where electric replaces fossils fuels, cross functional innovation teams replace engineering silos and digital replaces analog. A crucial accelerant in this respect are regulatory drivers towards a circular economy. IMSE's many benefits, such as its additive manufacturing processes, efficiency in design, and significant reductions in environmental impact can help businesses thrive in this new, smarter, more sustainable era.

Such changes are already in process, with new brands challenging industrial giants that have dominated for decades. Those that are slow to adapt will struggle to compete as most nations embrace carbon neutral goals. Generations born in a digital world are now coming of age and the road ahead is an inevitability rather than an unknowable future.

Digitalization is accelerating, as is interconnectivity and related changes in user behavior that span markets. As intelligent devices are integrated into a synergistic ecosphere of functionality and usability, smart distributed systems will become pervasive. IMSE is perfectly positioned to be integrated into the system that is taking form. Calls for more sustainable processes, smarter manufacturing, and lower total costs of ownership are all key supporting trends.

It is time to act.

IMSE enables countless applications today that complement this new and more sustainable way of life. Brand owners and suppliers have joined us in this vision of the future. If you like what you have read today, then get in touch. Together, we can help build smarter surfaces for a smarter world.

Contact:

Sami Hyyryläinen
SVP Field Operations
sami.hyyrylainen@TactoTek.com

Dave Rice
SVP Marketing and Business Development
Dave.rice@TactoTek.com

Jussi Harvela
CEO
jussi.harvela@TactoTek.com

OUR COMPANY

With TactoTek® IMSE® technology brands deliver high value, differentiated user experiences with smart molded structures—form, styling, electronic functionality and total cost efficiency that drive customer value across markets.

TactoTek® is dedicated to developing, validating and commercializing IMSE® technology that transforms the way electronics are designed and built. Manufacturing IMSE® parts uses clean additive processes, less plastics and reduces greenhouse gas emissions.

TactoTek® supports IMSE® licensees that globally design and mass produce reliable, economical smart molded structures.

TactoTek® is funded by Conor Venture Partners, Voima Ventures, Nordic Option Oy, Valeado AB, Faurecia Ventures, 3M Ventures, Cornes Technologies Limited, Repsol Energy Ventures, Plastic Omnium, Nanogate, Ascend Capital Partners, Leaguer VC, Nordea, Finnvera, ELY Center, Business Finland, various European Union's funding programs and private angels.

TactoTek is ISO 9001 certified.

Start building smarter surfaces with the help of TactoTek® today

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