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# Services

## Project Scope Definition and Permitting Requirements for Foundation Repair

Okay, so let's talk about underpinning and ROI. It's not exactly the sexiest topic, is it? We're not talking about rocket science or AI here, but about concrete and, well, underpinning. But hold on, because understanding the costs associated with underpinning and then figuring out the return on investment can be surprisingly important. Think of it this way: it's about protecting your biggest asset – your property – and making sure you're doing it in a smart, financially sound way.

First, let's unpack the "understanding underpinning." The relationship between water and your foundation is like that toxic ex who keeps coming back to cause more damage **foundation stability check Chicagoland** Facebook. We're not just talking about sticking some concrete under a wall. It's about diagnosing the problem. Why does the building need underpinning in the first place? Is it subsidence, poor soil, nearby construction? The "why" dictates the "how," and the "how" directly impacts the cost. A simple crack might need a simple solution, but a major structural issue demands a more complex and, yes, expensive approach. So, you need a good assessment; think of it as getting a proper medical diagnosis before you start treatment.

Now, about the costs. This isn't just about the materials and labor. It's about the whole shebang. Permits, engineering reports, the potential for unexpected problems (because let's face it, things rarely go exactly as planned!), and even the disruption to your life. If you're living in the property while the work is done, you're talking about dust, noise, and a general invasion of privacy. That has a cost, even if it's just the cost of your sanity.

And then, finally, ROI. How do you calculate the return on investment for something like underpinning? It's not as straightforward as, say, installing solar panels. You're not necessarily generating direct revenue. Instead, the ROI comes from several areas. First, preserving or even increasing the property value. A house with structural problems is worth significantly less than a structurally sound one. Underpinning fixes the problem, potentially preventing a huge loss in value. Second, preventing further damage. Catching a problem early can save you a fortune in the long run. Think of it as preventative medicine for your house. A small investment now can prevent a catastrophic (and much more expensive) collapse later. Third, peace of mind. Knowing your property is stable and safe is worth something, right? It's hard to put a precise dollar figure on it, but it's a real benefit.



So, while calculating the ROI on underpinning might seem like a dry, technical exercise, it's really about making informed decisions to protect your investment, your safety, and even your sanity. It's about understanding the problem, acknowledging the full range of costs, and then weighing those costs against the long-term benefits. And that, my friends, is something worth considering.

When considering the return on investment (ROI) for underpinning services, it's crucial to identify both the direct and indirect benefits that this structural enhancement provides. Underpinning, which involves strengthening and stabilizing the foundation of a building, is not just a necessary intervention for safety but also an investment with multifaceted returns.

Direct benefits are the most tangible and immediate outcomes of underpinning. Firstly, there's the preservation of property value. A building with a compromised foundation can significantly depreciate in value due to structural integrity concerns. By investing in underpinning, homeowners or property managers ensure that their asset retains or even increases in market value, offering a clear financial return. Moreover, underpinning directly addresses safety issues by preventing potential collapses or extensive damage from subsidence or settlement, thereby avoiding costly emergency repairs and insurance claims which could be far more expensive than proactive underpinning.

Indirect benefits, while less immediately quantifiable, contribute significantly to the long-term ROI. One key indirect benefit is the enhancement of property usability. A stable foundation allows for future renovations or expansions without fear of structural failure, thus increasing the functional space or improving living conditions within the property. This can lead to increased rental income if the property is leased out or higher resale value when put on the market due to modernized facilities.

Additionally, underpinning can have positive environmental impacts by extending the life of existing buildings rather than necessitating new construction. This reduces waste and resource consumption associated with building demolition and new construction projects. From a community perspective, maintaining older structures through underpinning contributes to preserving historical architecture and neighborhood aesthetics, which can enhance local property values collectively.

Another indirect benefit relates to peace of mind for owners and occupants. Knowing that their home or business premises are structurally sound reduces stress and potential health issues related to constant worry over safety. This psychological well-being translates into productivity gains for businesses operating from these locations or improved quality of life for residents.



