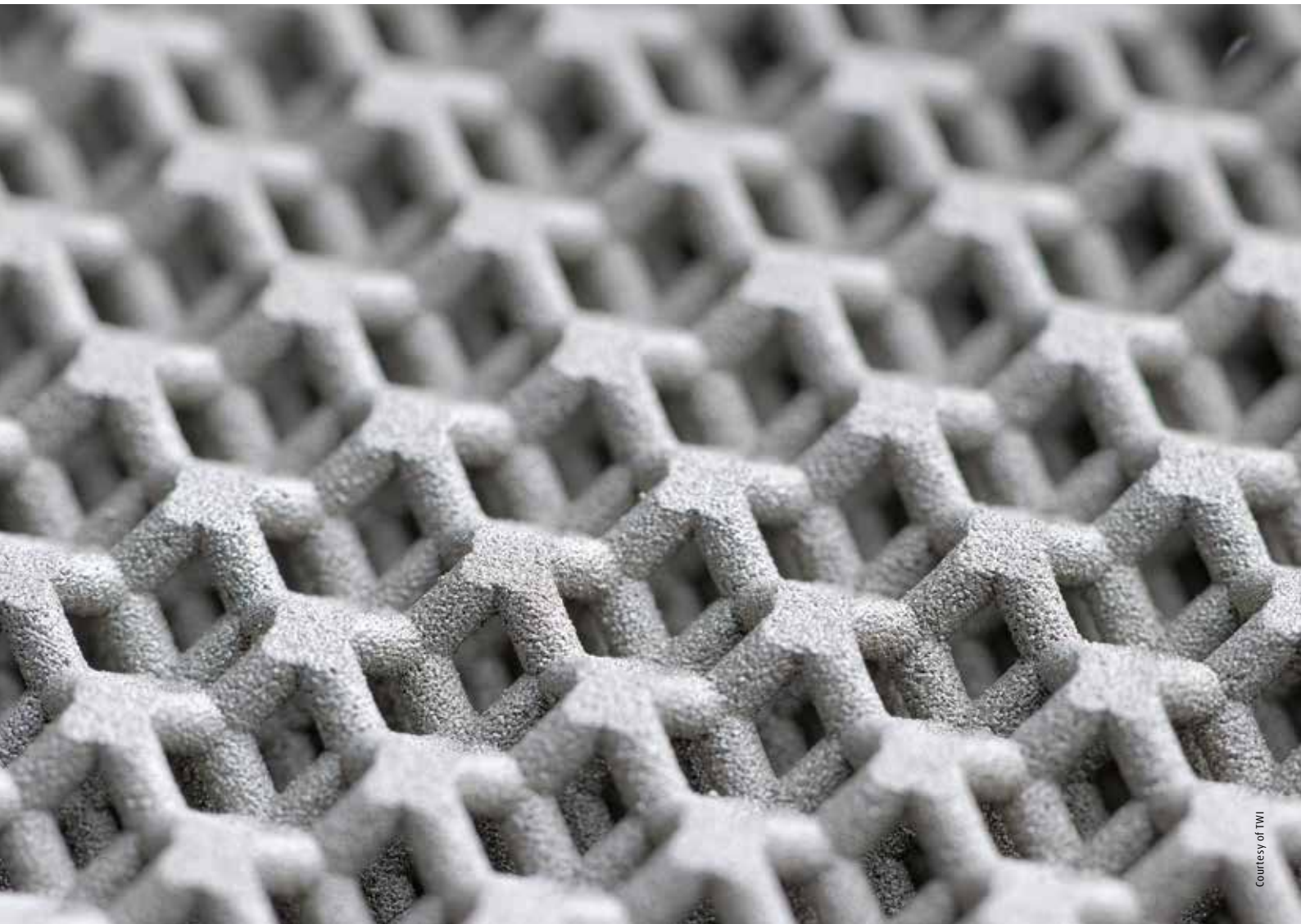
Making our world more productive

Additive manufacturing and powder metallurgy

Optimal product quality with tailored gas solutions



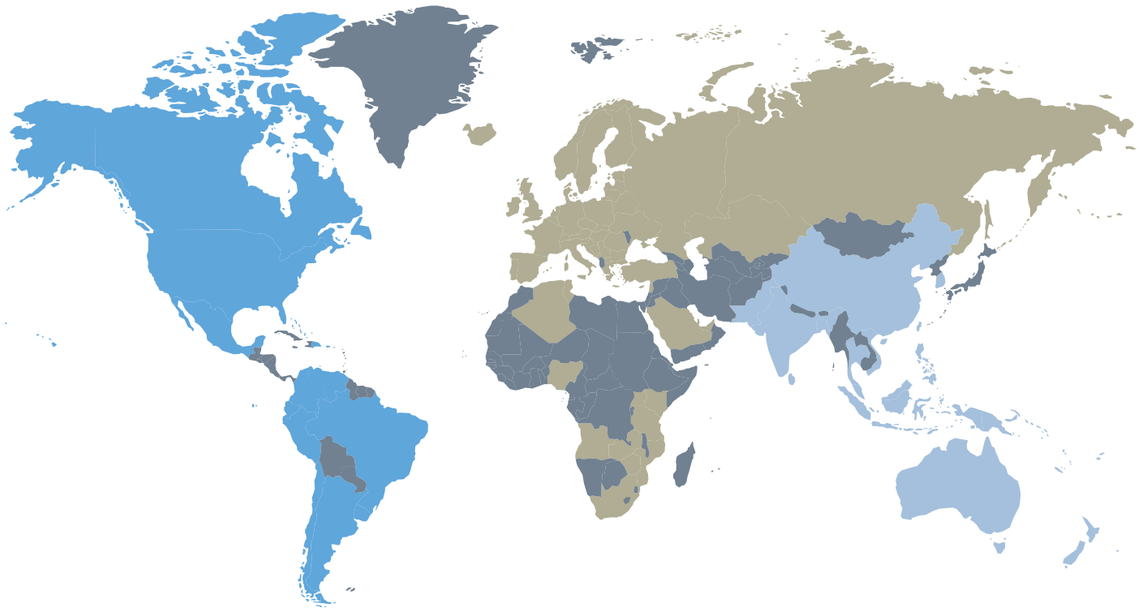
Courtesy of TWI

Linde – a world-class gas business

The Linde Group is a world-leading supplier of industrial, process and specialty gases and is one of the most successful global engineering companies. Linde products, gas solutions and services can be found in nearly every industry, in more than 100 countries.

Wherever you want to go – we are there to help.

Linde worldwide



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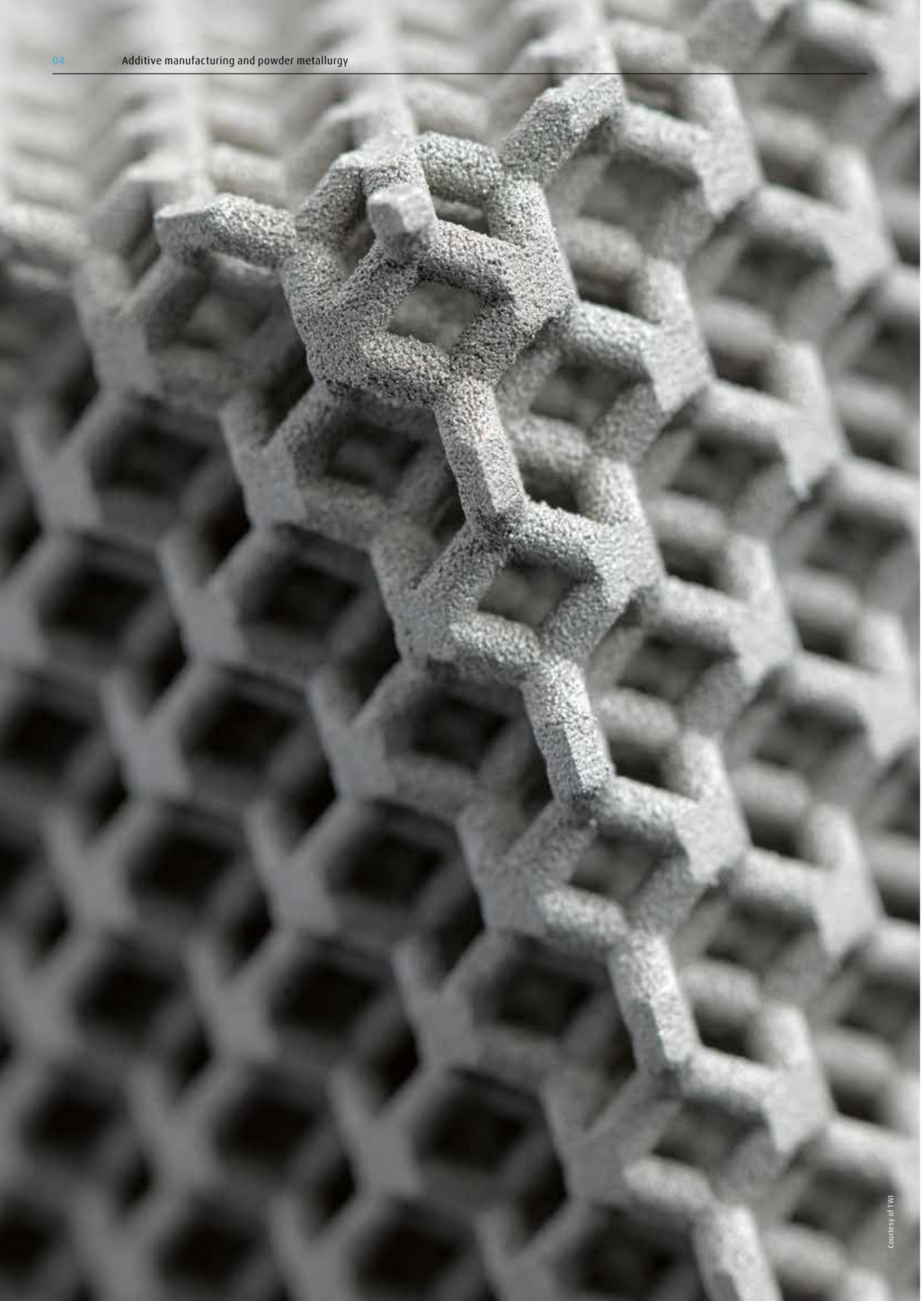


Overview of additive manufacturing and powder metallurgy processes

The metal powder industry has grown significantly in recent years due to the development and use of sintered parts and additive manufacturing processes. Linde is at the forefront of research and development not just for the metal powder industry and the metal additive manufacturing industry, but also for the entire powder value chain in additive manufacturing. Linde provides customers in powder metallurgy and additive manufacturing with industrial and specialty gases through a wide variety of delivery solutions, complementing these with technical support to ensure customer processes are efficient and effective.

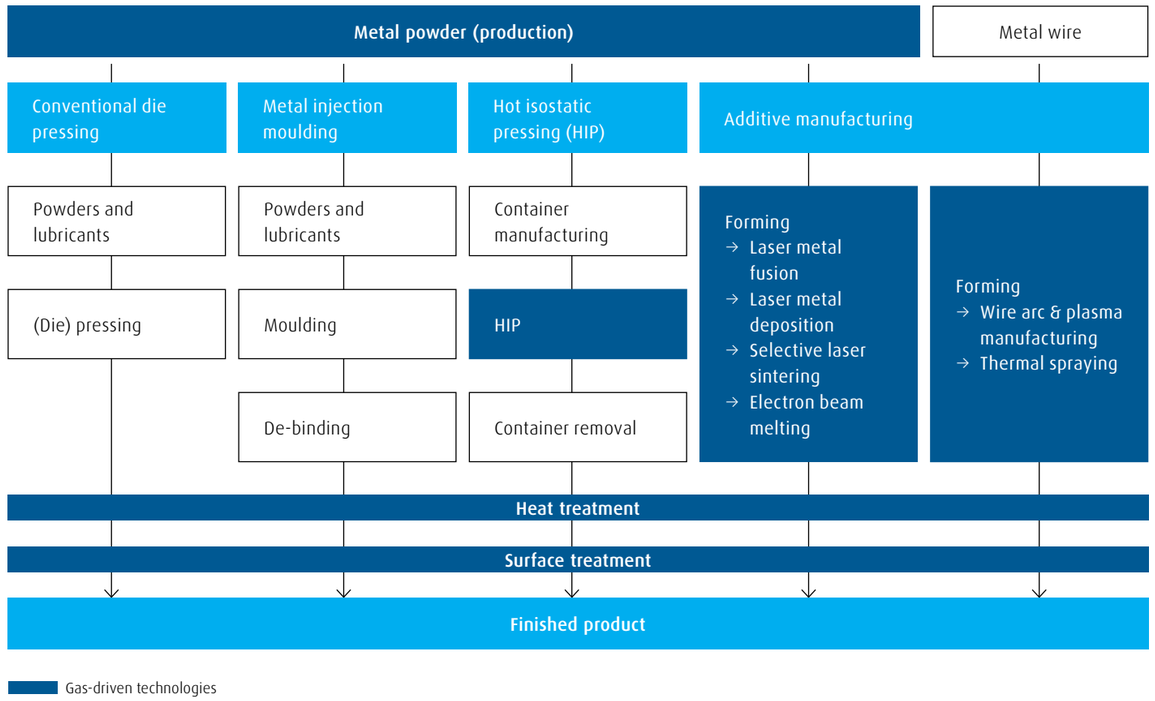
The additive manufacturing value chain

Linde is a major provider of applications, solutions, gases and equipment for these processes. Thanks to our expertise across the whole value chain spectrum, Linde is the leading gas and joining technologies supplier, providing a range of solutions and services to customers. This approach provides customers with the following advantages:

- A comprehensive range of industrial and specialty gases and technical support specific to powder metallurgy and additive manufacturing applications:
  - Optimised metal powder production and secure handling
  - Flawless 3D printing
    - Laser metal fusion (LMF)
    - Laser metal deposition (LMD)
    - Selective laser sintering (SLS)
    - Wire arc additive manufacturing
    - Electron beam melting (EBM)
  - Enhanced post-processing
    - Thermal spraying for surface finishing
    - Sintering
    - Hot isostatic pressing
    - Cleaning
- High-purity gases produced at ISO 9002-accredited facilities
- Dedicated support for original equipment manufacturers (OEMs) and customers
- Optimum process efficiency achieved through dedicated gas control equipment
- An extensive range of supply options tailored to suit customer requirements
- Manufacturing Technology Centres with research and development capabilities to support customer trials and technology exchange

The additive manufacturing value chain

Linde provides applications, solutions, gases and equipment for the following processes:



Optimised metal powder production and secure handling

The mechanical properties of a finished product are highly dependent upon the manufacturing process and the characteristics of the powder used in that process. Physical properties of the powder material must be preserved or adjusted exactly as required.

Linde's high-pressure gas supply schemes and technologies are used to atomise high-alloyed metals into powder particles that are spherical in shape and of uniform density.

The process:
There are many methods to produce metal powders. Atomisation is generally viewed as the best way due to the geometrical properties of the powder particles that can be achieved. For gas atomisation, water atomisation and direct reduction, appropriate gases and gas technologies are required:

- → Gas atomisation: argon and nitrogen
- → Water atomisation followed by oxide reduction under hydrogen atmosphere

Linde solutions for powder production:

- → Argon, nitrogen and hydrogen supply
- → Hydrogen supply – oxide reduction after water atomisation
- → Tailored supply schemes to satisfy customers' demands for high-quality gases and appropriate gas supply solutions (from cylinders to bulk delivery)
- → Flow control equipment for reliable high-pressure and/or heated gas supply
- → Customised process gas blends designed and adapted to the production requirements for special alloyed powder particles
- → Fine-tuning of atomisation processes to improve powder characteristics, reduce costs and eliminate rejects
- → Storage – ensure conditions for the storage of powder are optimised with ADDvance® powder cabinet

Flawless 3D printing

Additive manufacturing (AM), often referred to as 3D printing, is rapidly gaining in popularity as it offers a number of compelling benefits. These include material and productivity gains as well as greater design and production flexibility, thus paving the way for mass customisation. Linde is well positioned to support the AM industry. Linde provides world-class gases, gas supply solutions and technical expertise for additive manufacturing/3D metal printing processes.

The process:
AM, also referred to as 3D printing, refers to the fabrication of 3D components layer by layer from metal powder. As the demand for AM products has been steadily increasing, so have the many enabling technologies, including laser metal fusion, laser metal deposition, selective laser sintering, wire arc additive manufacturing, thermal spraying and electron beam melting. Products manufactured using these process technologies are typically forged, heat treated or sintered to achieve the quality, finish and mechanical properties desired. Process gases play a vital role in every step of the AM fabrication chain.

Linde solutions for AM processes:
- → Argon and nitrogen supply – gases for laser metal fusion
- → Helium – serving the electron beam melting processes
- → Nitrogen – polymer selective laser sintering processes
- → Arc and plasma welding gases
- → Thermal spraying gas mixtures
- → Specialty gases and their mixtures
- → On-site support – process and/or technical support
- → Engineering services
- → Optimising manufacturing atmospheres – ADDvance® O_2 precision

ADDvance O_2 precision

Courtesy of TWI

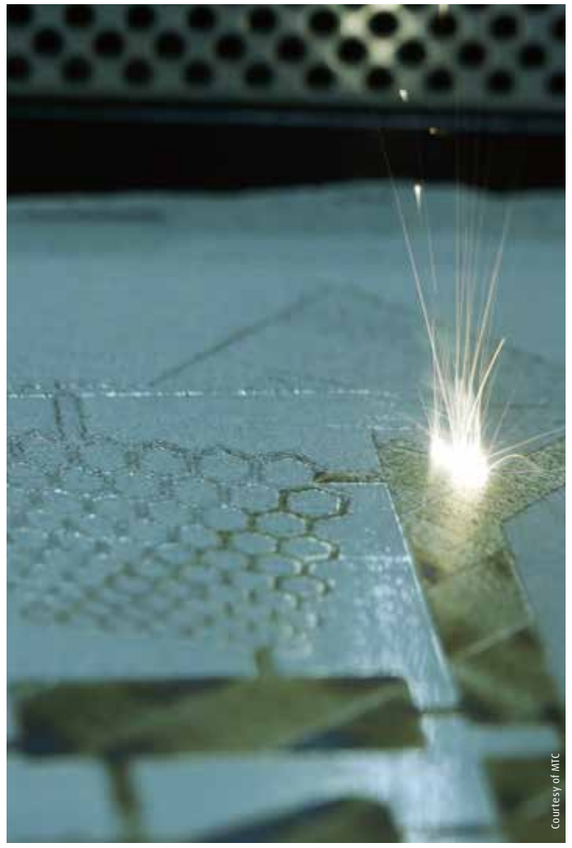
Additive manufacturing processes
Laser metal fusion

Laser metal fusion (LMF) is known by many names including metal selective laser sintering, metal laser melting, direct metal printing and direct metal laser sintering. We supply customers with pure gaseous or liquid argon systems to create the appropriate inert atmospheres for LMF processes.

The process:
A high-power laser beam is scanned over a bed of powder, sintering the powder into the required shape, in the path of the laser beam. After each layer, the bed is lowered by a short distance and a new layer of powder applied. This technique is suitable for smaller components where precision is a key requirement.

The entire process takes place in a sealed chamber with a controlled gas atmosphere which is either inert (e.g. argon) or active to fine-tune material/product properties. Typical products include combustor and fuel injector prototype parts for aerospace, wheel suspension and drive shaft fittings, and prototypes for the medical device industry.

Linde solutions for LMF processes:
- → Argon gas supply – design, provision and installation
- → Active gas supply – gases mixed in advance or on site satisfying process demands
- → Optimising manufacturing atmospheres – ADDvance O_2 precision
- → On-site support – process and/or technical support
- → On-stream gas system – design and maintenance services
- → Gas safety – equipment, safety checks and training


Courtesy of MTC

Additive manufacturing processes
Laser metal deposition

Laser metal deposition (LMD), alternatively known as near net shape, is a process which uses a high-power laser beam, connected to a robot or gantry system, to form a melt pool on a metallic substrate into which powder or metal wire is fed. We supply customers with gaseous or liquid helium, argon and nitrogen systems to assist with laser metal deposition processes.

The process:
In LMD, the powder is contained in a carrier gas and directed to the substrate through a nozzle that is concentric with the laser beam. Alternatively, a wire can be fed from the side.

The powder or wire is melted to form a deposit that is bonded to the substrate and grown layer by layer. An additional gas jet, concentric with the laser beam, provides additional shielding or process gas protection. The method is suitable for larger components where a higher deposition rate is required. LMD is used for a wide range of applications including cladding and repair carried out for example as mould-to-surface application for high-value parts such as aero engine components and military equipment.

Linde solutions for LMD processes:
- → Argon, helium, nitrogen gas supply – design, provision and installation
- → Active gas supply – gases mixed in advance or on site satisfying specific process demands
- → Optimising manufacturing atmospheres – ADDvance® O_2 precision
- → On-site support – process and/or technical support
- → On-stream gas system – design and maintenance services
- → Gas safety – equipment, safety checks and training


Courtesy of TWI

Additive manufacturing processes
Selective laser sintering

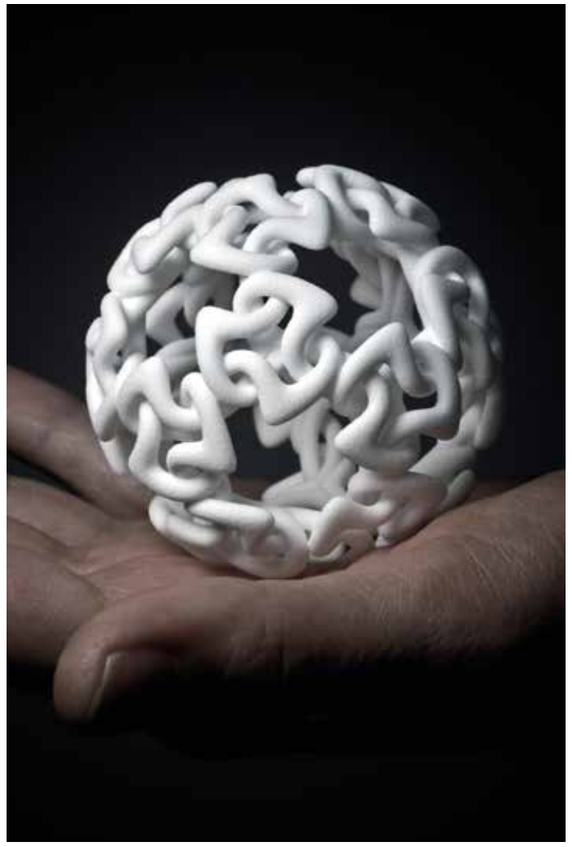
Selective laser sintering (SLS) is a popular additive manufacturing process using polymer powder such as nylon, carbon fibre, glass-filled nylon and fine polyamide. We supply customers with liquid gases and on-site nitrogen generation systems to assist with selective laser sintering processes.

The process:
SLS is popular with prototypers and product designers thanks to its ability to rapidly convert complex CAD geometries into working prototypes.

The SLS process commences with the polymer powder heated to just below melting point. A CO_2 laser then sinters the powder in an inert gas atmosphere.

Once the first layer has been completed, the build platform drops down before the levelling roller pushes fresh powder onto the platform. Nitrogen is frequently used to protect the heated powder and material from reacting with ambient air.

Linde solutions for SLS processes:
- → Nitrogen or argon gas supply – design, provision and installation
- → On-site support – process and/or technical support
- → On-stream gas system – design and maintenance services
- → Gas safety – equipment, safety checks and training



Additive manufacturing processes
Wire arc additive manufacturing

Gas-metal arc welding (MIG/MAG) and plasma welding techniques are used to melt metal filler to form a 3D component layer by layer. Gases are applied to protect the hot substrate against the ambient atmosphere and to adjust the metallurgical properties of the component.

We offer a wide variety of specialist welding gas solutions to protect and fine-tune material properties.

The wire arc AM process:
As in standard MIG/MAG welding, metal wire is added as the electrode melts in the arc and its droplets form layers on the substrate. Processes with lower heat input, such as controlled short-circuit metal transfer, are preferred given the heat sensitivity of most materials used in additive manufacturing. Shielding gases protect the layers against ambient air.

The plasma process:
Plasma additive manufacturing is similar to laser metal deposition in that powder is guided towards the substrate in a gas stream and fused by the plasma heat.

Additional processes:
Cooling of the generated component is required during the welding process. CO_2 cooling provides the required efficiency.

Linde solutions for arc processes:
- → Argon and helium gas supply – design, provision and installation
- → Active gas supply – gases mixed in advance or on site satisfying specific process demands
- → Plasma gases – required to generate the plasma
- → CO_2 gas supply – active cooling during generation
- → On-site support – process and/or technical support
- → On-stream gas system – design and maintenance services
- → Gas safety – equipment, safety checks and training

Additive manufacturing processes
Electron beam melting

Electron beam melting (EBM) is a powder bed fusion process using an electron beam in a vacuum. EBM processes are similar to direct metal laser sintering, but with a higher build-up rate and lower surface quality.

We provide customers with pure gaseous or liquid helium systems to assist with EBM cooling processes.

The process:
Electron beam melting grows complex parts in a vacuum chamber and is thus suitable for materials sensitive to reactions with air gas components such as titanium. The electron beam melts the metal powder bed, growing the component part layer by layer. The process temperature can be as high as 850 °C.

Orthopaedic manufacturers use electron beam melting processes to make bespoke and standard titanium implants. In the aerospace and defence industries, EBM is ideal for non-critical prototype components as it reduces both weight and costs by eliminating the need for conventional machining methods. Inert gases such as helium are applied for cooling during the component build process.

Linde solutions for EBM processes:
- → Helium gas supply – design, provision and installation
- → On-site support – process and/or technical support
- → On-stream gas system – design and maintenance services
- → Gas safety – equipment, safety checks and training


Courtesy of MTC

Enhanced post-processing

Powder metallurgy processes turn formed metal powder parts into useful components. Internal porosity and voids within the cast metal powder parts have to be eliminated. In addition, specific material properties such as extended hardness may be required. After the production of AM components, heat treatment processes are necessary to achieve the final desired functionality.

We offer a wide variety of gases, bespoke gas mixtures and application technologies to optimise post-processing outcomes.

The processes:
Most AM components require a heat treatment step to reduce stress. High-performance parts such as aerospace and turbine components will go through the hot isostatic pressing (HIP) process.

Linde solutions for heat treatment and surface cleaning processes:
- → Nitrogen and nitrogen/hydrogen mixtures for sintering
- → Argon for HIP in an inert atmosphere
- → Hydrogen, argon and nitrogen for heat treatment processes such as annealing
- → Gas supply systems and gas mixing units
- → Gas control equipment and monitoring systems
- → ADDvance® Cryoclean – for cleaning, pre-treating and finishing surfaces

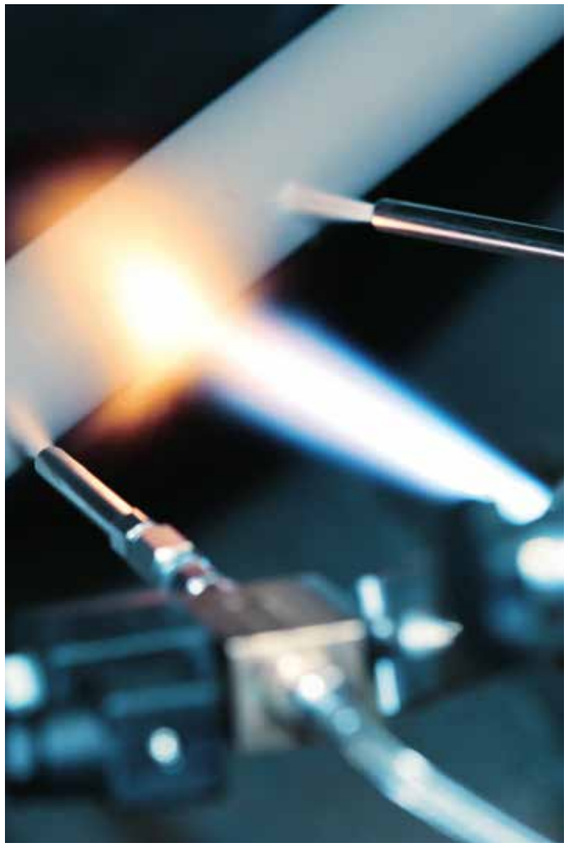
Enhanced post-processing
Thermal spraying

Thermal spraying involves a well-established range of industrial coating technologies used to improve component properties such as wear and corrosion resistance by adding a layer with a desired composition. We supply customers with argon, helium, nitrogen and gas mixtures in either gaseous or liquid form.

The process:
Molten, heated powder particles or droplets from molten wires are accelerated in a gas stream towards the substrate, where local adherence is ensured by kinetic energy and heat.

When used for additive manufacturing, thermal spraying is applied layer by layer to build up components without geometrical complexity, e.g. tubes or reducers. Process gases protect the hot material against ambient atmospheric gases and help to fine-tune material properties.

Linde solutions for thermal spraying processes:
- → Argon, helium and nitrogen gas supply – design, provision and installation
- → Active gas supply – gases mixed in advance or on site satisfying specific process demands
- → CO_2 gas supply – spot cooling of sensitive layers
- → On-site support – process and/or technical support
- → On-stream gas system – design and maintenance services
- → Gas safety – equipment, safety checks and training



Enhanced post-processing
Sintering

Sintering and sinter hardening are powder metallurgy processes which turn metal powders into useful components. Powder metallurgy techniques enable manufacturers to produce near net shape components with complicated geometries without subsequent machining. With a material usage rate of almost 100%, sintering results in little or no scrap.

We supply customers' sintering processes with liquid nitrogen or nitrogen and hydrogen gas mixtures, complementing these with SINTERFLEX® technology for precise control of gas atmospheres.

The process:
Powdered metal is compacted at room temperature in a press die that is shaped like the final component. After the mass of powder is compacted into a shape and ejected from the press ("green component"), it is fed slowly through a special high-temperature furnace to bond the metal particles together. The green component then goes through a series of thermal processes in the production chain. The key heat treatment processes are sintering, where parts become solid metal components ready for service, or sinter hardening, where parts become solid metal components and are then hardened in the same process cycle.

Linde solutions for sintering processes:
- → Nitrogen or nitrogen/hydrogen gas mixtures – design, provision and installation
- → SINTERFLEX® – atmosphere zoning technology and control equipment to support the sintering process; design and installation
- → On-stream gas system – design and maintenance services
- → Gas safety – equipment, safety checks and training

Enhanced post-processing
Hot isostatic pressing

Hot isostatic pressing (HIP) is an advanced material heat treatment process utilising elevated temperatures in a contained high-pressure atmosphere to eliminate internal porosity and voids within cast metal materials and components.

We supply customers with liquid argon gas systems to create the appropriate inert atmospheres for HIP processes.

The process:
The work-pieces are treated thermally in a vessel under high isostatic pressure during the HIP process. High-purity argon is typically used to provide the inert atmosphere necessary to prevent chemical reactions that might adversely affect the materials being treated.

Under the HIP process conditions of high temperature and high pressure, microporosity and voids in cast products are reduced or eliminated by plastic deformation, creep and diffusion bonding. This improves the mechanical properties and fatigue performance of manufactured parts. The reliability and service life of critical high-performance components are thus optimised. Typical HIP applications include gas turbine components, automotive engine parts, turbo charger wheels, aerospace structural parts, medical implants, prosthetics and near net shape components.

Linde solutions for HIP processes:
- → Argon gas supply systems – design, provision and installation
- → Atmosphere control – commissioning and provision of controlled atmosphere technology and appropriate control equipment to support HIP processes
- → On-stream gas system – design and maintenance services
- → Gas safety – equipment, safety checks and training

Enhanced post-processing
Cryogenic cleaning

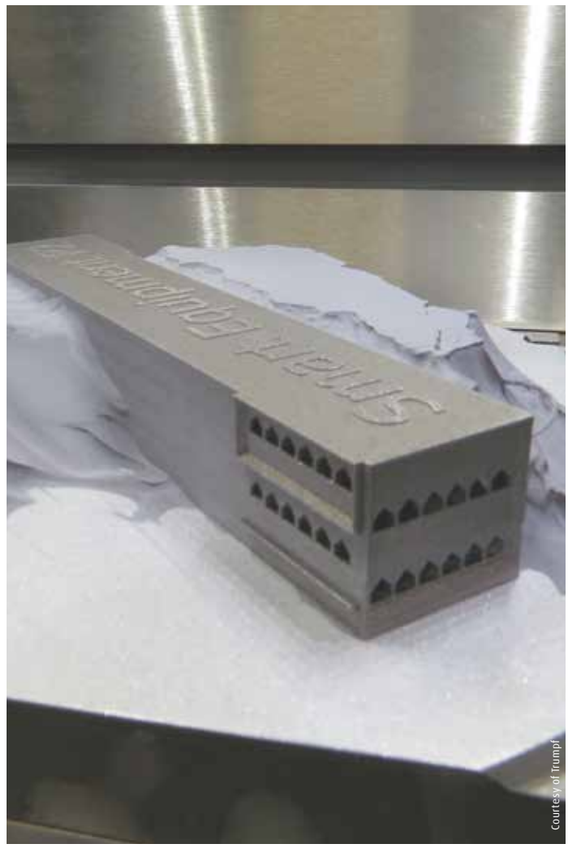
During the 3D printing process, blast powder residue or unfused powder can build up on the part being built. Particularly in the case of small, elaborate parts and components with complex geometries, removing particles from holes and cavities can be quite challenging, especially as melting metal residue requires potentially damaging high temperatures.

With ADDvance Cryoclean, we have created a dedicated solution that overcomes the downsides of high temperatures to achieve perfect cleaning results with all 3D parts – no matter how small or complex they are.

The process:
Depending on the application in question, a number of different surface finishing treatments can be applied to remove or reduce the surface roughness of AM parts. The most prevalent method is abrasive blasting but others include barrel finishing, abrasive flow machining, plasma polishing, micro machining and electrochemical polishing. ADDvance Cryoclean can be used to increase the effectiveness of abrasive blasting.

It creates dry ice particles by expanding liquid carbon dioxide (CO_2) directly. Using compressed air, the particles are accelerated up to sonic speed and shot onto the surface to be cleaned. The cleaning effect of this procedure relies on flash cooling, kinetic energy, embrittlement and gas impact. An abrasive agent can be admixed with the dry ice particles to remove stubborn powder residue. The operator can adapt the CO_2 snow/abrasive material ratio from gentle to abrasive to suit the task at hand.

Linde ADDvance Cryoclean solutions:
- → ADDvance Cryoclean and CRYOCLEAN® snow– manual or automated cleaning system, adding snow combines dry ice with abrasive blasting for difficult-to-remove residue
- → Liquid CO_2 supply scheme – design, provisioning and installation of a liquid CO_2 system
- → PRESUS® – CO_2 pressure control system
- → On-site support – process and technical support, maintenance included
- → Gas safety – equipment, safety checks and training



Linde – leading in powder metallurgy and additive manufacturing innovation

Catapult centre and research facility member:

Linde is proud to be a member of the Manufacturing Technology Centre (MTC) in Ansty, Coventry, the Nuclear Advanced Manufacturing Research Centre (NAMRC), Sheffield, and also the Welding Institute.

Linde is engaged in a number of development projects in the powder metallurgy and additive manufacturing field, aimed at shaping the future of additive manufacturing.

In-house R&D and customer trials:

Linde has invested in a Global Development Centre in Munich which includes investment in a number of 3D printing machines to improve its own knowledge of the effect of gases, gas purities and gas supply options on AM outcomes. Close cooperation with one of the leading AM machine suppliers further helps Linde to satisfy customer demands and to develop customised solutions.

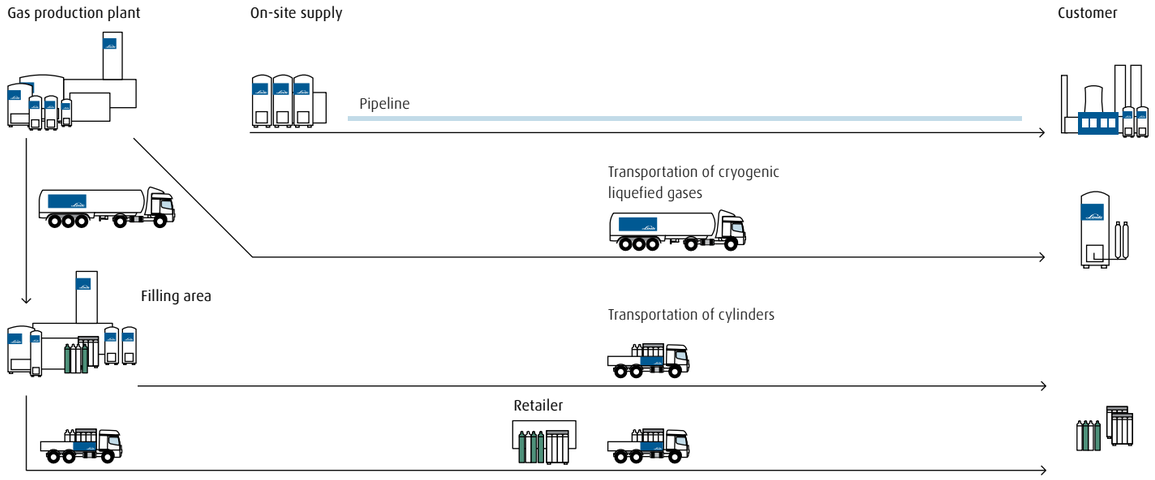
The 3D printing machine is also used for private customer research, testing and trials as well as to optimise customer processes and support new applications.

Linde – world-class gas supply options

Linde offers a complete range of gas supply options including single gas cylinders, manifold cylinder pallets, liquid deliveries and on-site generation of nitrogen (where applicable). In addition, Linde provides advice and guidance to help customers select the most effective supply solution to meet their process, quality, productivity and cost targets. Linde remains committed to developing and tailoring its services to customer needs, now and in the future, and to helping support increased productivity and growth.

Linde can tailor a gas supply scheme to the purity, pressure and flow rates required, taking into account the specific application and the constraints of the working environment.

Linde Gas supply modes



Linde – the leading gas partner

Environmental commitment

Linde recognises that all industrial and chemical processes impact on the environment and thus actively engages in various activities to reduce environmental impact. Linde works with many customers to help them improve their environmental performance, including assisting them to reduce greenhouse gas emissions, maximise the efficiency of their processes and improve waste water treatment processes.

Cylinder gases

Linde supplies atmospheric gases (such as oxygen, argon and nitrogen), fuel gases and other gases such as hydrogen, helium and carbon dioxide in gas cylinders. Cylinders are the ideal means of supply for smaller volumes of gas, offering flexibility of demand.

Bulk deliveries

For large-volume users, a bulk cryogenic storage vessel, filled regularly, eliminates cylinder handling and the need for delivery assistance. Liquefied industrial gases (nitrogen, oxygen and argon) are produced in large quantities at our air separation units (ASUs). These gases are produced by liquefying and distilling the air into its component parts at cryogenic temperatures. Liquefied carbon dioxide is recovered from a variety of sources including ammonia and hydrogen plants, and then purified.

On-site gas generation

For some customers, on-site gas generation is the best choice as it is economical, environmentally sound, flexible and reliable. Oxygen, nitrogen and hydrogen can be generated on site in purities from 90% to over 99.9%.

Special products

Linde supplies an extensive range of specialty gases, chemicals and refrigerants as well as gas control equipment. The gases portfolio is supported by a full range of services including gas handling, safety training courses and refrigerant reclamation.

Key areas of expertise are:

- → Specialty gases: High-purity gases (including helium), process and calibration gas mixtures and gases specifically for the electronics industry.
- → Refrigerants: The full range of fluorocarbons, plus ammonia, hydrocarbons and other natural refrigerants to meet the changing legislative demands of the automotive, refrigeration and air-conditioning markets. We are also licensed to provide full recycling and reclamation services for fluorocarbon refrigerants.
- → Chemicals: A wide range of gaseous chemicals for many key industry sectors including water treatment, chemical manufacture, materials science, foam manufacture, aerosol propellants, utilities and pharmaceutical manufacture.
- → Liquid helium: A special service for the supply of liquid helium, typically for nuclear magnetic resonance (NMR) or magnetic resonance imaging (MRI) machines, supplied in low-temperature dewars (vessels containing between 20 litres and 1,000 litres).
- → Safety products: Linde offers an extensive range of safety products. Gas equipment and gas safety are core areas of excellence.
- → Development centres: Linde operates a number of development centres in different countries focussing on cutting-edge technologies, improving manufacturing processes to satisfy the demands of the marketplace, and delivering customer efficiencies. Close cooperation with leading R&D institutes and OEMs ensures customer-oriented application development and gas supply solutions

Getting ahead through innovation.

With its innovative concepts, Linde is playing a pioneering role in the global market. As a technology leader, it is our task to constantly raise the bar. Traditionally driven by entrepreneurship, we are working steadily on new high-quality products and innovative processes.

Linde offers more. We create added value, clearly discernible competitive advantages, and greater profitability.
Each concept is tailored specifically to meet our customers' requirements – offering standardised as well as customised solutions. This applies to all industries and all companies regardless of their size.

If you want to keep pace with tomorrow's competition, you need a partner by your side for whom top quality, process optimisation, and enhanced productivity are part of daily business. However, we define partnership not merely as being there for you but being with you. After all, joint activities form the core of commercial success.

Linde – Making our world more productive

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