TOP 10 WMF TECHNOLOGIES

AUGUST 2020

WORLD MATERIALS FORUM

Dear all,

We are excited to bring you the 1st list of the annual
Top 10 WMF Technologies.

Based on the panel's research and numerous interviews, we think that these technologies can reach industrial scale by 2030 and that they can therefore make the WMF objective (decouple economic growth from the current use of our natural resources while creating value for the industry all along the global supply chain) happen sound and fast.

For each of these 10 Technologies you will find:
1. A summary of the technology with expected impact on one or more of WMF decoupling Key performance indicators.
2. The restitution of 3 interviews with a selection of Top Corporate (CEO or EVP), Top Academia or Experts (or Big Group CTO) as well as representatives from the Start Up community (CEO).

We wish you will enjoy the reading as much as we enjoyed performing the interviews.

PROF. VICTOIRE DE MARGERIE
Founder & Vice Chair WMF, France

PROF STÉPHANE MANGIN
Université de Lorraine, France

MATT PRICE
President Activate Global, USA

HIROFUMI KATASE
Executive Vice Chaiman
I-Pulse, Japan

Technology #1

RECYCLING OF PLASTICS AND CARBON FIBER COMPOSITES

WMF Objective: end of life recycling rate

Broadly there are two major ways to recycle plastics : mechanical where the plastic is washed, ground into powders and molten or extruded and chemical recycling where the plastic is brought back into monomers to then form pure polymers again. "Mechanical" covers 30% of plastic recycling needs due to intrinsic shortcuts: restricted food usage, impossible processing of colors, limited number of further recycling. Whereas « Chemical» is universal except for PVC that requires to be sorted from waste inflow. 360 Mtons of polymers were produced in 2018. If the same volumes are manufactured in 2030 and if we reach in 2030 the objective that 30% of polymers manufactured are made of recycled raw materials, the production of monomers will then be reduced by 108 Mtons.

NICK STANAGE
CEO HEXCEL, USA

Recycling is top on the list of our priorities.
And we need to do both recycling of carbon fibers and recycling of resins - be thermoset or thermoplastics.
In both cases we will investigate all possible technologies - be chemical or mechanical. Because this might be a different technology to recycle wastes of the pre preg process and wastes of finished parts that have been in an aircraft for more than 30 years.

Also we think that we should take time to find the best "pack" of technologies in order to recycle into high quality products rather than be quick into recycling high volumes of low quality products.

Our objective is that 50 % of used Carbon fiber composite products be recycled by 2050.

We started working on the various technologies a while ago - both in our R&D centers or in cooperation with start ups such as Carbon Conversion.

But we first need to collect enough wastes of composite products: the 1st aircrafts with high proportion of composite parts that will be disassembled are the A 380 maybe in 15/20 years time and the 1st B787 & A350 in 25/30 years.

Also economics need to work. Subsidies should only be temporary to kick off until enough volumes be available and right qualities be standardized.

So a good target for industrialization would be 2025 for carbon fibers & 2030 for resins.

As said before quantity and quality of waste collected is yet not sufficient that we can get the recycled material at a competitive cost and at an acceptable specification for the customer. And there is no business model today that can create value for all actors along the recycling supply chain.

Coperation between all composite manufacturers and their customers is key, first to identify and develop together the right technologies that will produce high quality recycled materials and second to classify wastes and design the product offering that will leverage high volumes of recycling.

Today each actor in the field of composite materials is very protective of their technologies. But in the field of recycling we should force common industry standards otherwise we will never supersede a 10% recycling rate.

So our responsibility is to find solutions, work together and standardize.

BERNARD PINATEL
PRESIDENT PETROCHEMICALS TOTAL, FRANCE

Current recycling technologies so called "mechanical" only cover 30% of plastic recycling whereas the so-called « chemical recycling » is universal even if some pre sorting might be required to eliminate some contaminants. The outcome of the process is heavy grade naphta that is then remixed with virgin naphta to re start usual polymerization process. Chemical recycling requires more energy than mechanical recycling (3 times more) but it avoids incineration of plastic wastes and it enables an endless loop that always produces high quality polymer.

The impact of this technology should be assessed on two KPIs:
- 50% of collected plastic wastes should be recycled by 2030
- 30% of polymers manufactured in 2030 should be made out of recycled raw materials.

All "majors" (Total, Sabic, Ineos ...) have industrial chemical recycling projects under development and due to start by 2024. The technology itself is quite well known but there is still lots of work going on now both on the process itself and on the catalysts being used in order to make the technology more versatile (meaning allowing for greater variety in the quality of plastic wastes to be treated) and the recycling more efficient (meaning a reduction in the cost of the recycled raw material).

The major hurdle towards industrialization is that there is (at least as of now) limited – if any - value creation along the recycling chain as the cost of recycled raw material is often above the cost of virgin raw material. Another issue is that quantity and quality of waste collected is often not sufficient.

So cooperating with the final industrial customers is key - such as our project with Recycling Technologies, Mars and Nestlé or our partnership with Pure Cycle and L'Oreal.

Schemes such as off take guarantees or premium prices for recycled materials - or penalties if decision not to use them - should also be set up at least for starting a virtuous process. And one off grants to build the 1st chemical recycling units should also be considered as these 1st units will need more time to be profitable than the 2nd wave (due to technical scale up and initial limited volume of waste available).

Total as well as all partners of Alliance to End Plastic Wastes (BASF, SABIC, EXXON, SUEZ ...) are very committed to finding solutions for plastic end of life.

And it is also important to remember how much plastics and composites contribute to the well being of our citizens (protection of food, supply of water, lightweighting of cars and aircrafts etc...).

JEAN HORNAIN
CEO CITEO, FRANCE

« Chemical recycling » is clearly a must on top of mechanical recycling if we wish to reach the commitments of many consumer good companies and the EU targets for 2030 in plastic packaging:
- recyclability solutions for 100% of plastics (vs 75% today)
- a minimum of 55% of plastic packaging actually recycled (vs 29% today)
- a minimum of 30% integration of recycled plastic in packaging, with food contact compliance (only in beverage packaging today).

Citeo is involved in all projects involving French stakeholders all along the supply chain from Total upstream to Mars and Nestle downstream.

From the technical stand point it seems that the technology should be industrial by 2025.

One major hurdle is the cost of recycled raw material that is above price of virgin raw material - and will remain higher even when sizable quantities will be recycled. And a second one is the « time lag » between short term expectations of public opinion and industrial longer term results in terms of plastic recycling rate.

Cooperation between all actors of the supply chain from petrochemicals to final industrial customers is key - such as project Pure Cycle with L'Oreal, or Recycling Technologies with Total, Mars and Nestlé.

Systems to share the burden of recycled materials extra cost still need to be invented. One possibility to drive up the recycled volumes would be an obligation to incorporate recycled materials in the fabrication of all new polymers. To give a tax advantage to polymers produced from recycled material could be another way. All solutions need EU harmonization to avoid competition problems.

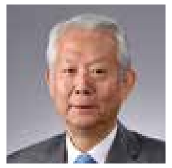
Citeo is very committed to facilitating efficient win win solutions between recycling organisations and industrial actors all along the supply chain in order to optimize access to technology and financial resources, accelerate circular economy of plastics packaging and prove that there are solutions to combine efficiency of plastic and protection of our planet. The commitment of polymer producers who have the best knowledge of the material itself is key if we want to accelerate circular economy of plastics packaging.

Technology #2

RECYCLING OF EV BATTERIES

WMF Objective: end of life recycling rate

When the 1M electric vehicles that were sold in 2017 will come to end of life, it could result in 250,000 tons of discarded battery packs. A huge challenge as batteries are not easy to disassemble but also a huge opportunity to recover Li, Mn, Co and Ni that are critical raw materials. The main stream technologies being developed are hydrometallurgical and bring high recovery rate while a new one called membrane solvent extraction offers high purity and makes all 4 elements available in separated form: Li, Mn, Co and Ni. If 50% of recycled material is used to manufacture new batteries in 2030 (100% in 2040), this will strongly reduce the use of these natural resources.



SHIGERU OI
CHAIRMAN
JX NMM, JAPAN

JX NMM has developed and patented an hydrometallurgical recycling technology that offers high recovery rate and low CO2 footprint. The impact should be assessed on two KPIs:
- 80% of used batteries should be recycled by 2030
- 100% of recycled material should be used to manufacture new batteries once there are enough waste batteries to cover the in flow needed in 2040

Energy savings and reduction of CO2 emissions should also be closely monitored throughout the process.

We aim to industrialize our technology in 2030 when a large enough amount of waste batteries will be generated.

When the system will be mature in 2040, the recycling rates of the different battery materials should be as follows: Cobalt and Nickel each 90%, Lithium 70%.

As of now, the major hurles on the road towards industrialization are illegal dumping and inconsistency of production safety standards as well as local regulations. And not to forget the possible variations in natural resources prices vs. recycling costs.

So we really need to set up a system in which all beneficiaries bear the recycling costs.

AT JXNMM, our technology is based on the closed loop system and our objective is to realize a system non dependent of natural resources.

But recycling units are not always located where the batteries are produced or utilized so that a global recycling scheme should be created that would bring together the contribution of industry, academia and governments.

PETER CARLSSON
CEO NORTHVOLT, SWEDEN

Northvolt has developed and patented an hydrometallurgical recycling technology with Chalmers University in Sweden and Oulu University in Finland.

The impact should be assessed on two KPIs:
- 80% of used batteries should be recycled by 2030
- 50% of recycled material should be used to manufacture new batteries in 2030

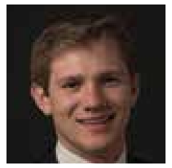
We will soon be starting the 150-200 M € fund raising in order to build our recycling plant that we expect to be fully operational in 2022.

The main hurdle on the road to industrialization is to get enough processed quantities in order to deleiver a competitive cost. So as minimum process quantities means enough used batteries collected, we just created Hydrovolt (Battery Return NGO) with Norwegian Aluminum Group Norse Hydro and the plan is to sign up OEMs such as Bosch into the loop.

Also recycling high voltage batteries can be dangerous especially the initial process part of discharging before the crush. Securing a safe discharging process means automation of this part of the process so a cooperation is on going with ABB Robotics hereto.

We see this recycling project as one more brick to the current Northvolt Batteries project in order to create a fully integrated circular economy of EV batteries.

In the end a customer should be able to buy a new battery with a discount on the price if he brings backs an old one to be recycled.



PRESTON BRYANT
CEO MOMENTUM TECHNOLOGY, USA

The goal of the US DoE is 90% recycling of all lithium ion batteries in 2030 - from 5% in 2019. After discussions with industry partners, we at Momentum believe that a 50% rate is achievable by 2030.

Our technology (Membrane Solvent Extraction or MSX) is capable of recycling Rare Earth magnets or Lithium Ion batteries. For batteries it is a 2 step technology that provides 99,9% purity in oxyde form and make all 4 elements available in separated form: Li, Mn, Co and Ni.

MSX can also be used to recycle the 3 to 10% waste generated at each step of the battery manufacturing process so that it can also contribute to improving the full recycling cost and the Buy to Use of batteries themselves (material weight in the final product vs material used throughout the production process).

We will have our prototype unit running in 8 months with a capacity of 150T/y plant.

Once in operation, we will ramp up to a 1000T/y capacity by end of 2021 in order to meet the demand of our 1st industrial partner - and the ramp up will cost between 7 and 10M$.

All companies we speak with are familiar with smelting and hydrometallurgical process but not with Membrane Solvent Extraction so a change of mindset is required.

Also reaching a competitive cost will be the usual challenge.

Otherwise we see no major technical hurdles on the road to industrialization. Currently 50% of recycling costs are logistics.

So bringing the MSX technology to battery materials manufacturers, batteries manufacturers & battery recyclers will be key.

Also competitive cost will depend on processed quantities. So public support such this of DOE is essential to start a virtuous circle. As well as WMF support to call attention to this new technology.

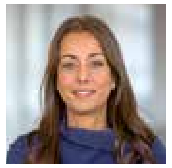
We see international cooperation with all actors along the battery supply chain as a must for sound and fast development of our technology.

Technology #3

EV BATTERY CHEMISTRY : CONTINOUS IMPROVMENT OR BRAND NEW ?

WMF Objective: better performance (charging time & range) to weight

The race is ongoing between 3 options : 1. Continuous improvment of the current ion lithium design with the cathode being the limiting factor and safety the key attribute from the elctrolyte, 2. The solid state project which features solid electrolytes rather than the liquids and gels used in current ion lithium designs and 3. The technologies based on largely available resources such as sodium or sulfur but that are still at very early stage. Better performance (charging time & range) to weight is the objective and even more so a better performance to volume when it comes to mobility applications.



ILHAM KADRI

CEO SOLVAY, BELGIUM

By 2030 (and maybe earlier) we need to reach an optimum of performance (gravimetric and volumetric energy density), safety and cost for the automotive industry.

Solvay is and will remain « agnostic » to the choice of technology - be continuous improvement of current ion-lithium chemistry, be the solid state project or be the other breakthrough options such as sulfur or sodium based.

Our focus will be on developing and up scaling the right materials (such as PVDF) and solutions (such as membranes and new electrolytes) required by our customers for reaching the above mentioned optimum.

The battery is now at nearly 50% of the cost of an EV and the current ion lithium chemistry will be really « industrial » when it reaches 25%. Presumably in 2025 when enough volumes will be manufactured and the production process will have reached an acceptable efficiency.

Lack of harmonisation is clearly an issue as too much money is being spent on a variety of R&D programs without clear results.

And there cannot be a focus on industrialization until « standard» technologies are being identified and highlighted.

So we need to get major actors all along the supply chain (from producers of metals and polymers to battery producers, car makers and recycling groups) to work together and produce a regulatory frame that will allow stronger, faster and more efficient development of Electric Vehicles. We also need further support from States or European Union beyond regulation.

The necessary involvement of all major actors of the EV supply chain worldwide to establish the above mentioned regulatory frame is crucial.

And so is the necessary commitment of public entities (be at national or regional level) to invest quickly into building charging infrastructures: without such infrastructures, there will be no uptake of EV sales, and without volumes, there will be no reduction of battery cost.

RICHARD WANG

CEO CUBERG, USA

By 2030 we need to reach a gravimetric energy density above 400 Wh/kg (we are at 250 Wh/kg now). And we also need to reach 1000 Wh/L volumetric energy density- this is just as important or more important for large volume/ automotive applications. The 1000 Wh/L is why sulfur will never make it commercially for automotive applications, even if it ends up working for other uses.

Industrializing continuous improvement of the ion lithium design requires top level production experts who can continuously upgrade existing production units with limited capex in order to deliver further improved battery performance at competitive cost.

And Scale up of any change in the battery design is even more so THE question as even incremental changes in one area can cause problems in the other areas. This is why Cuberg cell design is now ok for small lots and will be «industrial» by around 2024 when we will have completed proper scale up.

The main challenge towards industrialization is putting together the right teams and upgrading them at the right pace in order to deliver cost-effective production scale-up and demonstrate true maturity and reliability in a wide range of operating conditions. To overcome this challenge, we need major groups and start ups to work together in a win win mode that will allow to combine the start ups' agility/ability to innovate and the big groups' financial strength/ expertise in efficient manufacturing in order to improve battery performance faster.

Major performance improvements if the past years resulted from expensive work on the cathodes done by big groups. We now see future battery performance improvement to come in a more balanced manner from cathode and anode/electrolyte as well as from big groups and start ups.

Also we should always watch early signs of battery innovation and performance to come from adjacent markets (unmanned drones for cargo delivery, small electric aircrafts…) before they make it into large volume/automotive applications.

And Safety is and should remain a top priority above any consideration of performance improvement.

PROF. VICTOIRE DE MARGERIE

FOUNDER & VICE CHAIR WMF, FRANCE

Issues common to battery technologies are fire safety, energy density (both gravimetric and volumetric), durability and recyclability.

Both industry and academia are heavily involved on « beyond lithium ion batteries » whether solid state batteries or more long term designs that allow to access largely available resources such as sulfur or sodium.

But there is also concerted effort to continously improve the current lithium ion chemistry.

Common objective for all is by 2025 to reach minimum 80% charge in 15 minutes, 400Wh/kg gravimetric density and 1000 Wh/L volumetric energy density. The ion lithium design is already industrial and continuous improvment to improve performance is on going for both the cathode, the anode and the elctrolyte – with the usual scale up challenges as any change in the battery design in one area can cause problems in the other areas.

As to solid state, the « world » objective is to make it industrial by 2030. But there are 4 technical issues to be adressed : stable chemical interfaces between electrolyte and electrodes, effective tools for characterization, sustainable manufacturing processes and design for recyclability.

So we must find solutions to address all 4 issues at the same time. Which means finding both talented and experimented people specialized in each of the key 4 areas and convincing them to use collective intelligence and develop their solutions in a time consistent manner.

Which also means getting MultiNational Groups, States, Universities, Start Ups and Non Governmental Organizations to work better and faster together on a Win Win mode.

Our overall objective at World Materials Forum is to decouple economic growth from the use of our natural resources while ensuring the needs of our citizens in terms of food, housing, mobility and connectivity.

Electrification of vehicles will strongly contribute to this decoupling objective only if every step of the supply chain (from sustainable mining of critical materials to end of life battery recycling) is managed towards a consistent objective of improving batteries energy density, durability and recyclability while always prioritizing safe solutions.

Technology #4

STORAGE OF RENEWABLE ENERGY AT LOWER COST

WMF Objective: storage duration (beyond 12 hours and more than 25 years life cycle)

Energy storage technologies offer significant benefits : improved stability of power quality, reliability of supply etc... As solar and wind power need to play a major role for decarbonization of electricity, development of large scale storage at low cost will be even more critical. Given the size of global demand for such storage, long life of more than 25 years and high recyclability will be necessary to minimize the impact on environment. Lithium ion battery will not be able to meet these criteria. Many technologies are under research and development. Pump hydro and vanadium redox flow battery are the most promising towards achieving competitive cost.

BERNARD SALHA

CTO EDF, FRANCE

For us at EDF the objective is to deal with peaks of energy consumption and energy storage is one solution among others. There are many other ways to deal with it, such as demand management or achieving a balanced power supply mix of solar, wind and nuclear.

And whatever the share of energy storage, as we need to reduce carbon emission, the life time of battery is very important. The longer the lifetime the better with the objective to overcome 20 years.

How much storage will play the role will depend on its cost. As a minimum, storage will play a big role in ancillary services such as frequency regulation that requires rapid response. If the storage cost gets very low it could play a much bigger role.

For EVs for example, half of the battery cost today is the cost of materials. If this percentage of 50% can be brought down to 25%, there can be a huge development of volumes sold.

If a battery can function both as peak management and ancillary services for example, cost will be improved. One battery will play more than one role in the future. So if a battery can function both as peak management and for ancillary services, cost will be improved.

Also cost will decrease as overall volumes increase so the target should be to develop volumes simultaneously on the 3 market segments: EVs, home storage or grid usage.

Finally acting to decrease energy consumption in the whole supply chain of battery production, including mining, is very important.

In the end, we will support any technology that can secure a long lifetime, low CO2 footprint and an acceptable cost.

HIROFUMI KATASE

EXECUTIVE VICE CHAIMAN I-PULSE, JAPAN

The world needs a gigantic volume of large scale storage at low cost as solar and wind power will play a bigger role in power supply. In order to minimize its impact, the storage needs to have a life time of at least 25 years and to be fully recyclable. It also needs to be very safe. Pump hydro is a well established and low cost technology that meets these criteria but have a geographical constraint. Thus new technologies such as redox flow battery, compressed air storage and fly wheel are being researched and developed. Among these, vanadium redox flow battery is already deployed commercially and fully meets these criteria.

Securing a stable and low cost supply of Vanadium will be very important to secure industrialization of the redox flow battery technology. Vanadium is an abundant resource. However,as the current use of Vanadium is mainly for steel industry, it is necessary to increase the production to meet a large demand for batteries.

And it is a chicken and egg situation, where vanadium producer cannot increase vanadium production as there is no certainty of demand from battery company and vice versa. In such a situation, when vanadium redox flow battery in early stage, it will be necessary for battery producers to invest in producing vanadium.

Altogether and at least for now and the coming 10 years, I see vanadium redox flow battery as the only storage system which is long life, low cost, fully recyclable and very safe.

DR. MIANYAN HUANG

CEO VRB ENERGY, CHINA

The VRB system life time is longer than 25 years. The electrolyte is fully recyclable and most of the non electrolyte part will be easily recyclable. Based on our Roadmap, and scale-up, we will have a lower cost battery compared to LiB by 2024 for 4-hour systems (just the battery) At the same cost as LiB we have about a 15% LCOE advantage vs LiB (this assumes 80% usable DoD, replacement in year 10 at 50% of current costs for LiB). For 8-hour systems we will be almost 30% lower cost, and 40% better LCOE. LCOE is a tremendous advantage for project developers and owners. Our system response time is very short with unlimited number of charging-discharging cycles. It can be used for ancillary applications such as frequency regulation. This will make our system even more attractive as our system can serve multiple applications at the same time and and this will improve the economics of the projects even further.

We are ready to deliver 100MW projects in China next year. With the release of our Gen3 product in 2021, we will be able to service multiple 100MW-class projects globally. We also have plans for localized manufacturing in global locations - e.g. US, Australia, South Africa - we do not need a gigafactory as we have a simple, flexible, capital-light manufacturing requirement, and our capital costs for a manufacturing plant are about 1/10th that of Tesla for the same capacity for example.

The 1st hurdle on the road to industrializing our technology is vertical integration of vanadium supply. There are almost unlimited sources of vanadium in this planet. Traditionally the steel industry has been 70% producer of vanadium (contained in their slag), and 90% consumer of vanadium (for alloying steel). Breaking this "closed" market with a massive new market for batteries will bring about investment in vanadium production, and lower overall costs. Second hurdle is the pre-mature supply chain support for volume scale up. It will take some time for the suppliers to scale up their own production to match the volumes required.

VRB Energy, with the help of our parent HPX is unlocking vanadium sources. For supply chain support for volume up, the good way is to let the key supplier involved in the big size project development so they can be aware the fast growing of market size and can make decision to favor their volume up production and R&D facility investment.

VRB Energy is scaling up to serve multiple 100MW-class projects in China, which is the ramp for us to achieve scale and lower costs. Bloomberg predicts that renewables will be 90% of $11.1 trillion to be invested by 2050, and our technology is perfect for integrating wind and solar on the grid including for ancillary applications. An estimated 800GWh storage needed by 2030. Robust, non-degrading, safe.

Technology #5

LOW ENERGY ACCESS TO POTABLE WATER

WMF Objective: performance (H2 cost and % of renewable energy) to stack weight

The treatment and transportation of water is incredibly energy intesive. The amount of energy needed to provide clean drinking water varies depdending on regions, technology and infrastructure. In the US alone it is estimated that 4% of the US's energy consumption goes towards providing clean drinking water and that is in a region with available ground water and significant infrastructure in place. New technologies in electrochemistry, membranes, and material science are significantly reducing the energy intensity of drinking water treatment systems and opening up new forms of distributed water generation applications. These technologies can play a key role in addressing the WMF objetive of Using Less Energy.

CODY FREISEN

CEO ZERO MASS WATER, USA

The energy intensity of producing and delivering water is challenging to define because it varies depending on geography and the various technologies that municipalities use to treat and transport water.

For Zero Mass Water the solar powered panels create potable drinking water on site by dehumidifying the air while using solar power and ambient air as the only inputs.

The process is entirely infrastructure-free and the result is high quality drinking water produced independent of the factors that must be considered when dealing with surface or subsurface water.

Many surface waters are indeed polluted and deep real-time knowledge of contaminants is necessary to ensure that truly potable water is being delivered, and often the consumer has no transparency to inconsistency in potability.

On the other end of the cost spectrum, bottled water serves as a lifeline for many across the emerging markets with failing or nonexistent infrastructure and can take 5 – 10 million joules of energy per liter of bottled water (in the US). Worldwide consumption of bottled water is over 200 billion liters so there is an enormous amount of energy savings and waste offset potential.

Our Hydropanels are commercialized today with units operating in over 40 countries across many hundreds of types of installations from schools, to homes, to hotels, and communities.

SAM RIGGALL

CEO CLEAN TEQ, AUSTRALIA

CleanTeq has developed a number of technologies that aim at reducing the energy intensity of providing clean water. One technology specifically aimed at reducing the energy cost of potable water is the graphene oxide (GO) membrane technology that significantly increases the flux of water passing through the membrane while also achieving a higher level of selectivity. Compared to traditional membranes the GO ones are demonstrating a 85% reduction in energy consumption.

When it comes to scale up, membranes are needed in the millions of square meters to meet the water treatment demand. Clean Teq has produced membranes on a commercial coating machines in the hundreds of square meters quantity which are able to deliver the low energy outcome. The aim is to have commercial quantities of GO membranes available for use in spiral wound modules by 2021.

The biggest hurdle for new technologies like this to get deployed is dealing with the fact that water is a subsidized product in most parts of the world and the conservative and complex nature of the water supply chain. Municipalities are conservative as are the large engineering firms that act as gate keepers to what solutions get deployed.

The approach often taken to overcome these hurdles is to partner with the large system integrators and get components adopted into their systems. Other approaches include marketing directly to the end users and using them to help influence the gate keepers at the large engineering firms.

MATT PRICE

PRESIDENT ACTIVATE GLOBAL, USA

At Activate we see several promising technologies to help reduce the energy intensity of creating potable water. We have seen the development of wave energy converters desiged for robust and cost effective submerged operations that can provide a significant amount of pressure needed for desalination systems. Traditional desalinisation plants can consume 10-15 kWh for every thousand gallons of treated water. These wave energy converters could eliminate most of that energy cost. The newest generation of wave energy converters are going through pilot scale trials now and could be scaled up to first commercial systems in 5 years.

We have also seen the developement of a new class of highly porous and active materials called metal-organic-frameworks or MOFs. Different chemical formulations of MOFs have been in developement in academia for many years and now we are seeing a handful of companies tackle the scale up challenges associated with making MOFs using industrial processes while maintaining the large surface areas which give them their unique performance including the ability to absorb large volumes of liquids and be easily regenerated. Industrial pilots using MOFs are underway and if successful industrialization of the technology could be achieved in the next 5 to 10 years.

Technology #6

SPINTRONICS

WMF Objective: lower energy consumption

Technology summary : Cisco predicts that "The number of devices connected to IP networks will be more than 3 times the global population by 2023", driven in particular by the advent of IoT, AI and the related increase in machine-to-machine connections. Thus, "devices and connections are growing faster -10 % Compounded Annual Growth Rate (CAGR) than both the population - 1 % CAGR - and the Internet users - 6 % CAGR". The biggest issue with this development is its overall impact on the environment, both on the critical materials needed to build the various devices, but even more so on energy consumption. Spintronic or Spin Electronic differs from traditional electronics in that, in addition to charge state, electron spins are exploited as a further degree of freedom, with implications in the energy efficiency of data storage and transfer. Consequently, this technology can strongly impact power consumption in computing and data storage applications. Depending on each sub application, spintronics could improve the energy efficiency by 10% to 10,000%.

PROF. HIDEO OHNO
PRESIDENT TOHOKU UNIVERSITY, JAPAN

Spintronics allows one to dramatically reduce power consumption of information technology. This is because it offers a high-performance nonvolatile working memory option not available in current technology dominated by power hungry "volatile" DRAM and SRAM. One of the many fronts Spintronics has its potential impact is AI chips for autonomous driving. It requires 1000 TOPS (trillion operations per second) or more to safely guide the automobile in level 5 but the current technology requires 1000 W to achieve this; a power consumption far beyond a car can carry. Performance of prototype AI chip using spintronics technology made at Tohoku University suggests that it is appropriate to set KPI for the application as 10 W by 2030 and 1 W by 2040.

The main hurdles on the road to industrialization are capital investment and integration of talent. To develop a new AI chip technology requires not just designing circuits but also developing manufacturing and design tools, creating testing and verifying technology, understanding of physics and materials that are new to the semiconductor industry, and capability of prototyping such an AI chip along with the capability to field-test the prototype. Showing successfully the integration of broad spectrum of technologies is the only way to convince the industry that this is where the future is, which is certainly an extremely demanding task that one has to overcome.

I believe that the combination of a university environment that can bring many talents of different fields together plus successful industry-university collaboration plus an appropriate level of public funding can overcome these hurdles and "integrate" all the required technology. Tohoku University's Center for Innovative Integrated Electronics Systems is exactly doing this.

PROF. ANDREW KENT
FOUNDER SPIN MEMORY, USA

It is important to note that Spintronics has provided the first new embedded memory technology since Flash memories, technology known as magnetic random access memory (MRAM). Embedded means that the memory can be integrated closely with the semiconductor components on a chip. This reduces the «von Neumann bottleneck,» the separation of memory and computation on a chip that leads to delays and energy associated with the transfer of data.

A key characteristic of this memory is that it is persistent (or non-volatile); no energy is needed to retain information. Energy is only used for reading and writing data. MRAM is also a very high-density memory. It uses just 1/4 of the space of SRAM. MRAM's write speed is 10 to 50 times faster than embedded NOR (eNOR) Flash memory and has much lower write power that eNOR (100 to 1000s lower). And prototype devices show that the technology can scale to sizes below 20 nm, making it a potential DRAM replacement is likely within the next 15 years.

Thus the most immediate impact of MRAM will be in IoT, AI and mobile devices. MRAM will enhance IoT and AI, allowing higher memory capacity with lower energy consumption. The main advantage in IoT and AI will be smarter devices with lower energy usage. A big saving in energy will be in mobile systems with a greater than 50% energy reduction expected by 2030.

Semiconductor companies (Intel, Global Foundries and others) have low density MRAM (less than 1Gb memories) already integrated into specialized chips. Delivering sizable quantities at a competitive cost requires several things to happen. First, semiconductor tool manufacturer need to develop systems that allow high capacity wafer processing (greater wafers/hour provides less cost/chip). Initial demand for AI, IoT and other specialized chips should drive this development and industry purchases. It is expected to have widespread embedded STT – MRAM on the market by 2027.

A main hurdle on the rod to industrialization is the availability of manufacturing sites and tools. However, even more important is an educated workforce that can advance and sustain this technology.

Basic research drives innovation and trains people in the field, particularly in technology leadership and problem solving that is essential to progress. The advances in MRAM came from fundamental research, starting with the discovery of Giant Magnetoresistance (GMR) in France and Germany (which was awarded the Physics Nobel Prize in 2007). There continue to be discoveries that can lead to important societal benefits and investments in university research, start-up companies and education are essential to continuing this cycle.
To overcome these hurles, multiple concerted action to support the development of energy efficient information technology are needed, from mobile systems to supercomputing. Sustained government and industry funding and visionary investments that can reduce energy consumption in mobile, IoT and AI.

Investment in basic science and emerging technologies can lead to important societal benefits. Spintronics is a demonstration of this. It is clear that a decade from now autonomous systems, IoT and mobile devices will have increased functionality with lower energy usage because of advances in the applications of spintronics.

PROF STÉPHANE MANGIN
UNIVERSITÉ DE LORRAINE, FRANCE

The energy consumption of the ICT (information & communication) sector is predicted to represent 11% of the global electricity consumption in 2020. This energy consumption is growing rapidly with the increasing demand related to Artificial Intelligence (AI) and Internet of Things (IOT). In this context Spintronics devices are considered as one of the best candidates for next-generation electronics to complement CMOS technology.

For instance, spintronics logic is promising for ultralow power electronics due to the low intrinsic energy needed to manipulate nanomagnets. Spintronics devices are attractive for future energy-efficient neuromorphic computing systems, as they behave like neurons and synapses in the human brain. In this case, a reduction of the energy consumption of 90 % is possible.

Neuromorphic computing with small spintronics systems already demonstrated energy efficient novel computing. For face recognition, several research teams have shown that spintronics approaches could reduce the energy consumption by a factor of one hundred. Depending on the investment made we can expect the technology to be on the market in 10 years.

There exist several hurdles in scaling up spintronics systems for useful pattern recognition. Moving toward beyond CMOS technologies requires great advances in experimental and theoretical understanding of the materials, devices and circuits. Moreover the huge CMOS technology platform have to be redesigned which will generate important financial investment.

Spintronics is a new technology. Fundamental understanding of the basic mechanism is still needed to improve the performance of spintronic technology.
I would then recommend strong collaborations between scientific research centers and industries.

Technology #7

NO CO2 PRODUCTION OF BULK MATERIAL

Technology summary : Due to the volumes involved, Bulk materials such as steel (1,900 Mt produced in 2019), cement (4,100 Mt produced in 2019) or chemicals (520 Mt produced in 2019) are essential to tackle climate change problem. Introduction of decarbonized electolysis process, use of hydrogen for source of heat /reduction element, carbon capture and storage are the key technologies being developed in each sector.

PHILIPPE VARIN

CHAIRMAN WMF, FRANCE

There are are two main routes for bulk materials to decrease CO2 emissions: one is on energy saving for current processes and the other are new processes that can deliver no emission from the start.

It should be relatively simpler for the chemical sector as it just needs to replace oil & gas with electricity as source of heat. In France, 90 % of electricity is already produced from nuclear or renewable.

As for aluminium, achieving no CO2 production in processing recycled alminium is not a big problem. For production of primary alminium, it is necessary to replace carbon anodes with inert anodes. Alcoa and Rio Tinto Alcan are building an industrial pilot plant in Canada. They plan to industrialize at prototype level in the next 10 years.

It is more challenging for steel and cement. One option would be carbon capture and storage (CCS) but it may not be profitable. Major steel companies are working on development of deoxidazation process using hydrogen but it is still in R&D stage. A development of electrolysis and other extraction processes for steel are also being conducted. Developing anode resisting high temperature as high as 2000 celsius will be key.

Also for the electrolysis process, stable supply of electricity is important. Nuclear energy shouldplay an important role. PV and wind power need to be combined with batteries to offer the requiredstability.

Finally developing the Hydrogen supply chain is a highly strategic matter for our planet. Carbonpricing can be effective but current price of about 25 euro/ton in europe is too low to trigger the investment. A level above 60 euro/ton seemsnecessary, but it will take some time before ithappens because of social and political reasons. In the meantime, developments will have to besubsidized by the public authorities.

We need to establish a global coalition of bigplayers to reduce the cost drastically in a mannersuch as was seen as Moore's law in semiconductor.

TADEU CARNEIRO

CHAIRMAN AND CEO, BOSTON METAL, USA

Steel production is the largest industrial source of CO2 – responsible for 9% of global CO2 emissions. In addition, steel production is set to increase over the coming decades. Boston Metal is developing the molten oxide electrolysis (MOE) process that, when powered by clean electricity, will produce high-volume, liquid steel with zero CO2 emissions.

We have already developed an inert anode which is the key enabler of emissions-free production, and we have successfully demonstrated the full MOE process at semi-industrial scale. We are currently building industrial scale cells and plan to pilot the technology for high-volume steel production in 2023. As the technology is modular, a successful pilot test will allow us to quickly deploy demonstration plants by utilizing multiple cells.

Obtaining a stable and economic supply of zero-emission electricity, such as hydro, nuclear, geothermal, and solar or wind combined with battery storage, is key for realizing truly emissions-free steel production from our MOE process.

In areas such as Canada or Brazil, where hydro powered electricity is very cheap and abundant, our technology will have a natural cost advantage over the conventional process. In areas where emissions-free electricity is not so cheap, certain measures such as a carbon tax may be necessary to fill the cost gap versus the conventional process.
Steel production has been associated with high CO2 emissions since the Iron Age. By the middle of this decade, Boston Metal intends to demonstrate that the future of steel is emissions-free. To achieve this ambitious goal, we have assembled a world-class team, top-tier investors, and industry-leading partners to ensure that we can successfully bring the MOE technology to market in just a few years' time.

ENRICO BORGARELLO

GLOBAL PRODUCT INNOVATION DIRECTOR HEIDEL-BERGCEMENT, ITALY

Cement production is responsible for 5 to 7 % of total global CO2 emissions. Our goal is to reduce our emissions from clinker production (Scope 1) by 30% until 2030 compared to 1990 and to be able to provide all our customers with carbon neutral concrete latest by 2050. This means, our clinker production would then have to reach a net zero carbon emissions level.

At the same time, we are working with customers to reduce the downstream related CO2 emission at the construction site, for example in reducing construction time thanks to new cement grades allowing for more precast or modular construction. Another innovative technology is the use of 3 D concrete printing, which offers the potential to reduce the material intensity up to 50 %.

In order to achieve our 30% reduction goal by 2030, we need to use alternative fuels to an extend of at least 30% worldwide (current rate worldwide: 23%), reduce the content of clinker in cement production from 74% down to 70% by using more supplementary cementitious materials like slag and fly ashes and also further improve the efficiency of our production sites by installing new, high efficiency plant equipment, as done in recent years in Germany as well as in Italy.

The main hurdle on the raod to industrialization is the market acceptance of new, more sustainable and therefore often also more expensive products by our customers. Even if we can guarantee that the new products will have better performance characteristics than the previous product generation, customers are often hesitant to accept higher prices. Clients adopt new cements only if mainly the costs and only in secondary order also the performance is the same as with the existing cement. I am convinced we can achieve our 2030 CO2 reduction target with our new product lines at a similar or even better "price to performance ratio" than with the existing products. Another key hurdle are many outdated construction codes and standards, which make it rather difficult to place new and innovative products. We are therefore working closely with authorities and law makers to replace those regulations with appropriate new ones.

Our preferred solution would be to have a globally unified carbon price at a level that allows producers like us to realize the ambitious goal of providing all customers with carbon neutral concrete. But this still seems to be not feasible quickly, therefore we propose for short term to keep the emission trade system like the one here in Europe in the way as it is now designed for Phase 4. On a medium term, along with a further reduction of the CO2 emissions allowed, a new system has to be implemented to ensure, that advanced markets like here in Europe, are protected against unfair imports of products, which do not meet the same ambitious emission limits. We hope that latest by 2050, comparable national standards will be in place to allow all producers to produce carbon net zero products.

Concrete is already a construction material of superior sustainability characteristics and will become the most sustainable building material, latest after we have implemented our ambitious decarbonation strategy.

HeidelbergCement will deliver the reduction of our carbon footprint by min. 30% until 2030 and be able to provide all our customers worldwide with carbon net zero concrete latest by 2050.

We see recycling of construction materials in combination with innovative carbon capture und use technologies as the most promising pathway into a more sustainable future for our industry.

Technology #8

LOWER COST HYDROGEN BASED ON RENEWABLE ENERGY FOR FUEL CELL APPLICATIONS

WMF Objective: lower energy consumption

Making hydrogen a safe and cost efficient solution for electromobility is the objective of a set of technologies (gas turbine, water electrolysis, high performance fuel cells) all along the H2 supply chain. Making all these technologies evolve at a consistent pace will be the challenge of the 10 years to come in order to get the TCO (Total Cost of Ownership) of the Fuel Cell light commercial vehicles below the TCO of Battery EV before 2030.

SHUNICHI MIYANAGA

CHAIRMAN MITSUBISHI HEAVY INDUSTRIES, JAPAN

Our contribution to the H2 value chain is the Gas Turbine technology and we already use hydrogen as a combustion fuel partially (30%).

We are involved in a project at a 440 MW power plant in the Netherlands where our F Class (1.400 °C) is expected to reach 100% H2 combustion by 2025. Our J Class (1.600 °C) should reach 100% H2 combustion by 2040.

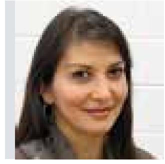
We see transportation of hydrogen to be the most difficult hurdle on the road to industrial scale. Ensuring safe transportation is clearly feasible but it will cost a lot to cover compression or liquefaction plus transportation itself (including loading and off loading) plus final usage preparation (regassification etc..).

Also stable power supply is key to water electrolysis efficiency - and therefore lower cost - but this will be difficult with renewable energy only.

We should always try to make short the distance between the H2 production site and the H2 usage site. For example always install water electrolysis close to existing or new power plant and connect it to the power grid with enough grid capacity.

And we should always consider nuclear energy in combination with renewable energy power supply. On top of renewable energy, nuclear energy is an essential power supply to expand the usage of green H2 globally.

Also in the transition phase, low cost “non green” electric power for H2 production could be used as soon as it allows to speed up the adoption of H2 with a resulting reduced CO2 impact over the full supply chain. For example in existing coal fired plants, half of existing boilers and turbines could be stopped and water electrolysis could be installed instead: huge CO2 reduction impact to be expected at low capital expenditure.



JELENA STOJADINOVIC

CEO MEMBRASENZ, SWITZERLAND

For me the key green technology on the hydrogen value chain is water electrolysis and we will “make it” when we will have increased two parameters:
1. the share of hydrogen from renewables at 70%
2. the electrolysis efficiency above 80%

I see Scandinavia, Germany and maybe France, Switzerland and Japan to be there in 2025, and the rest of the world in 2030.

Upscaling membrane solutions, while keeping the quality - meaning gas tightness – will be the toughest challenge. Capex reduction of electrolysis systems is also a key challenge as we are at 1200 euros/kWh today and we need to divide this amount by 2 by 2030.

Our contribution to improving alkaline electrolysers’ efficiency is to increase ion conductivity that directly impacts water splitting (with 250 mS/cm we are already at the double from what is commercially available) and to be able to keep this performance at industrial scale - we should be there in 2023.

To reach this objective, besides collaborating with different partners, we are also considering to design and build in house a machine capable of producing our membrane at the right specs.

And we also think that AI will be needed to reduce the consumption of raw materials when it comes to industrialization.

I think that we should also bring H2 closer to general audience and provide information in a simple way about the possibilities offered by H2 (also for residential/domestic applications) and the very limited risks contrary to what people usually think (for example on safety of hydrogen tank stations). End users could have a huge impact on early adoption of H2.

PATRICK KOLLER

CEO FAURECIA, FRANCE

Our contribution to the H2 value chain is, together with Michelin, to develop fuel cell high performance products.

On top of safety, our key objective is power density:
- by volume: 4,2 kW/l vs 3,1 kW/l today
- by weight: 2,6 kW/kg vs 2 kW/kg today

For mobility applications, power density by volume might be even more important than by weight.

The Hydrogen Council is forecasting the cost of hydrogen to decrease by up to 50% by 2030 for a wide range of applications making it competitive with other low carbon alternatives.

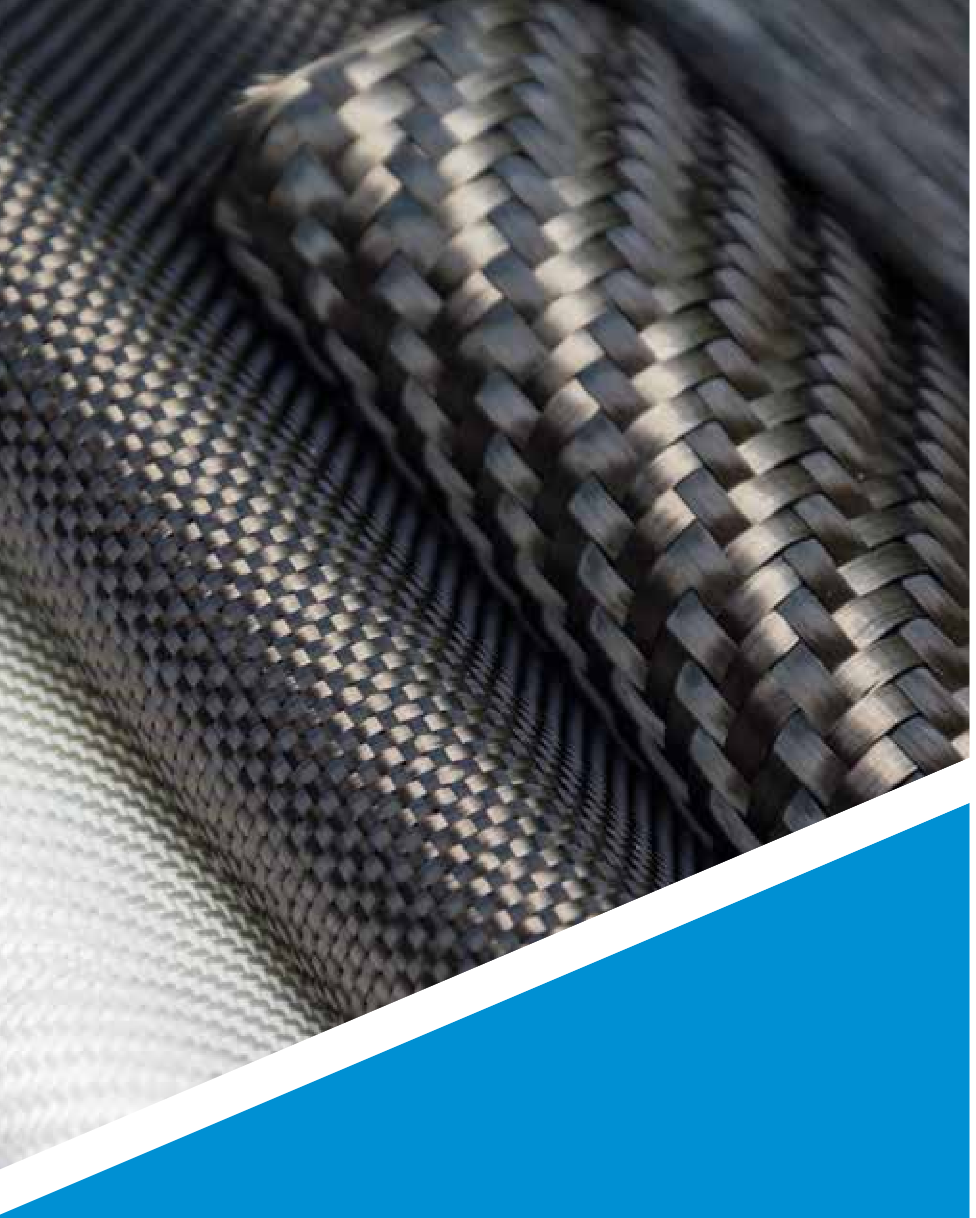
For light commercial vehicles we anticipate the TCO (Total Cost of Ownership) of the Fuel Cell EV to be lower than the TCO of Battery EV before 2030.

The availability of green H2 at acceptable cost will be the main challenge on the road to industrial scale as well as the adoption of coordinated product standards at Regional level. The installation of proper infrastructures will also take time even if countries like Japan, Korea, Germany, France or Switzerland have already announced major investments in the field of infrastructures.

Cooperation will be therefore be key between countries, industrial actors, financial investors, shipping companies and ports in order to invest in the right projects (be green H2 production, infrastructures or direct mobility Capex) that will deliver the most efficient solutions at an acceptable cost in the best delays. This is the major objective of the Hydrogen Council with more than 100 members worldwide at CEO level.

Hydrogen based on renewables is probably THE energy of tomorrow but it will take time not only because the amounts to be invested are high but also because the Capex choices need to be right the 1st time.

Hence the importance of designing coordinated product standards as well as involving the financial investors community in parallel to developing the right technologies.



Technology #9

3D MANUFACTURING OF PLASTICS AND CARBON FIBER COMPOSITES

WMF Objective: performance to weight

Technology summary : Additive manufacturing has evolved very quickly during the last few years towards production of industrial parts made in an extanded range of printable materials and new fields of application have emerged. Significant progress has been achieved and will still be achieved in the 10 years to come to further improve speed of production, material performance, cost and reliability. 3D printing should heavily contribute to reduce not only final part weight (WMF KPI: Performance to Weight) but also the full amount of wastes generated on the full production process towards the final part (WMF KPI: Buy to Use).

THIERRY LE HÉNAFF

CEO ARKÉMA, FRANCE

3D manufacturing offers many benefits. The ability to deliver higher specific performance per unit weight is one of the key features, thanks to a combination of optimized design, and smarter materials.

3D printing allows to design parts with reinforcement localized precisely where it is required to sustain the load, and with empty space or lighter material where it is not needed. This topology cannot be produced by injection or tooling alone. Combined with the use of materials like high performance polymers, composites or hybrids, we should expect to reach by 2030 an overall KPI gain of at least 40% on specific performance such as strength or stiffness per unit weight.

To some extent, although not in every sector, 3D Manufacturing is already industrial, in the sense of sizable quantities at competitive cost.

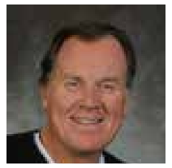
10 years ago, 90% of 3D printing applications were in prototyping vs. 10% in manufacturing. Today, we are at 70:30. This proportion will be reversed by the end of the decade: by 2030 more than 70% of 3D-printing activity will be manufacturing. We expect that polymer parts manufactured by 3D-printing will grow into a $40bn opportunity by 2030.

The challenges which have been limiting the rate of adoption of 3D manufacturing have long been identified: primarily printing speed, limitations in materials properties, production cost and reliability in quality.

The most severe of these hurdles is definitely reliability. Consistent production quality is a primary requirement in the aerospace, medical and automotive sectors, especially for structural parts. 3D manufacturing has the ability to produce high quality parts, but it has been suffering from a lack of consistency and from a lack of supporting data. But this is now progressing fast, thanks to industry leaders such as Boeing and Airbus, and the effective collaborations they encourage through the value chain.

We think that 3D Manufacturing is still in its infancy. There is still a long road in front of us even if the start is promising.

And we can accelerate its development and adoption by continuing innovating in materials, design and printing technologies through strong partnerships along the value chain. So, the key here is really partnerships.



JOS BURGER

CEO ULTIMAKER, NL

We expect 3D printing to be at a stage of much broader adoption in a period of 3 to 4 years. It will affect in a positive way a wide range of industries. We expect that the combination of software, right material choices and printers (including design, software and intel strategy) will lead to weight reductions, depending on the material between 20 and 70%

3D printing is already effective in the traditional domains of prototyping but also very effective in the domain of manufacturing aids and replacement parts.

For large quantities, it will take a little bit more time but what we do see is that 3D printing is very effective in producing smaller series of products that are very much geared toward specific needs of individual customers. For these customers, 3D printing is absolutely superior and way ahead of the traditional production technologies.

We see two major hurdles on the road to industrialization: one is that the driving forces accelerating adoption is people and we need people embracing 3D printing and proving that it is a viable option. That will take some time but will inevitably happen, as we have seen with the adoption of other technologies in competitive environments.

The second hurdle is software. Companies need digital warehouses of 3D print files. Do we have software supporting integration with company's workflow? Is it completely safe to use? Can we do remote management of printers? Can software support in optimizing designs for 3D printing?

So we need top management to embrace 3D printing, deploying it and supporting it, we need great managers to support our technologies and we need to open the door for young talent using 3D printing and proving that it can work in all kinds of different use cases in different industries.

As a summary, talent management will be key to be successful. And so will be the ability to create efficient partnerships between various industries and between industry and academia. We need organisations like WMF to promote our case.

PROF. BRONWYN FOX

SWINBURNE UNIVERSITY, AUSTRALIA

At Swinburne, our 3D Manufacturing technology is focused on a range of industry applications including space and satellites as well as logistics. Our technology will allow to increase the performance and reduce the cost of manufacturing. We can reduce the weight of trucks and drones which mean you can carry more cargo, we can lightweight electric cars and electric planes which means they have a longer range. We can also lightweight space and satellite technology. To launch a kilogram into space it cost 10 000$, so in this domain, so every kilogram counts.

Reaching industrial scale, meaning delivering quantities at a competitive cost depends strongly on the type of raw materials. In our case, we will be working with our industry partners to prototype parts and to trial components by end of this year. We will be working with a range of newly developed materials that will be fit for purpose. One of the benefits of the Fill Multilayer process is that it enables digitalization and the use of hybrid materials. This facilitates the optimization of part performance and cost with the ability to manufacture at a very fast rate (up to one part per minute). The next key challenge is to increase the volume of parts and the size of the components. This challenge will be met in the next 5-10 years.

I think the way to scale up faster is to incentivize more partnerships between research and industry globally. And also to recruit bright, enthusiastic PhD students who are able to focus their research on meeting industry needs and also have the freedom to think deeply and to pursue some of their ideas. This will provide industry with a pipeline of talent bringing fresh ideas to solve complex problems in multidisciplinary teams.

I have personally witnessed the benefits of global partnerships, and the unique outcomes that arise when we bring different cultures together. Teams with a diversity of backgrounds, culture and thought can find solutions that we didn't' realize were possible. Partnerships between industry engaged universities can promote business to business relationships between industry partners leading to the commercialization of new technologies.

Technology #10

AI AND QUANTUM FOR ACCELERATED MATERIALS DISCOVERY

WMF Objective: % of innovative materials

The timeframe for discovering, developing and commercializing new material inovations is often viewed as a 10 – 20 year process. Two areas that make up a large percentage of this time are 1) the manual process of designing experiments, creating new formulations, testing a variety of results and 2) going through the various material evaluations and testing regimes to meet regulations. Artificial intelligence and quantum computing are being developed to significantly reduce the time it takes to cycle through repetitive processes associated with new formulations and material evaluations. While some industries like aerospace and automotive will likely always have long qualification time periods AI and quantum computing are seen as major enablers of reducing design and qualification time for new materials to get deployed in less regulated applications. These technologies therefore can play a major role in addressing WMF's objective of increasing the percentage of innovative materials in final products.

LUC JULIA

CTO SAMSUNG ELECTRONICS, USA/ KOREA

AI for materials development can have a large impact especially as it relates to simulating material performance. Rather than running fatigue, life, reliability tests over and over AI is really good at predicting the results of repetitive work. This can go a long way in speeding up material certification.

There are a lot of AI algorithms right now that can predict material behavior. The bigger issues industry is facing are 1) is there enough data to feed the models, and 2) is the data unbiased. Companies need to do a better job of managing their data to make this technology more relevant on an industrial scale, but it's a business practice limitation not a technology limitation.

In addition to the quality and quantity of data and other hurdle is the energy intensity of the AI calculations. To put it in perspective in 2016 when the DeepMind computer beat the reigning Go champion the computer consumed 440 kW compared to a human brain which consumes 20 W. More efficient CPUs and GPUs will help reduce the energy consumption on the hardware side, but on the software side the key is reducing the amount of data that is needed to generate accurate models.

GREG MULHOLLAND

CEO OF CITRINE INFORMATICS, USA

AI for material discovery and optimization today is consistently demonstrating the ability to reduce the time from new product idea driven by materials innovation to a first market demonstration by 70% (Generally speaking from 5 years down to 2 years). In the next 10 years this number could grow to an 80-90% reduction in time. To achieve this level of impact the AI technology needs some additional development, but a bigger determinant is how well materials company invest in connecting their data systems and business norms to take advantage of the interrelationship between different data streams to create new products.

The other potential impact of AI on material discovery is that in the next 5 – 10 years model-based certification could become the standard approach for certifying new materials for many applications where regulatory and product safety risks are minimal, enabling the insertion of new sustainable materials in record time.

Today, there are well over 100 non-commodity materials companies that are exploring in the idea of AI for materials discovery and they are spending money in this area. In the next 5 years we expect over 50% of materials companies will be utilizing AI to enable smarter uses of materials.

One of the hurdles we face is public market quarterly earnings pressure that hampers the ability to make multi-quarter investments in longer-term technology platforms.

ALEXEI MARCHENKOV

CEO OF BLEXIMO, USA

At Bleximo we develop quantum processors that can be used to accelerate the computations associated with very specific applications. One of the 1st applications we target is computational chemistry in order to accelerate drug developement.

In drug development the 1st phase is « drug discovery » which includes identifying up to 5000-10000 different candidate compounds. Using traditional approaches, this phase can take 3 to 5 years. With quantum processors we believe that we can get this part of drug development to under 1 year. The use of quantum processors can also impact the number of compounds tested in the pre clinical phase by about 50% thus cutting significantly the cost of this phase and the quantities of subsequent clinical trials.

We anticipate that quantum proessors for drug discovery will be deployed by several drug developers by 2025.

The same logics of faster and more precise calculations and a better understanding of the materials 'composition and chemical properties could also be used for the discovery of other materials.

WORLD MATERIALS FORUM