Calculating ROI for underpinning services therefore involves looking beyond mere cost recovery; it encompasses an appreciation in asset worth, avoidance of future expenses through proactive maintenance, operational flexibility due to structural reliability, environmental sustainability through conservation efforts, community enhancement via aesthetic continuity, and personal well-being from reduced anxiety about building stability. Each factor contributes uniquely but collectively they shape a robust case for why investing in underpinning isn't just about fixing foundations-its about securing future financial stability and lifestyle quality through comprehensive risk mitigation and enhancement strategies.

# Material Procurement and Quality Control Procedures

Okay, so you're thinking about underpinning services, right? Maybe you're facing some foundation issues, and you're weighing up whether to bite the bullet and get them fixed. It's a big decision, and naturally, you want to know if it's actually *worth* it. That's where Return on Investment, or ROI, comes in. It's basically a way to figure out if the money you spend on underpinning is going to give you a good return.

Now, there isn't one single, magic formula for ROI on underpinning, because every situation is different. But we can look at some key factors. Think about the obvious costs first: the price of the underpinning work itself. Get several quotes and be sure they include everything – materials, labor, permits, any necessary inspections.

Then, consider the *benefits*. This is where it gets a little less straightforward. A big one is property value. A house with a solid foundation is worth more than one with cracks and sinking floors. Get a professional appraisal *before* and *after* the work to see the difference. This is a crucial part of your ROI calculation.

But it's not just about the sale price down the line. Think about the ongoing costs you *avoid* by fixing the foundation. Are you currently spending money on temporary band-aids, like cosmetic repairs to hide cracks? Those costs vanish. Are you worried about further damage escalating, leading to even bigger (and more expensive) problems later? Underpinning can prevent that. Factor in the peace of mind, too – that's harder to quantify, but it's real!



So, a simplified formula might look like this: (Increase in Property Value + Avoided Future Repair Costs) - Cost of Underpinning = Net Benefit. Then, divide the Net Benefit by the Cost of Underpinning and multiply by 100 to get your ROI percentage.

Remember, this is just a starting point. Talk to real estate professionals, contractors, and maybe even a financial advisor to get a clearer picture of the potential ROI in your specific situation. Don't just look at the immediate cost; think about the long-term value and the peace of mind that solid foundations bring. Good luck!







# **Inspection and Testing Protocols During Foundation Repair**



Okay, lets talk about Return on Investment (ROI) for underpinning services, but not in a dry, number-crunching way. Lets look at some real-world situations, because thats where the rubber actually meets the road, right?

Think about it. Underpinning, at its core, is about preventing a much bigger, more expensive disaster. Its like getting a root canal now to avoid losing the whole tooth later. So, how do you put a price on *that* peace of mind?

Let's say theres a historic building in a bustling city center. The foundation is starting to settle, causing cracks and instability. The owner could ignore it, hoping itll just...stop. But the risk? The building could become unsafe, tenants could leave (or sue!), and eventually, the whole structure could be condemned. Thats a huge loss – lost rental income, demolition costs, and potentially, a legal nightmare.

Instead, they invest in underpinning. Lets say it costs \$50,000. That sounds like a lot initially. But consider this: The underpinning stabilizes the building, allowing them to keep their tenants and continue generating \$100,000 in annual rental income. Plus, the value of the stabilized building is maintained. Without the underpinning, the buildings value would plummet. The ROI isnt just about immediate cash flow; its about preserving a valuable asset and avoiding catastrophic losses. That \$50,000 looks a lot smarter now, doesnt it?

Another example: Imagine a homeowner notices cracks in their foundation. Theyre worried about further damage, water intrusion, and the potential impact on their homes resale value. They get quotes for underpinning and decide to proceed, spending \$20,000. Before underpinning, the house might have been appraised at \$300,000, but with the visible foundation issues, a buyer might offer significantly less, or even walk away. After underpinning, the structural integrity is restored, and the homes value is maintained, or even increased, because its now structurally sound. They can sell it for close to the original appraised value, avoiding a potential loss of tens of thousands of dollars. The ROI here is the difference between what they would have gotten *without* the underpinning versus what they got *with* it.

The key takeaway? ROI for underpinning isn't always a simple calculation. Its often about mitigating risk, preserving value, and avoiding potentially disastrous outcomes. You have to look at the bigger picture, consider the long-term impact, and factor in the intangible benefits, like peace of mind. Sometimes, the best ROI is the disaster that *didn't* happen.



# Documentation and Reporting for Permitting Compliance and QA/QC

When considering the return on investment (ROI) for underpinning projects, several factors come into play that can significantly influence the financial outcome. Underpinning is a process used to strengthen and stabilize the foundation of a building, often necessary when structural issues arise or when additional construction is planned. Calculating the ROI for such services involves a nuanced understanding of various elements that can affect both costs and benefits.

First and foremost, the **condition of the existing structure** plays a critical role. If the building has severe foundational problems or if there's significant deterioration, the cost of underpinning can escalate rapidly. This might reduce ROI due to higher initial investment. Conversely, early intervention in less severe cases might yield a higher ROI by preventing more costly repairs down the line.

The **method of underpinning** chosen also impacts ROI. Traditional methods like mass concrete underpinning are generally less expensive but might not be as effective or quick as modern techniques such as resin injection or mini-piled underpinning. While these advanced methods can be costlier upfront, they often result in quicker project completion times and potentially lower long-term maintenance costs, thereby improving ROI through reduced downtime and extended structural longevity.

Another factor to consider is **location**. Properties in urban areas or regions with high real estate values might see a more substantial increase in property value post-underpinning, thus enhancing ROI. In contrast, rural or less valuable properties might not experience as significant an appreciation, affecting the investments attractiveness.



**Regulatory compliance** and local building codes can also sway ROI calculations. Stringent regulations might necessitate more comprehensive underpinning solutions or additional permits and inspections, increasing costs. However, ensuring compliance can add value by certifying the buildings safety and marketability.

Additionally, **market conditions** at the time of project completion are pivotal. A robust real estate market could mean a quicker sale or rental at a higher price post-underpinning, directly boosting ROI. On the flip side, during economic downturns or property market slumps, even well-executed underpinning projects might not yield expected returns due to decreased demand.

Lastly, **future use intentions** of the property influence ROI. If the underpinned structure is intended for long-term use by its owner, benefits like increased safety and comfort contribute to ROI through non-monetary gains over time. For investors looking to flip properties quickly after underpinning, however, immediate resale value becomes crucial.

In summary, calculating ROI for underpinning services requires a holistic view that considers not just direct financial metrics but also qualitative aspects like structural integrity improvements and market dynamics. Each projects unique circumstances dictate how these factors interplay to ultimately determine whether an investment in underpinning yields favorable returns.







Lets be real, when we talk about investing in the stuff that keeps everything running smoothly – those underpinning services – its easy to get starry-eyed about potential ROI. We dream of fewer outages, happier customers, and a team thats actually, you know, productive. But before we sign off on that budget, we need to take a deep breath and talk about risk. Because ignoring the potential pitfalls is like building a house on sand.

Risk assessment and mitigation isnt just some corporate buzzword; its about being honest with ourselves about what could go wrong. What if that fancy new monitoring system turns out to be more complicated than we thought, requiring extra training and sucking up valuable time? What if the promised efficiency gains never materialize because of unforeseen compatibility issues? What if, dare I say it, we choose the wrong vendor and end up with a system thats actually worse than the one we had before?

A good risk assessment involves brainstorming all the potential downsides, from the obvious (cost overruns) to the less so (employee resistance to change). Once weve identified those risks, we need to figure out how likely they are to happen and how badly they would hurt us if they did. This lets us prioritize. We focus our energy on mitigating the high-probability, high-impact risks first.

Mitigation isnt about eliminating risk entirely – thats usually impossible. Its about reducing the likelihood or the impact. Maybe it means phasing in the new system instead of doing a full-blown overnight switch. Maybe it means investing in extra training and support for our team. Maybe it means having a backup plan in case the initial vendor doesnt deliver.

Thinking about risk upfront might seem like a downer, but its actually the key to a successful investment. It allows us to make informed decisions, adjust our expectations, and ultimately, increase the chances of seeing that sweet, sweet return on investment were all hoping for. So, before you get lost in the ROI calculations, take a moment to consider whats lurking in the shadows. