



**Committed to Providing Members
with Technical Information, Membership
Services and Programs During
COVID-19 and Everyday!**

PCMI Journal
August 2020

Photo Chemical Machining Institute

VIRTUAL TECHNICAL CONFERENCE

October 19 - 21, 2020

Featuring live technical sessions, on-demand access to all recorded sessions, opportunities for group interaction and discussion, and a sponsor/trade show component.

ABSTRACTS

SCHEDULE

REGISTRATION

SPONSORSHIP

Programs in Development Include:

- Business Outlook | Global Electronics Industry
- COVID-19 Impact | Group Discussion
- Dry Film Resist
- New Member Services Showcase
- PCM Educational Session for Colleges and New Staff
- PCM Equipment Overview: Exposure | Lamination | Wet Process
- PCM Process Video
- PCM Surface Textures
- Wrap Up | Interactive General Session
- Zapp Precision Metals 2021 Tour Preview

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The PCMI Journal is the official publication of the Photo Chemical Machining Institute. Its purpose is to serve the needs of the PCMI members: to keep them up-to-date on activities of the PCMI, and to provide technical information about the industry. To make the PCMI Journal as valuable as possible, we ask that members contribute technical articles and newsworthy items, including new material on state-of-the-art photo chemical machining – equipment, techniques, etc.

We also accept articles that have appeared in other publications if they are relevant to our members. All material should be forwarded electronically in PDF format to:

cflaherty@pcmi.org

Advertising is accepted for both the PCMI Journals and the annual PCMI Membership Directory.

For information concerning ad deadlines, formats, sizes and rates contact the PCMI Office:

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Photo Chemical Machining Institute

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Photo Chemical Machining Institute's

INTERNATIONAL SPRING TECHNICAL CONFERENCE

May 8 - 12, 2021

Lindner Hotel City Plaza Hotel, Köln, Germany

**The Spring Conference will run from May 8 – 12, 2021.
The Conference will be held at the
Linder Hotel City Plaza in Köln, Germany.**

The Conference will feature two full days of technical sessions for the PCM industry, networking with colleagues from around the world and the opportunity to explore emerging PCM technologies.

Technical Sessions In Development

- ◆ Automation of Prefabrication of the Etching Process
- ◆ Beyond State-of-Art: A Case Study on the Industrial Production of Iron Nickel Ultra-Thin Foils for Etching Applications
- ◆ Direct Imaging – Versatile Automation – Data Format Management
- ◆ Etching the Strongest and Most Corrosion Resistant Steel Strip in the World
- ◆ High Resolution Direct Laser Processing for Surface Functionalization and Micro Drilling
- ◆ How Contact Angle Measurements Can Help To Optimize Photoresist Adhesion
- ◆ LDI Experience by Operators Point of View
- ◆ PCM Academic Educational Session for Colleges and Technical Universities
- ◆ Pulsed Academic Electrochemical Machining: A New Process Line for the Fabrication of Complex Microstructured Tools
- ◆ Strengthening the Weakest Links in the PCM Process Chain: #4. Factors Affecting Photoresist Adhesion

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Peter Jefferies

Dear PCMI Colleagues,

It's been a remarkable year thus far, truly one for the history books.

2020 has turned our way of life upside down. It has forced innovation and adaptability upon us, and the PCM industry was not exempt from this upheaval. At PCMI, things are no different. Beginning the year, we never thought we would have to move from having two in-person international conferences to a virtual one! While we cannot meet together in person, please know, the upcoming Virtual Conference will give you excellent value.

From October 19th - 21st, the PCMI Virtual Technical Conference will include information-packed technical sessions, networking opportunities to connect with colleagues, and sponsorship platforms as we have never seen! I am eager to see your reactions and feedback to this new endeavor, as I think it will be a great one.

In addition to rethinking PCMI's major programs, the Institute continues to evaluate how we can operate to serve our members best. I am sure each of you had to reinvent the way you run your businesses too. Know that my thoughts are with you during this challenging time.

I hope you and your loved ones continue to stay safe and well. I am looking forward to seeing you 'virtually' in a couple of months and hopefully face-to-face in 2021.

With my very best wishes,

A handwritten signature in black ink, appearing to read 'P. Jefferies', with a long horizontal flourish extending to the right.

Peter Jefferies
President, PCMI
Heatric, Division of Meggitt



PCMI Member Spotlight Advertising Opportunities

PCMI's website has a new look and layout that is better than ever! The most impressive update is PCMI's Member Spotlight, which now features tracking abilities, making this a prime and inexpensive advertising opportunity for members.

CMT Rickenbach SA
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Certificated to ISO 9001:2008, medical, aeronautical and locomotive specifications. We provide swiss quality precision products to consumer and high-end industrial applications, implementing photochemical machining, laser cutting, decorative and functional galvanic surface treatments, laser microwelding and precision engravings.

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PCM Products, Inc.

PCM Products etches all alloys of metals from .100" to .0001" thick and also parts as wide as 54" to hundreds of inches long.

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Benefits

The [Member Spotlight](#) is located on the website home page. Each package includes:

- Your logo or a product photo;
- A link to your website;
- A 230-word description; and a
- Premium service directory listing.

Cost

The average redirect clicks per ad totals 385. The current cost of a Spotlight advertisement can be as low as \$133.00 per month. That's an average cost of less than [\\$2.00 per click!](#)

- Platinum Package (12 months) for \$1,590.00
- Gold Package (6 months) for \$1,255.00

Order

[Click here](#) to order your Member Spotlight online.



Catherine Flaherty

Hello PCMI Members,

I hope you, your family and colleagues are all staying healthy as we continue to navigate this worldwide COVID-19 pandemic.

At PCMI, we have continued to work to provide you with benefits and services worthy of your investment in the Institute. The crisis has slowed us down a bit, but we keep moving.

Earlier in the year, we worked to finalize plans for the Spring Conference that was supposed to take place in Köln, Germany. When we realized that we could not safely conduct a conference with attendees from around the world, we quickly pivoted and started planning the Virtual Conference for this October.

While we cannot meet in person this fall, the [Virtual Conference](#) will provide live technical sessions, on-demand access to all recorded sessions, opportunities for group interaction and learning, and a sponsor/exhibitor program.

As we traversed through the ever-changing world dominated by the virus, we have managed to conduct and summarize both an [Industry Trends Survey](#) and a [Coronavirus Assistance and Business Trends Survey](#). We have also updated the [PCMI website](#) to allow for a cleaner look and more precise action items that better reflect current PCMI educational programs and membership benefits.

During these challenging months, PCMI also created a brand new and FREE membership benefit that we hope you will utilize. The New Product Spotlight showcases a member's product and capabilities. Each spotlight includes the product photo, description, and the company website link, which provides tracking abilities. These are added to the PCMI website and shared on the Institute's social media platforms. To have your product featured, [click here](#).

I am looking forward to finding new ways to make your PCMI membership valuable, and I hope you will plan to attend the Virtual Conference. The program is an excellent opportunity for you and your colleagues to receive top-quality technical training without traveling!

Best Regards,

A handwritten signature in black ink that reads "Catherine C. Flaherty". The signature is written in a cursive, flowing style.

Catherine Flaherty
PCMI Executive Director

Product Spotlight

PCMI New Members-Only Benefit

PCMI can help you share your company's work with the world!



The graphic features a red circle on the left with the text "PRODUCT SPOTLIGHT" and a white arrow pointing to the right. To the right is a photograph of various custom-machined metal parts. Above the photo is a red rectangular box with the text "Fotofab Custom Parts". Below the photo is a white text box containing a paragraph of text, and at the bottom is a red text link.

PRODUCT SPOTLIGHT

Fotofab Custom Parts

Fotofab custom parts and PCM go hand in hand. Complex parts are produced with the strictest of tolerances and configurations at higher volumes, faster rates, and affordable costs. Fotofab works with material thicknesses from .0001" to .125" (.0025mm to 3.175mm), depending on the features required.

[Visit Fotofab, LLC Website](#)



Several years ago, PCMI created a package of promotional materials to provide an overview of the PCM process. The package contained sample etched parts that represented a cross-section of the wide range of components that can be produced by PCM. Members shared the sample parts package with potential customers at trade shows and with academics to encourage students to enter the industry.



Now, PCMI has created a tool that can provide members with a new opportunity to digitally expand the knowledge of PCM capabilities.

PCMI's new Product Spotlight appears on the website and social media platforms to present member's sample parts and descriptions.



PCMI will create your exclusive showcase, upload it to the PCMI website, and then share it in a campaign on the Institute's social media platforms. This member benefit provides marketing on your behalf and increases the overall knowledge of PCM.

To participate, [click here](#) to submit a photo and description of one of your parts.

PCMI Elects New Directors

PCMI is pleased to announce that the membership has voted to accept the Nominating Committee's Slate for election to the Board Directors. The election was held electronically as the PCMI Annual Meeting was not held in person due to the worldwide COVID-19 pandemic.

The following members were elected to serve their first two-year term.

- Blake Parkinson, Watlow Electric Manufacturing,
- Neil Walker, Tecan Ltd (part of Muon)

The following members were elected to serve another two-year term.

- David Allen, Cranfield University
- Damian von Rickenbach, CMT Rickenbach SA

PCMI would like to acknowledge Board members whose terms continue. They include:

Officers

President

Peter Jefferies, Heatric, Division of Meggitt

Vice President

Eric Kemperman, Etchform

Secretary

Peter Engel, Newcut, Inc.

Treasurer

Mike Soble, Chemcut Corporation

Immediate Past President

Michael Lynch, United Western Enterprises, Inc.



Directors

- Philip Greiner, PEI
- Steffen Herz, Ätztechnik Herz GmbH & Co Kg
- Lawson Lightfoot, Lightfoot Consulting
- Mason Reichel, Orbel Corp.

SPECIAL THANKS



A special thanks is due to Harrie Knol from Veco B.V., for his many years of dedicated service. Harrie's term on the Board ended this year, but we are pleased to report that he will remain an active PCMI member.

H.G. (Harrie) Knol has over 35 years of experience in the Photochemical Industry. His area of expertise is Photo electro forming (PEF). He is an inventor/author of many patents in the field of electroforming.

Currently he holds the position of Principal Product Development Engineer at Veco in the Netherlands.

Harrie has been a PCMI member for more than 20 years. He joined the PCMI Board of Directors in 2010.

Thank you all for your time, efforts and expertise serving on PCMI's Board of Directors!

Meet the New PCMI Board Members



Blake Parkinson

Blake Parkinson has been involved with Photo Chemical Machining processes for the past five years. He has over a decade of experience in the semiconductor industry with a focus in Reactive Ion Etching and Advanced Process Control.

He recently received a Master of Business Administration from William Woods University. He has also received a Master of Science in Chemical Engineering from the University of Texas at Austin, a Bachelor of Science in Chemical Engineering from the University of Idaho, and an Associate of Applied Science in Chemical Engineering from Brigham Young University – Idaho.

Blake has been published in IEEE and in four conference proceedings. In his work with Watlow Electric Manufacturing, Blake leads an engineering team focused on using PCM processes to develop and prototype new products.

He lives with his wife of 19 years and their 4 daughters in Missouri. In his spare time, Blake enjoys watching college football, reading, serving in his church, and spending time with his family.



Neil Walker

Neil Walker has a 30 years proven track record within the manufacturing sectors across the world.

He is experienced within applications engineering, technical sales, marketing, the management of teams and businesses in the major industrial segments.

Neil joined Tecan Ltd in 2016 with responsibility for the groups centre of excellence for Photo Chemical Machining, SMT Stencils and Plating. His focus is on achieving high levels of customer satisfaction through the on-time delivery of profitable, precision and often co-developed products, to our diverse customer base.

Before joining Tecan and having exposure to PCM Neil operated as a Managing Director and Director of Sales serving blue chip customers in all major sectors throughout the UK, Ireland, Scandinavia, the Middle East and South Africa. Neil was educated at Technical College, has a strong bias in automotive and studied business management at the University of Warwick.

Outside of work he has a healthy appetite for sport, adventurous activities and serves as a senior officer in the British Army reserve forces. He is married to Niamh, has two children at University and owns a gun dog that allows exploration of the open countryside.

Welcome New Members

		
<p>Circuit Tech International Ltd. 12 Tamar Close Worthing, UK BN13 3JZ Phone: +44 7703 188144 www.ct-int.net Andrew Prince International Sales andy@ct-int.net</p>	<p>IPG Photonics 7313 Gray Gables Lane Wilmington, NC 28403 Phone: (408) 691-0299 www.ipgphotonics.com Dean Brennan Systems Sales Manager dbrennan@ipgphotonics.com</p>	<p>IRCA Spa Via Podgora, 26 Vittorio Veneto, IT 31029 Phone: +39 0438 4901 www.zoppasindustries.com Alberto Meroni Process Engineering Specialist alberto.meroni@zoppas.com</p>



Professor David Allen's Photochemical Machining and Photoelectroforming Book is Available for Purchase!

(ISBN 978-1-5262-0188-1)

This second PCM-focused book, written by Professor David Allen, incorporates all aspects of modern PCM technology and includes a chapter on photoelectroforming (PEF). This book also covers phototool production, automation, process control and environmental compliance issues relevant to today's industry. The 237-page book is printed in full color on glossy paper and perfectly soft-bounded in a laminated cover for durability. It is available for sale at \$110 (US dollars) which includes postage and packing. There are a limited number of books for sale through PCMI.



"Photochemical Machining and Photoelectroforming has taught our company more about etch chemistry interactions in 6 months than we have learned in almost 30 years of etching. Yields have increased and scrap costs have gone down. It has become a well-used reference and I highly recommend purchasing a copy."

Blake Parkinson, Staff Engineer | Watlow Electric Manufacturing

"Professor Allen's book is the definitive work on all aspects of photochemical machining and electroforming. I have been in the industry for over 35 years and frequently refer to this book for references and assistance with complex issues. His depth of knowledge and experience is essential to anybody working in the field."

Dr. Peter Jefferies | Heatric, Division of Meggitt





Are you interested in getting more involved in PCMI?

We encourage and welcome your participation on a PCMI Committee! You can serve on the Education, IT, Membership, Virtual or Spring Conference Committee(s).

PCMI committee members work to expand and improve the Institute’s conferences, educational programs, membership roster, and technology services. As a committee volunteer, you help the Institute, make sure your company interests are heard and have more opportunities to network with your colleagues.

You can [click here](#) to volunteer, or contact PCMI directly for more information. You may volunteer to serve yourself, or you can nominate someone else for committee service.

Current Committee Members

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 Bill Fox, Conard Corp.
 Phil Greiner, Photofabrication Engineering, Inc.
 Kirk Lauver, Chemcut Corporation
 Mike Soble, Chemcut Corporation

Education Committee

David Allen, Chair, Cranfield University
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 Bill Fox, Conard Corp.
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Germany Conference Committee - Spring 2021

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 Steffen Herz, Ätztechnik Herz GmbH & Co KG
 Paolo Iellici, Lasertech Srl
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 Eric Kemperman, Etchform BV
 Harrie Knol, Tecan Ltd (part of Muon)
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 Steffen Herz, Atztechnik Herz GmbH & Co KG
 Mike Soble, Chemcut Corporation
 Eric Kemperman, Etchform BV
 Lawson Lightfoot, Lightfoot Consulting
 Harrie Knol, Tecan Ltd (part of Muon)
 Neil Walker, Tecan Ltd (part of Muon)

Nominating Committee

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 Kirk Lauver, Chemcut Corporation
 Michael Lynch, United Western Enterprises, Inc.

Fall Conference Committee - Fall 2021

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 Matt Erlichman, Chemcut Corporation
 Phil Greiner, Photofabrication Engineering, Inc.
 Peter Jefferies, Heatric, Division of Meggitt
 Eric Kemperman, Etchform BV
 Michael Lynch, United Western Enterprises, Inc.
 Mike Soble, Chemcut Corporation

Virtual Conference Committee - Fall 2020

David Allen, Cranfield University
 Phil Greiner, Photofabrication Engineering, Inc.
 Peter Jefferies, Heatric, Division of Meggitt
 Eric Kemperman, Etchform BV
 Michael Lynch, United Western Enterprises, Inc.



Emeritus Professor David Allen started his career as a chemist (BSc, 1968) and moved into photochemistry research (PhD, 1972) while studying at Cardiff University. Following post-doctoral research at Warwick University and imaging technology development in industry, David joined Cranfield University in 1976. He was appointed a Technical Liaison Member to the Photo Chemical Machining Institute (PCMI) in 1981 and is currently on the Board of Directors of PCMI responsible for education. David became Professor of Microengineering at Cranfield University in 1998 and was elected as a Fellow of The International Academy for Production Engineering (CIRP) in 2006.

David has published:

- Two PCM books: “The Principles and Practice of Photochemical Machining and Photoetching” (1986) and “Photochemical Machining and Photoelectroforming” (2015, reprinted 2016, 2017 and 2019);
- Five book chapters on non-conventional machining and contributed the chapter on ‘Etching’ to the on-line CIRP Encyclopedia of Production Engineering;
- Seven confidential industrial PCM consortium reports;
- 200 journal and conference papers and was awarded the higher doctoral degree of DSc from Cranfield University in 2013 for his thesis entitled “Contributions to Photochemical Machining and Photoelectroforming”.

David retired from academia in 2011 and he now carries out consultancy and staff training in PCM companies across the world. He has worked with 21 different companies over the past 8 years.

Abstract

PCM involves many processes in its production process chain and each process has an associated environmental impact. To remain competitive with rival processes, PCM must minimise its overall environmental impact as the costs of environmental compliance are currently increasing at a rapid rate.

This paper reviews the environmental impact of each process in the PCM process chain and suggests how it can be minimised utilising clean technologies (employing radical revision and/or innovative modification), waste minimisation through improved quality control, recycling and 'end of pipe' treatments to meet emission requirements.

The costs of environmental impact reduction are also discussed together with the various financial benefits accrued.

Introduction

The environment has always been important to mankind. Remember, the ancient Greeks believed in four classical elements: Fire, Air, Water and Earth. They were, quite correctly, thought to be of vital importance to human life. The modern equivalents are:

- Energy (for cooking, heating and cooling)
- Atmosphere (the need to breathe clean air)
- Water (for drinking, natural vegetation and crop irrigation)
- Land (the source of all food).

All the above must be protected from pollution and conserved for mankind to thrive in the future. However, there is growing public concern that the planet has become polluted by a population that is increasing continually and that the damage caused to the environment will have a permanent, detrimental effect on us, our descendants and the natural world in which we live on planet Earth.

TV images of

- Oceans, rivers and lakes polluted with waste matter
- Marine life entangled in plastics and stomachs of dead marine life filled with plastics
- Plastics waste from developed nations dumped in undeveloped countries

- Disappearing ice in the Polar regions and rising sea-levels due to global warming,
- Greta Thunberg (teenage climate activist) at the recent UN Climate Change Summit

and reports of

- Plastics microparticles in Antarctica snow and teas made from premium teabags
- Photochemical smog and atmospheric pollution in cities killing young children through asthma attacks
- Destruction of the ozone layer by chlorinated fluorocarbons (CFCs) increasing skin cancer risks

show that environmental impact needs to be minimised by making it mandatory to control waste discharges from industry in compliance with environmental legislation. It must be noted that the PCM industry has transgressed the law in the past and quite recently a PCM plant in France has been closed for environmental violations.

What is meant by Environmental Impact?

The following definitions have been extracted from ISO 14001 (2015): Environmental Management Systems — Requirements with guidance for use.

Environment: surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans and their interrelationships. Note that “surroundings” can extend from within an organization to the local, regional and global system and can be described in terms of biodiversity, ecosystems, climate or other characteristics.

Environmental impact: change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's environmental aspects.

Environmental aspect: element of an organization's activities or products or services that interacts or can interact with the environment.

It must also be recognised that the environment crosses man-made local, state and national boundaries.

Environmental management and environmental legislation

One of the challenges to environmental management and legislation is that protection of the environment differs from country-to-country and state-to-state so that it has become an uneven playing field across the world. As national environmental management standards vary, it is not surprising that environmental legislation is variable across the world.

The solution to the challenges lies in international Environmental Management Systems (EMS) standards that have been developed, such as ISO 14001. This could be regarded as the quality standard for manufactured by-products in contrast to its companion ISO 9001, Quality Management Systems standards for products and services. The act of manufacturing a product always produces (usually unwanted) by-products according to the Law of Conservation of Matter that states “matter cannot be created nor destroyed” (Figure 1).

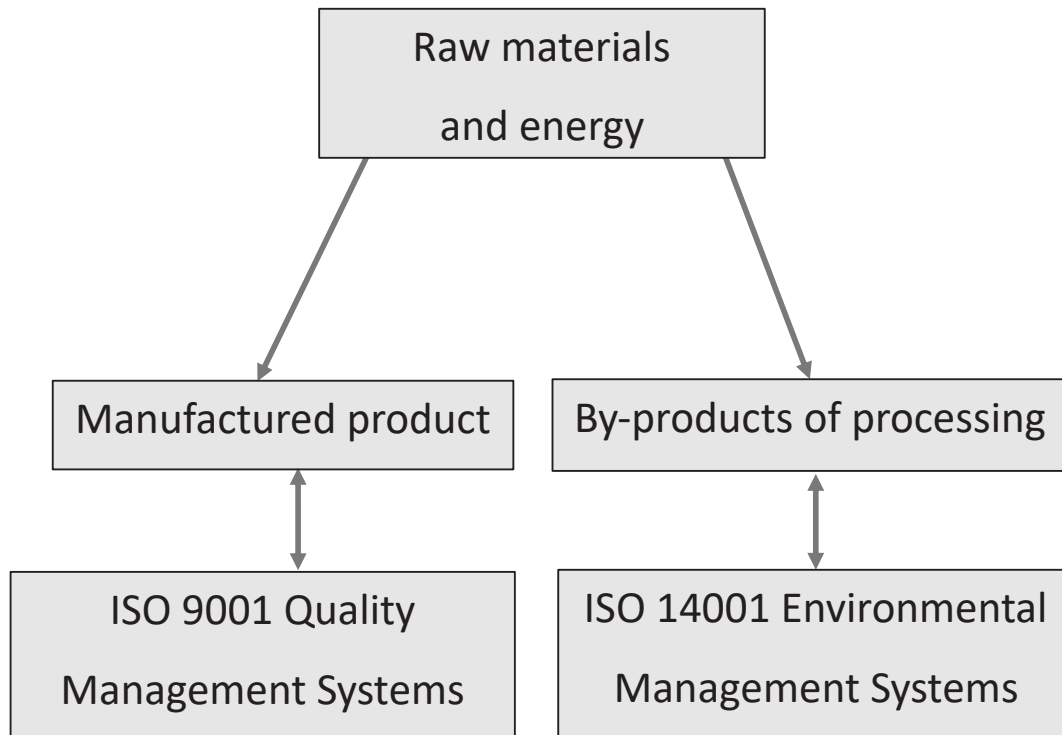


Figure 1. Relationship between ISO 9001 and ISO 14001.

Environmental impact of PCM

This subject was rarely discussed until the 1980s when PCMI Conferences were made aware of the increasing importance of the topic by Dan Goffredo (Chemcut and GOCO) and others who had detected increasing legislation, applicable to PCM, designed to protect the environment after a number of distressing environmental pollution catastrophes. At that time, the US Congress was concerned with the presence of toxic chemicals in groundwater. Dan Goffredo noted: “A 10-acre toxic waste site in Hamilton, Ohio will be cleaned up by 158 companies. The groundwater cleanup will take 10 years and cost \$10 million. The companies must also pay penalties of \$7 million” [1].

Allen [2] suggested the following five strategies to reduce environmental impact of PCM:

- Clean technology employing radical revision and/or innovative modifications
- Waste minimisation including better quality control of the process
- Recycling and re-use
- Waste exchange and
- “End of pipe” treatments to meet waste emission compliance to legislative environmental requirements.

The costs of non-compliance with environmental legislation include:

- Fines – “the polluter pays” principle
- Supply chain disruption
- Adverse publicity affecting staff retention and recruitment
- Increased insurance premiums to continue in business
- Attention of green pressure groups and activists plus
- **House arrests and custodial sentences for directors and employees.**

In consideration of the traditional PCM process outlined in Figure 2, it can be seen that many processes are involved in a chain to produce parts. Each process has an environmental impact and will need this impact to be defined before it can be eliminated or minimised.

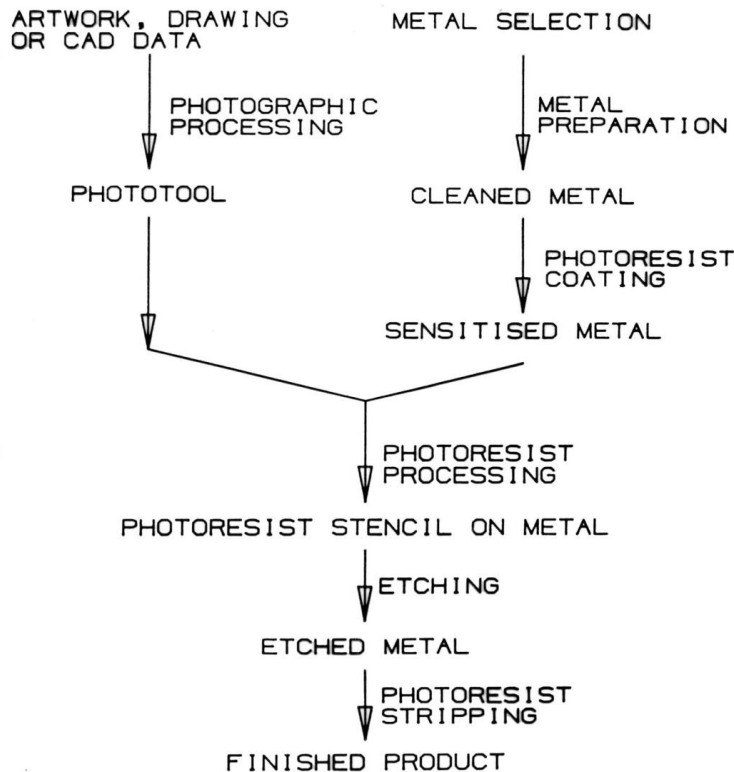


Figure 2. Schematic of the traditional PCM process chain.

Environmental considerations of individual processes in the PCM process chain

Phototool production

The environmental impact of phototool production is shown in Table 1. It is substantial and may be eliminated totally by the innovative, greener process of laser direct imaging (LDI) that avoids the production of a phototool altogether.

Table 1. Traditional phototool production showing individual process steps, waste products produced and resultant environmental impact

Process	Waste	Environmental Impact
Delivery of films and processing chemicals	Gaseous emissions	Atmospheric pollution
Packaging	Cardboard, plastic	General waste
Film exposure	Light source disposal	Electricity consumption
Development	Spent developer	Chemical waste water
Rinsing	Chemically-contaminated water	Chemical waste water Water consumption
Fixing	Spent and excess fixer	Chemical waste water
Rinsing	Chemically-contaminated water	Chemical waste water Water consumption
Drying	Heat	Energy consumption
Silver reclamation from used fixer	Recovery of valuable silver waste metal by electrolysis	Electricity consumption
Quality control	Phototool rejects	Polymer and mixed waste

Metal preparation and cleaning

The environmental impact of metal preparation and cleaning is shown in Table 2. It is significant and may be substantially reduced by replacing VOC (Volatile Organic Compound) solvent cleaning with aqueous solution cleaning and by eliminating the optional processes of conversion coating and microetching.

Liquid photoresist coating: dip-, spin-, whirler-, roller- and electrophoretic-coating

The environmental impact of liquid photoresist coating is shown in Table 3.

Table 2. Metal preparation and cleaning showing individual process steps, waste products produced and resultant environmental impact

Process	Waste	Environmental impact
Metal conversion	Metal off-cuts	Waste scrap metal can be recycled
Organic solvent cleaning	Dissolved oils and greases in solvents (VOCs)	Atmospheric pollution. Potential groundwater pollution via leakages
Alkaline aqueous solutions	Saponified oils and greases in alkaline solution requiring neutralisation	Chemical waste waters. Can also reduce waste acid disposal through waste exchange neutralisation
Acidic aqueous cleaners	Dilute metal-containing solutions	Chemical waste waters needing neutralisation (see above)
Conversion coatings (optional)	Acids and heavy metals in aqueous solution	Potential land and groundwater contamination
Microetching (optional)	Acids/alkalis and heavy metals in aqueous solution	Potential land and groundwater contamination

Table 3. Liquid photoresist coating showing individual process steps, waste products produced and resultant environmental impact

Process	Waste	Environmental Impact
Negative-working solvent/aqueous-soluble photoresist	Solvent emissions	Atmospheric pollution from solvent releases
Positive-working solvent/aqueous-soluble photoresist	Solvent emissions	Atmospheric pollution from solvent releases
Defective production	Coated metal sheet	Strip and recycle metal rather than scrap metal

Dry film photoresist (DFR) coating and development

The environmental impacts of dry film photoresist coating and development are shown in Tables 4 and 5. Note that the evolution of DFRs from solvent developable to totally-aqueous developable was forced essentially by increasing environmental regulation and legislation. Good DFR development practice necessitates replacement of developer based on throughput (resist loading) by monitoring the development of DFRs through continuous on-line measurement of pH change (see Figure 3) and not on time elapsed since the previous change (leading to developer wastage).

Table 4. Dry film photoresist coating showing individual process steps, waste products produced and resultant environmental impact

Process	Waste	Environmental impact
Removal of polyethylene protection sheet	Polyethylene	General waste.
Hot lamination	Chemical vapours	Atmospheric pollution
Hot lamination	Heat	Electricity consumption
Defective production	Coated metal sheet	Strip and recycle metal rather than scrap metal

Table 5. Dry film photoresist development showing individual process steps, waste products produced and resultant environmental impact

Type of DFR	Waste	Environmental impact
Organic solvent-developable resist	Contaminated organic solvents (VOCs). Polymer PET cover sheet.	Atmospheric pollution. Solvent chemical and general waste
Semi-aqueous developable resist	Contaminated organic and aqueous waste liquids. Polymer PET cover sheet.	Atmospheric pollution. Solvent/aqueous chemical and general waste
Totally-aqueous developable resist	Contaminated aqueous waste liquids. Polymer PET cover sheet.	Aqueous chemical and general waste

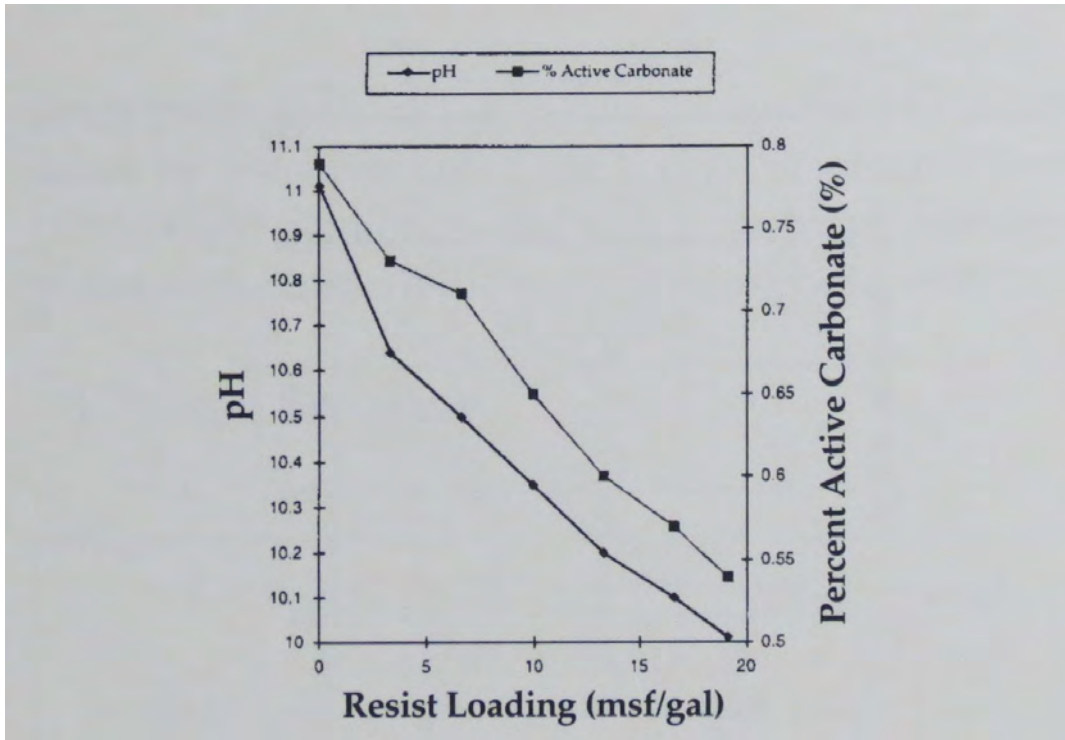


Figure 3. DFR development control through monitoring pH. [3]

Elimination of both phototool and photoresist through Ink Jet Printing (IJP) is an example of an innovative process that eliminates the environmental impacts of phototool production, photoresist coating and photoresist development. Table 6 compares the financial benefits accrued when using LDI or IJP.

Table 6. Waste reduction through new innovative technologies.

Innovative technology	Waste reduction	Financial benefits
Laser Direct Imaging (LDI)	No phototool production	No costs for film or film processing. Reduced waste disposal costs
Ink Jet Printing (IJP)	No phototool production No photoresist wastes. (Ink is only applied to the metal where required)	As above. Elimination of photoresist waste disposal costs

Waste etchant, recycling and disposal

The PCM process usually involves etching with ferric chloride solution due to its versatility and ability to be recycled according to the equation:



The environmental impacts are shown in Table 7.

Environmental auditing of PCMI member companies, identified only as A-T to preserve anonymity, using and not using etchant regeneration gives the required data to demonstrate that the environmental impact of PCM can be greatly reduced by etchant recycling (Figure 4). The results are shown in comparison to the number of theoretical (1-4) regeneration cycles [4]. The benefits of reduction in purchases of ferric chloride produce a significant cost saving.

The next significant advance in recycling waste etchant to be considered in the future is the extraction of valuable dissolved metals (such as nickel in the form of nickel chloride) from waste ferric chloride etchant [5], i.e.

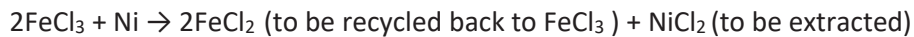


Table 7. Environmental impacts of ferric chloride etching and etchant regeneration

Process	Waste	Environmental Impact
Etching with ferric chloride solution	Mixture of ferric and ferrous chlorides plus dissolved metals from part production	Disposal in landfill (as solids after treatment or as untreated liquid).
Regeneration of ferric chloride from ferrous chloride	Excess ferric chloride containing dissolved metals from part production.	Extends lifetime of etchant, with a financial benefit, but must be disposed in landfill as solid or liquid eventually.
Etching less-corrosion-resistant metals with partially spent ferric chloride	Mixture of ferric and ferrous chlorides plus dissolved metals from part production	Disposal in landfill (as solids after treatment or as untreated liquid).

Waste exchange

This technique can be beneficial when waste products can be used for a useful function that reduces cost. Typically, in PCM, waste acids can be used to neutralise waste alkalis with no purchase of commercial acids or alkalis required for the task.

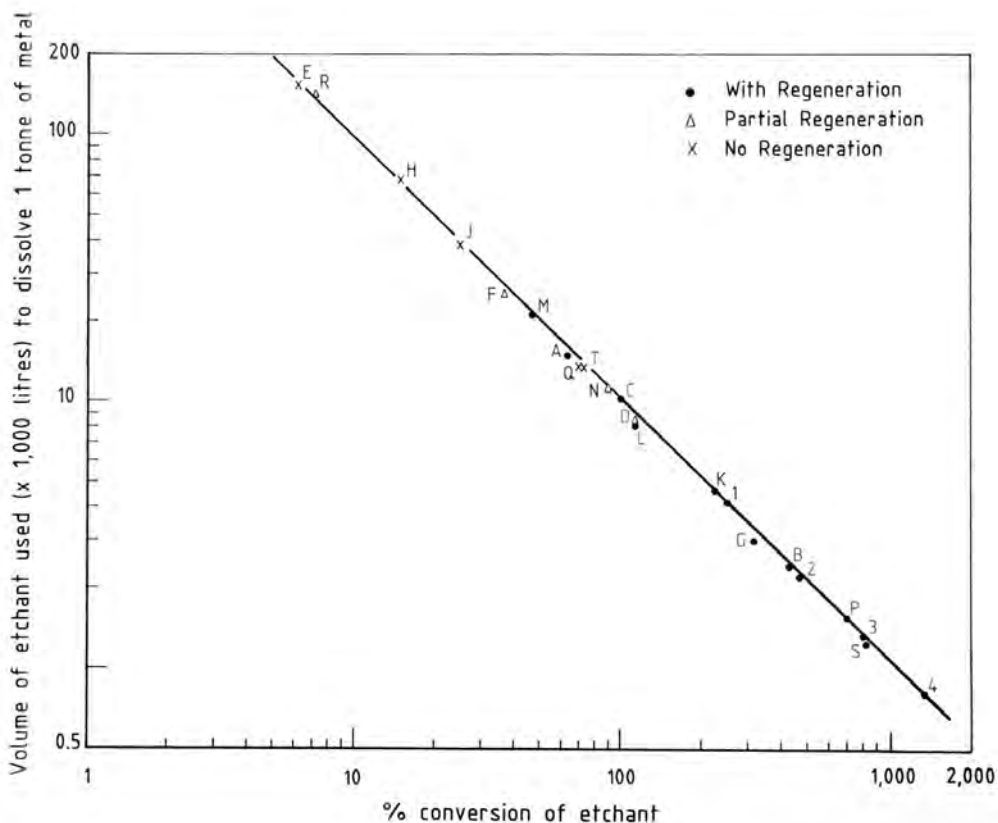


Figure 4. Illustration of the benefits of etchant regeneration on etchant consumption. [4]

'End of pipe' treatments

Aqueous solutions containing heavy metals, such as ferric chloride waste etchants or process rinse waters, can seep into the ground from landfill sites and contaminate groundwater. Precipitation of metals from these solutions to form insoluble oxides or sulphides is a viable alternative option. The solids can be separated from solution by using a filter press and the resultant filter cake can then be landfilled without the risk of heavy metals leaching into groundwater.

The regulated disposal of ferric chloride waste etchants has become expensive from country-to-country and from state-to-state (as shown in Table 8) especially where land is at a premium, environmental regulation is strictly controlled and any contravention of legislation is punitive. It can be seen from the survey that, in many countries and states, the cost of disposal exceeds the cost of purchase!

Table 8. World survey of costs of disposal of waste ferric chloride compared to its purchase price on 4th March 2013. Data provided by PCMI member companies. [6a]

Country	% of disposal cost compared to purchase price
Italy	104.0
Germany	66.7
Denmark	81.5
Sweden	106.4
Switzerland	53.8
UK	24.9
South-West USA	66.4
North-West USA	146.8
North-East USA	13.4
Average	73.8

Aqueous DFR stripping

While the production of waste photoresist from the stripping process is inevitable, a reduction in the environmental impact of stripping can be achieved by optimising photoresist stripper consumption (see Table 9). As in the case of photoresist developer replacement, photoresist stripper replenishment should be based on photoresist throughput and not on time elapsed since the last change.

Waste minimisation

In general terms, financially-beneficial methods of minimising waste are shown in Table 10. The role of good quality control in identifying and rectifying faulty processes, leading to defective parts, is important and relates back to Quality Management Systems helping to improve environmental management performance.

Table 9. Environmental impacts of DFR stripping.

Process	Waste	Environmental Impact
Photoresist removed in alkaline aqueous solution	Spent liquid stripper can be neutralised by waste acid solutions	Resultant solids require landfill.
Photoresist removed as solid flakes in alkaline aqueous solution	Solid waste can be separated from the spent liquid stripper. The spent stripper can be treated as above.	Requires landfill
Quality control	Optimise stripper consumption (dependent on its formulation)	Reduced waste

Table 10. Waste minimisation techniques and benefits.

Process	Minimisation technique	Benefits
Photoresist development	Optimisation of chemical consumption via pH control	Financial benefit via reduced purchases of chemical developer. Fewer reject parts.
Etching with ferric chloride	Regeneration and conversion of dissolved iron to fresh etchant	Financial benefit as purchase costs reduced and disposal costs reduced
Photoresist stripping	Optimisation of chemical consumption	Financial benefit via reduced purchases of chemical stripper. Fewer reject parts.
Quality Control	Identification and rectification of faulty processes leading to defective parts	Financial benefits from increased product yield

Rinse water minimisation

PCM can utilise considerable volumes of rinse water. Table 11 shows various techniques that should be used to reduce water consumption and its cost.

Table 11. Rinse water minimisation techniques

Process	Minimisation technique	Benefits
Rinsing	Cascade rinsing technology (see Figure 5)	Financial benefit as water used several times before disposal.
Rinsing	Activation by sensing: use of water only when required by sensing incoming parts requiring rinsing	Financial benefit as water consumption reduced when supply is not permanently turned on.

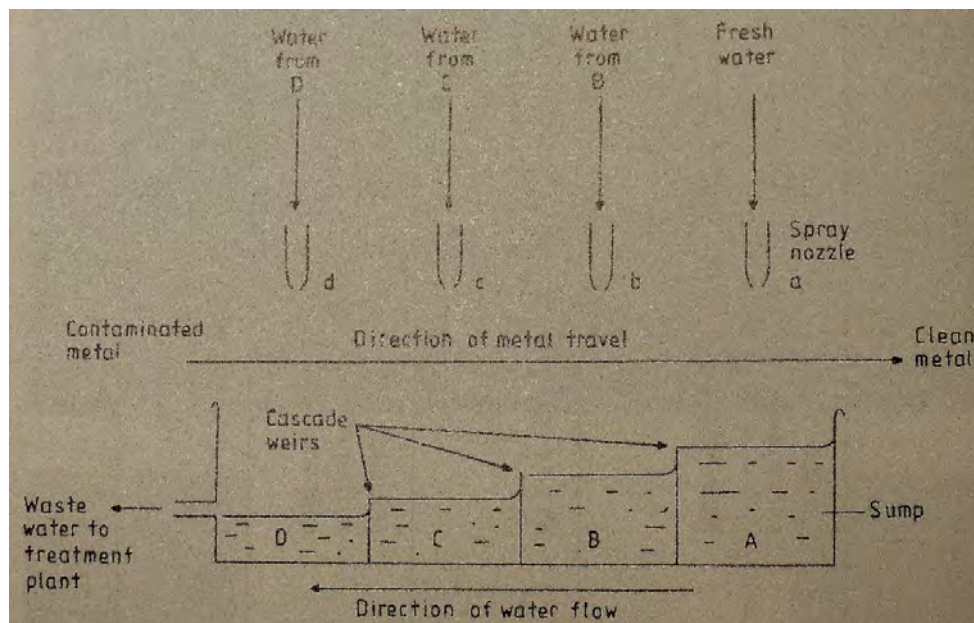


Figure 5. Schematic of cascade rinsing technology. [6b]

Preventative maintenance

Reducing environmental impact implies total control of all PCM processes. The following points are vitally important:

1. Do not let the equipment degrade to the point where it is not fit for purpose! I have seen in PCM companies across the world, laminators, developing lines, etching lines and stripping lines all with defective parts that are decreasing process yield. It is

imperative that these underlying problems are solved rather than applying a short-term “bandage” to mask or hide the problem.

2. Prevent liquid spillages by bunding equipment. Be especially wary of sodium chlorate (etchant regenerator) solution spillages presenting a fire hazard.

General waste

Quantitative monitoring is essential. Waste generation can be monitored by gathering quantitative information such as:

- Number of skip collections per month
- Water consumption per week
- Paper consumption per year
- Electricity consumption per month
- Gas consumption per month and
- Scrap metal and chemistry reductions

Costs of environmental compliance

Figure 6 shows the increasing cost of landfill disposal in the UK. It is, without doubt, a situation where costs will always increase with time due to a shortage of suitable landfill sites. All wastes must therefore be reduced, where possible, to control the cost of the PCM process.

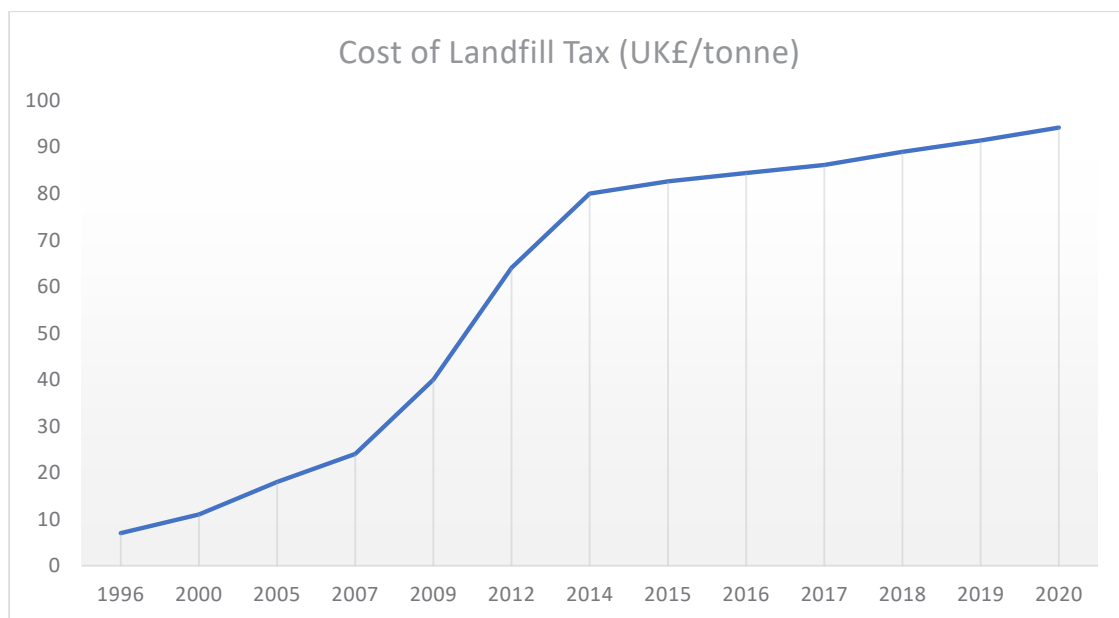


Figure 6. Costs of landfill disposal in the UK from 1996 to 2020.

Summary

- The new, innovative technologies of LDI and IJP will shorten the PCM process chain and thereby reduce the environmental impact of the traditional PCM process that uses a phototool.
- The target of reducing environmental impact should be regarded as increasing PCM process efficiency through improved quality control and not as an additional financial cost burden. It is therefore beneficial for PCM companies to link their Quality Management Systems to their Environmental Management Systems rather than isolating them as separate systems.
- PCM companies need to produce a higher overall yield of products with a lower consumption of process chemistry, materials, rinse water and energy. This approach to part production will produce significant cost savings by reducing water and energy consumption and reducing waste disposal costs.

References

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3. DR McGregor, Aqueous resist development considerations for fine feature resist image formation, PCMI Journal, 71, 9-13, 1998.
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6. DM Allen, *Photochemical Machining and Photoelectroforming*, ISBN 978-1-5262-0188-1, (a) 66, (b) 27, 3rd reprint 2019.

Online Training

The A-Z of Photochemical Machining

Presented by David Allen, Emeritus Professor, Cranfield University



Short Course Webinar

PCMI Online Employee Training Webinar

PCMI is pleased to present an employee development webinar that will give PCM companies the educational tools needed to provide new workers with the knowledge necessary to perform effectively.

Module # 1

- ✓ Introduction to PCM products and the principles of PCM and part design
- ✓ Photoresist types and suppliers
- ✓ The role of photoresists and etch factors in successful chemical etching

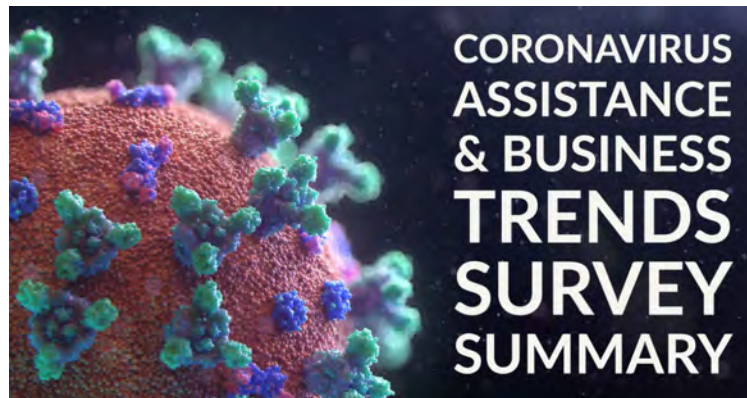
Module # 2

- ✓ Metals and their etchants
- ✓ The importance of maintaining constant etchant composition and the role of etchant regeneration
- ✓ Health, safety and environmental aspects of PCM and associated legislation

Module # 3

- ✓ Inspection, defects and quality control
- ✓ Rival and complementary processes - the economics of PCM in comparison to other manufacturing techniques
- ✓ The strengths of, and opportunities for, PCM as a production process





There are many ways that PCMI member companies have met the challenges of the COVID-19 pandemic. Some stepped up to produce equipment needed by healthcare professionals, and others provided support to their local communities. To learn what steps PCMI members took to address the crisis and how it has impact their business, PCMI conducted a Coronavirus Assistance and Business Trends Survey. The results follow.

Q1 Please tell us how your company is assisting during the coronavirus pandemic. You can provide a short summary, video or photo.

Answered: 11 Skipped: 9

Manufacturing parts used in ventilators and test kits.
Microphoto LLC

We've launched a whole campaign which includes lab services, remote instrument demos, webinars, etc. to stay connected to and support our customers during this difficult time.

Anonymous

We supply our products (equipment) either to PCB company that are working on the medical industry and university in the medical research i.s. Johns Hopkins University

Automatic Lamination Technology

1. Provide separate rooms for workers from Hubei province.
2. Monitoring workers' healthy state.
3. Provide free face mask to workers.

Shenzhen Zhuolida Electronics Co., Ltd.

PEI provides many critical components that support Medical applications. We have implemented necessary safety protocols internally to hinder any spread within our organization in order to allow us to seamlessly continue to support our customers. Priority was given to medical & military customers before all other business.

Photofabrication Engineering Inc. - PEI

During the COVID-19 pandemic, Veco B.V., together with our sister company Tecan Ltd., has been critical to the supply chain of the medical industry. In the only closed system nebulizer available in treating ICU ventilated patients, Veco's nebulizer nozzle plate releases millions of micron-sized droplets per second for targeted drug delivery to the lung with no necessity to open the circuit.

This not only helps patients avoid unnecessary pain, but also protect caregivers from exposure of viral contamination by the Covid-19 patient. Besides nebulizer plates for effective lung treatment, Veco and Tecan also supply various crucial medical parts enabled by our high precision technologies Electroforming as well as Chemical Etching. Examples include oxygen flow parts, medical sieves/plates, saw blades, vascular stiffeners, implants, stents, etc.

Veco B.V.

Continuing operations is as normal a fashion as possible. We are deemed a life sustaining organization and as such are permitted to remain in operation, but with reduced staff and working hour adjustments to maintain social distancing.

Anonymous

We are producing our own hydroalcoholic gel and provide it to any people who may need some. We gave lenses, gloves that were available in our stock. One employee is manufacturing at home face protection (transparent shield).

Mecachimique

Lasertech Chemical Machining Group is supporting with a special 24 hours delivery time customers involved in production of Respiratory Apparatus needed to treat COVID affected peoples, we supply till today over 150.000 pieces within Europe.

Lasertech Chemical Machining Group

United Western has been asked to increase its production of parts that go into ventilators, units that are used to calibrate ventilators and other medical devices used for diagnoses.

United Western Enterprises

Since March 2020 CONARD has been producing a number of components for ventilators that are being assembled by General Motors at the rate of 10,000 units per month for the US Government's strategic stockpile. GM wanted to contribute to the virus emergency and the shortage of ventilators with its manufacturing prowess. GM approached CONARD's long term customer that while having limited capacity, had one of the best ventilator designs.

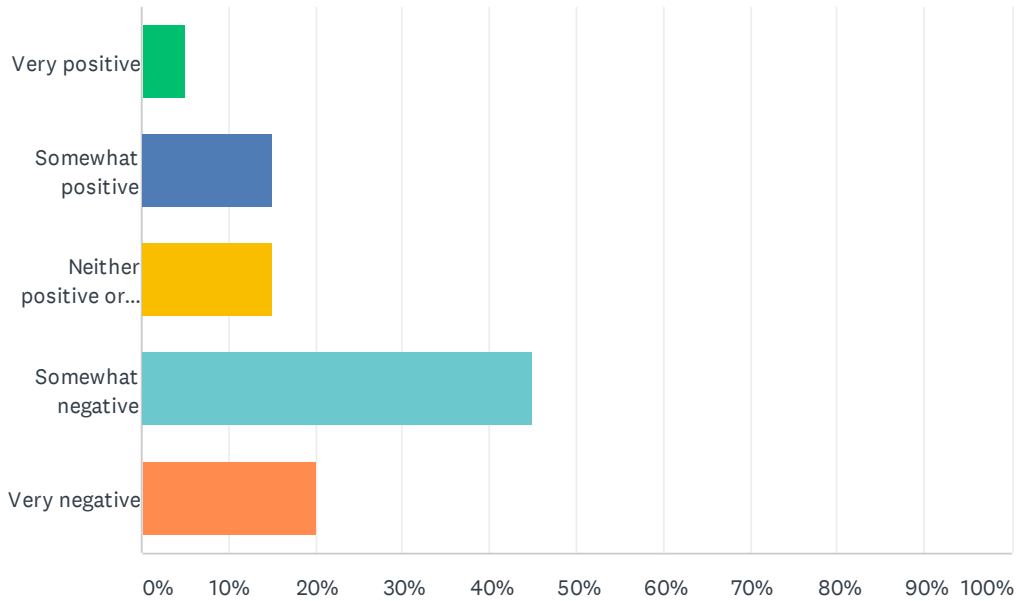
They shared their product design, engineering and supplier base and GM put its heft into a rapid ramp up of production.

The April 26th edition of "60 Minutes" CBS' news magazine featured GM's ventilator assembly operation that included some of the components made by CONARD. For CONARD this was the proverbial silver lining in the cloud that offset some other customer orders that were scaled back

Conard Corp.

Q2 Has the coronavirus pandemic had a positive or negative impact on your overall business operations?

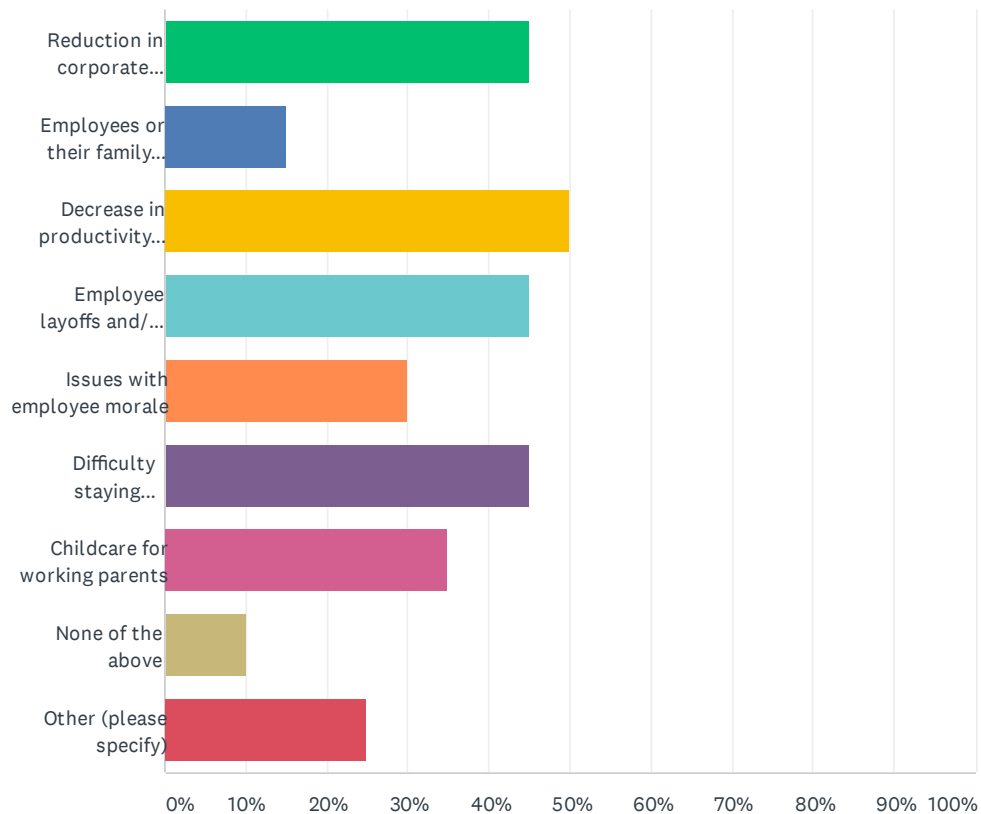
Answered: 20 Skipped: 0



ANSWER CHOICES	RESPONSES	
Very positive	5.00%	1
Somewhat positive	15.00%	3
Neither positive or negative	15.00%	3
Somewhat negative	45.00%	9
Very negative	20.00%	4
TOTAL		20

Q3 What challenges has your company experienced as the result of coronavirus? Select all that apply.

Answered: 20 Skipped: 0



ANSWER CHOICES	RESPONSES	
Reduction in corporate spending	45.00%	9
Employees or their family members being diagnosed with coronavirus	15.00%	3
Decrease in productivity due to remote work	50.00%	10
Employee layoffs and/or furloughs	45.00%	9
Issues with employee morale	30.00%	6
Difficulty staying connected with your customers	45.00%	9
Childcare for working parents	35.00%	7
None of the above	10.00%	2
Other (please specify)	25.00%	5
Total Respondents: 20		

#	OTHER (PLEASE SPECIFY)	DATE
1	reduced inquiries from many markets	5/18/2020 4:40 AM
2	Significant drop in customer demand	5/18/2020 3:20 AM
3	Absence rate increase	5/18/2020 2:42 AM
4	Drastic decrease of aeronautic business	5/4/2020 12:03 PM
5	collecting accounts receivable; fall off of customer orders	5/1/2020 4:28 PM

Q4 How can PCMI be a better partner to your company during the coronavirus pandemic?

Answered: 9 Skipped: 11

#	RESPONSES	DATE
1	PCMI might have to become completely digital for the coming years.How can we keep the networking on a high level without being able to meet in person.	5/27/2020 7:27 AM
2	Be well!!	5/20/2020 11:13 AM
3	schedule periodically some webinar with all members could be an opportunity	5/16/2020 10:36 AM
4	The conronavirus situation in China now is under control, we have many customers from all over the world, most in US, we hope this world would come out of this andemic soon, and if there is any news about the situation all over the world we would like to know.	5/15/2020 10:55 PM
5	No actions required...thank you :-)	5/15/2020 1:05 PM
6	(more) informative newsletters	5/5/2020 4:21 AM
7	No idea. It is so uncommun...	5/4/2020 12:05 PM
8	Just doing what you are doing and take care yourself!	5/4/2020 4:23 AM
9	more communication about best practices identify new benefits pcmi can provide members	5/1/2020 4:29 PM

2020 INDUSTRY TRENDS SURVEY RESULTS

PCMI conducted a new updated and streamlined Industry Trends Survey earlier this year. The summary data is outlined in the following pages. The goal of this survey is to ensure that PCMI continues to meet the industry's need for up-to-date market data.

Survey responses have been kept strictly confidential. Data from this research is reported only in the aggregate.

Many thanks to all members that took the time to complete the survey. Thanks are also due to the Industry Trends Task Force, including:

Phil Greiner | Photofabrication Engineering, Inc.

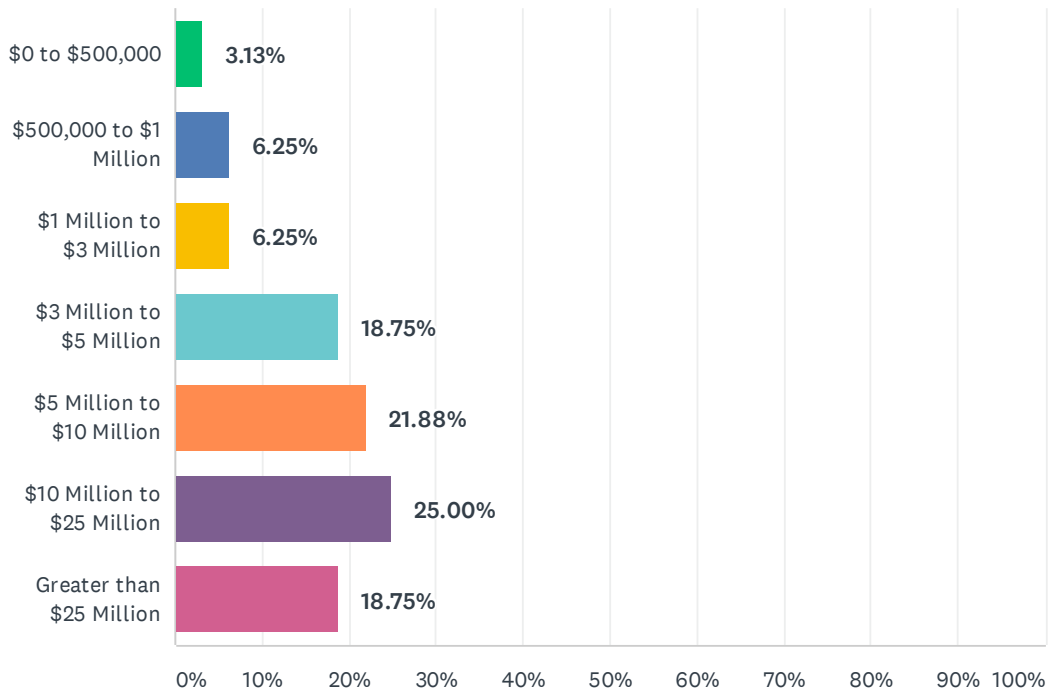
Peter Jefferies | Heatric, Division of Meggitt

Eric Kemperman | Etchform BV

Ian McMurray | Precision Micro

Q1 What is the approximate annual value of sales of photo chemically machined components produced by your company? (Including directly related allied services sold with the photo machined parts.)

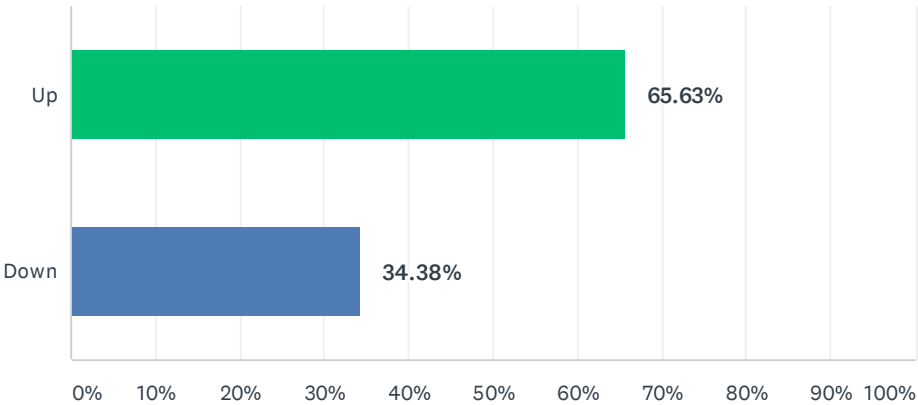
Answered: 32 Skipped: 0



ANSWER CHOICES	RESPONSES	
\$0 to \$500,000	3.13%	1
\$500,000 to \$1 Million	6.25%	2
\$1 Million to \$3 Million	6.25%	2
\$3 Million to \$5 Million	18.75%	6
\$5 Million to \$10 Million	21.88%	7
\$10 Million to \$25 Million	25.00%	8
Greater than \$25 Million	18.75%	6
TOTAL		32

Q2 During the past 12 months, my company's photo chemically machined business been:

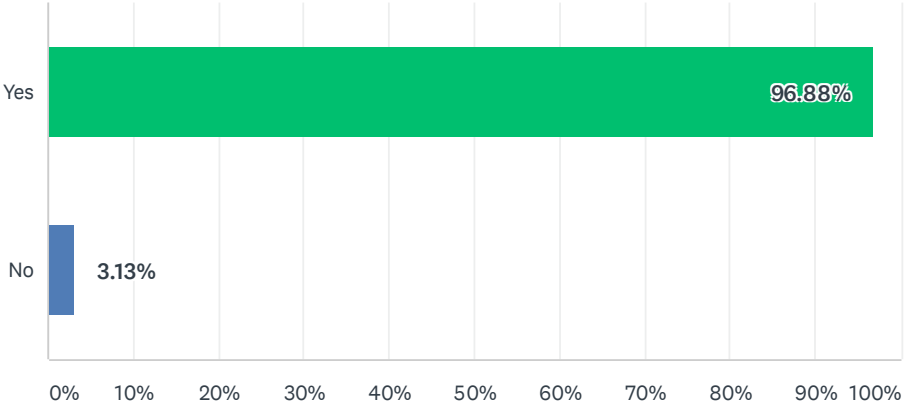
Answered: 32 Skipped: 0



ANSWER CHOICES	RESPONSES	
Up	65.63%	21
Down	34.38%	11
TOTAL		32

Q3 In the next 12 months, are you planning to make a new investment in your company?

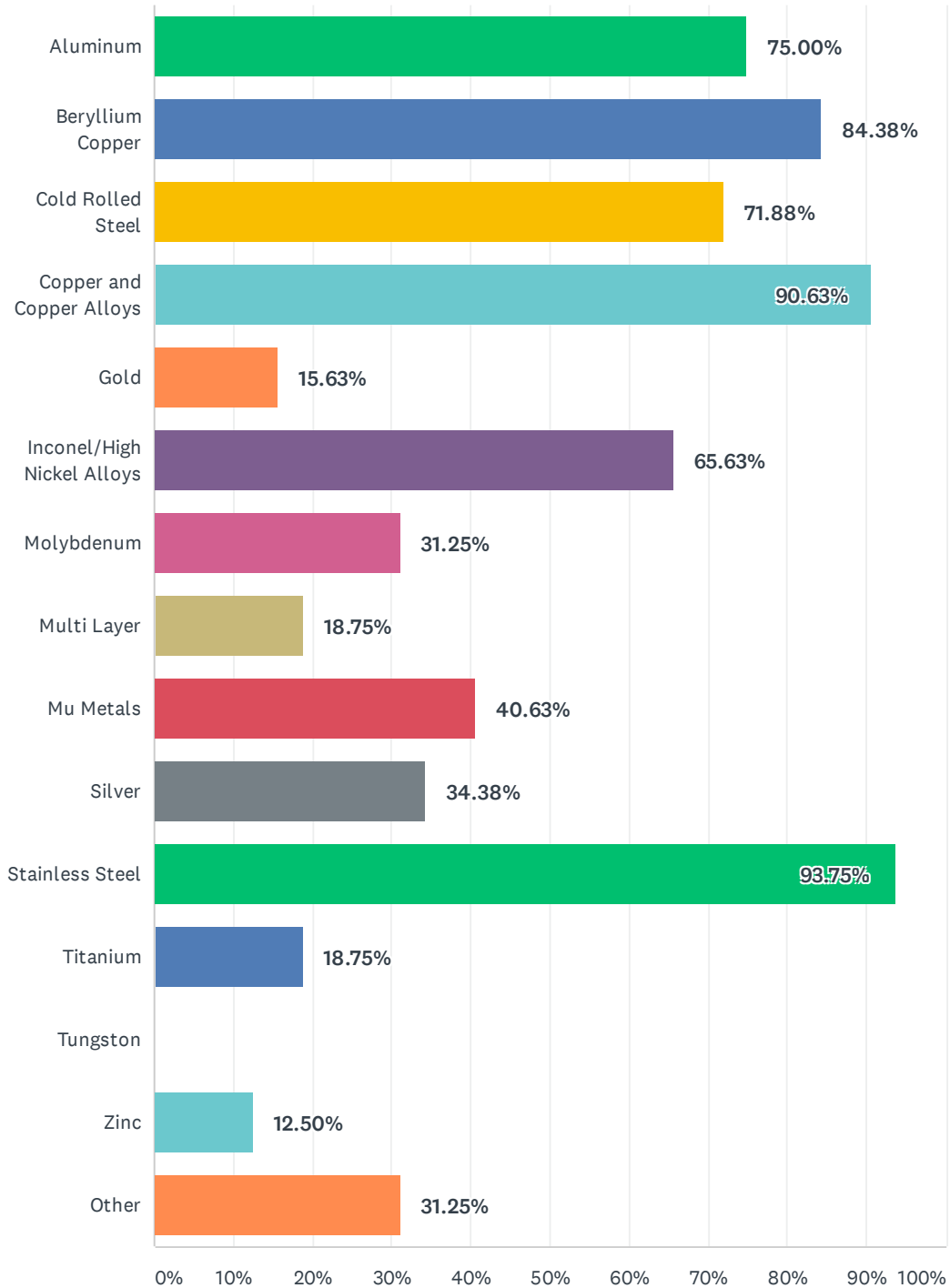
Answered: 32 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	96.88%	31
No	3.13%	1
TOTAL		32

Q4 What metals did your company use in the previous 12 months?

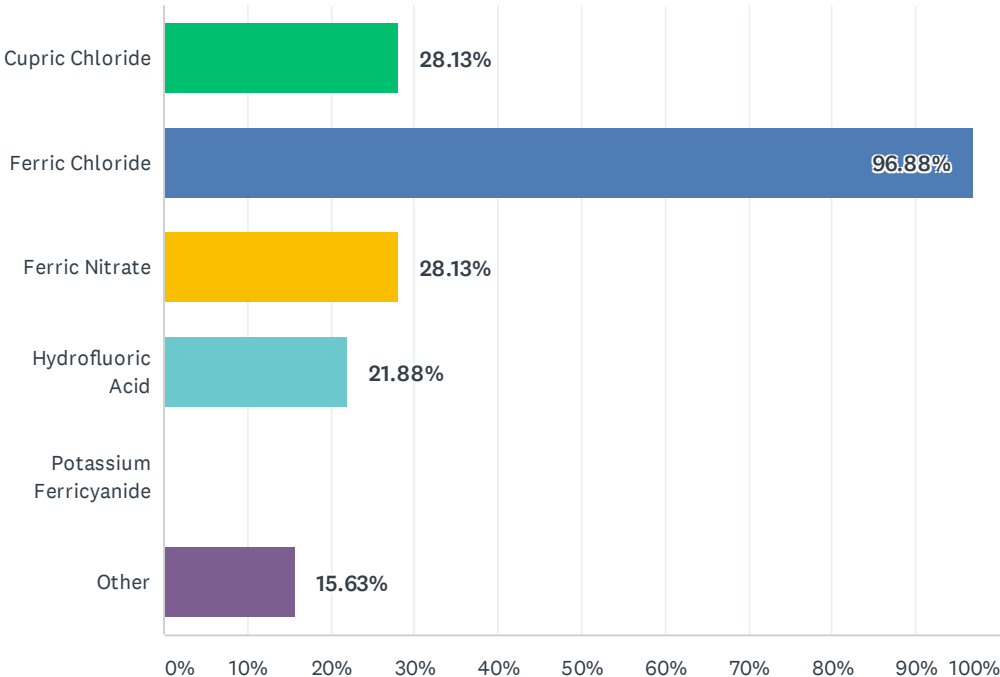
Answered: 32 Skipped: 0



ANSWER CHOICES	RESPONSES	
Aluminum	75.00%	24
Beryllium Copper	84.38%	27
Cold Rolled Steel	71.88%	23
Copper and Copper Alloys	90.63%	29
Gold	15.63%	5
Inconel/High Nickel Alloys	65.63%	21
Molybdenum	31.25%	10
Multi Layer	18.75%	6
Mu Metals	40.63%	13
Silver	34.38%	11
Stainless Steel	93.75%	30
Titanium	18.75%	6
Tungston	0.00%	0
Zinc	12.50%	4
Other	31.25%	10
Total Respondents: 32		

Q5 What type of etching chemistries does your site use?

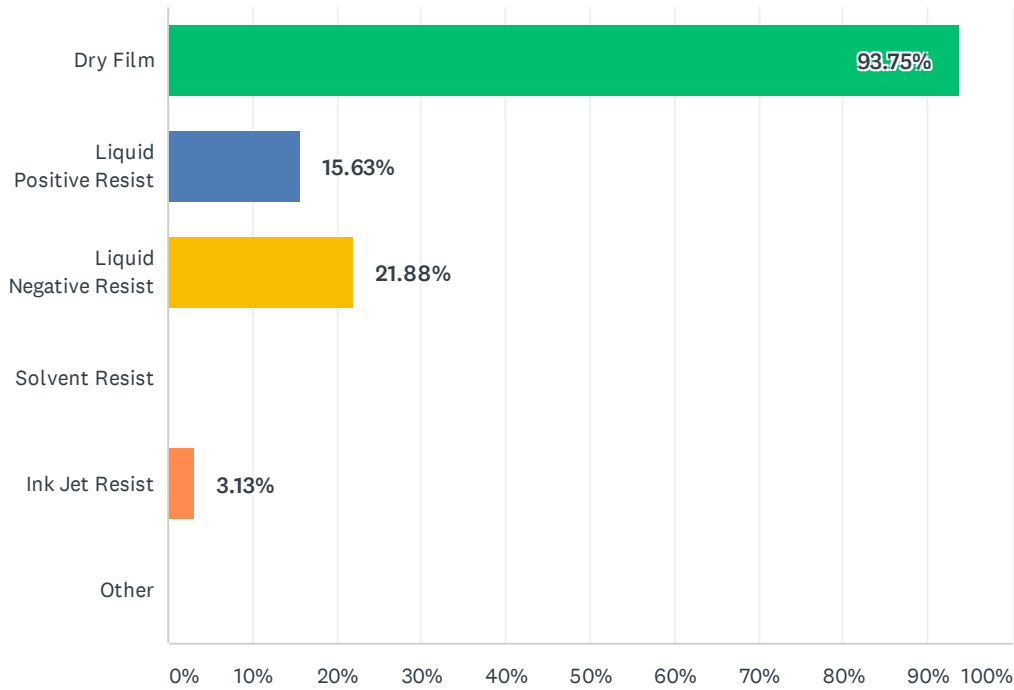
Answered: 32 Skipped: 0



ANSWER CHOICES	RESPONSES	
Cupric Chloride	28.13%	9
Ferric Chloride	96.88%	31
Ferric Nitrate	28.13%	9
Hydrofluoric Acid	21.88%	7
Potassium Ferricyanide	0.00%	0
Other	15.63%	5
Total Respondents: 32		

Q6 What types of resist does your site use?

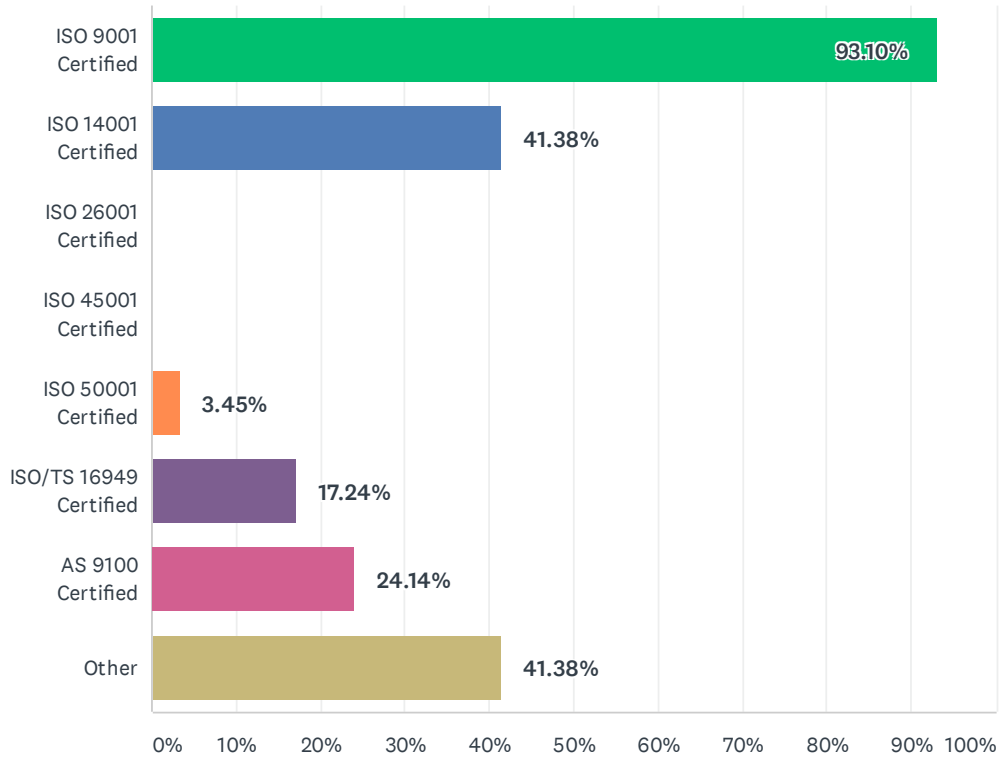
Answered: 32 Skipped: 0



ANSWER CHOICES	RESPONSES	
Dry Film	93.75%	30
Liquid Positive Resist	15.63%	5
Liquid Negative Resist	21.88%	7
Solvent Resist	0.00%	0
Ink Jet Resist	3.13%	1
Other	0.00%	0
Total Respondents: 32		

Q7 Below we list a number of actions which your site or company may have taken concerning quality and quality management. Please tell us whether you have done any of these activities.

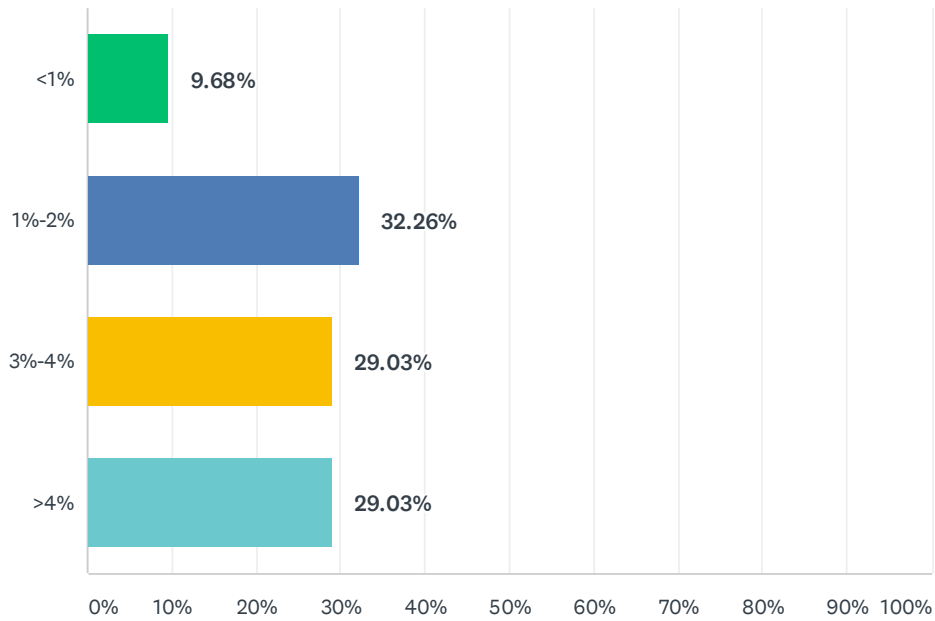
Answered: 29 Skipped: 3



ANSWER CHOICES	RESPONSES	
ISO 9001 Certified	93.10%	27
ISO 14001 Certified	41.38%	12
ISO 26001 Certified	0.00%	0
ISO 45001 Certified	0.00%	0
ISO 50001 Certified	3.45%	1
ISO/TS 16949 Certified	17.24%	5
AS 9100 Certified	24.14%	7
Other	41.38%	12
Total Respondents: 29		

Q8 What percentage of scrap/reject as a percentage of sales does your company typically experience?

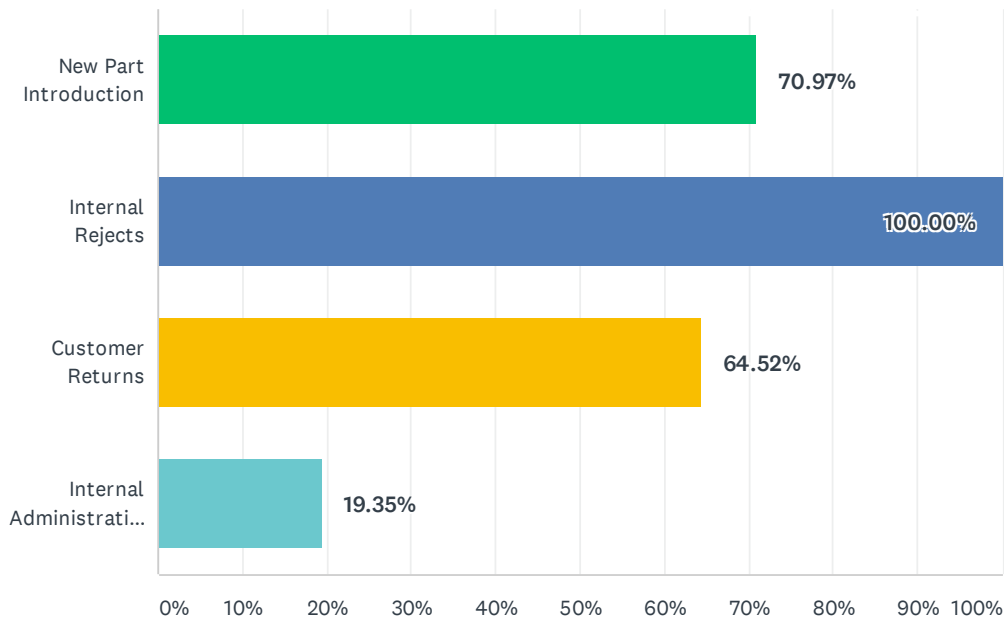
Answered: 31 Skipped: 1



ANSWER CHOICES	RESPONSES	
<1%	9.68%	3
1%-2%	32.26%	10
3%-4%	29.03%	9
>4%	29.03%	9
TOTAL		31

Q9 What is included in your scrap/reject calculation? Please select all that apply.

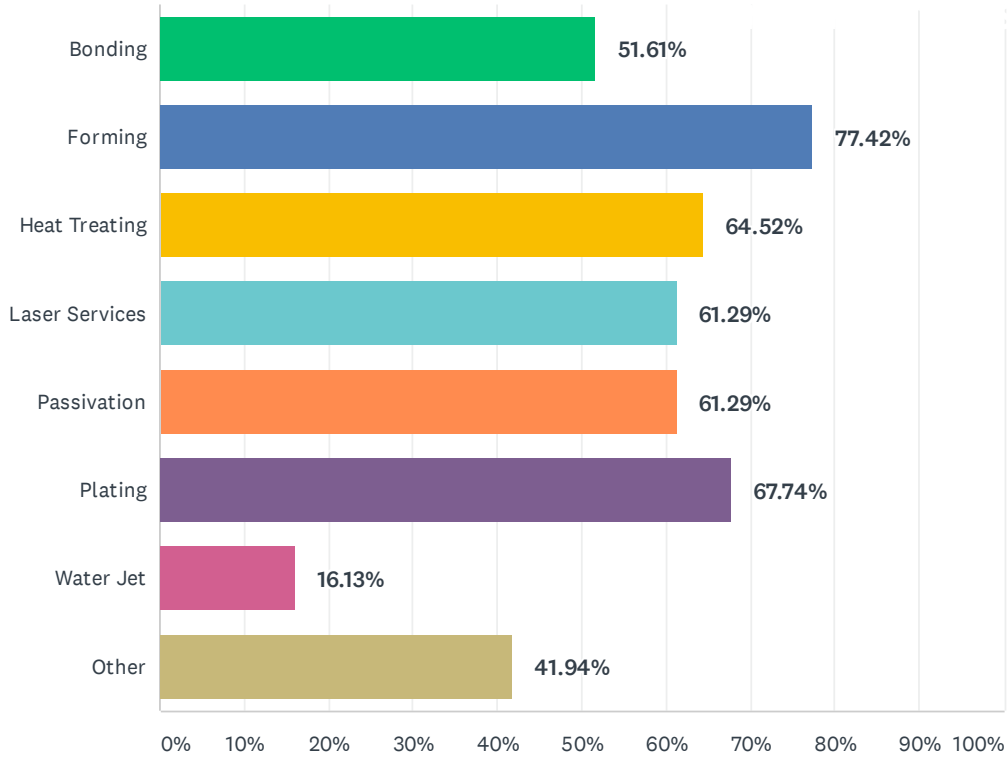
Answered: 31 Skipped: 1



ANSWER CHOICES	RESPONSES	
New Part Introduction	70.97%	22
Internal Rejects	100.00%	31
Customer Returns	64.52%	20
Internal Administrative Costs	19.35%	6
Total Respondents: 31		

Q10 What allied services do you provide for your chemically machined parts? (in-house or by subcontract)

Answered: 31 Skipped: 1



ANSWER CHOICES	RESPONSES	
Bonding	51.61%	16
Forming	77.42%	24
Heat Treating	64.52%	20
Laser Services	61.29%	19
Passivation	61.29%	19
Plating	67.74%	21
Water Jet	16.13%	5
Other	41.94%	13
Total Respondents: 31		

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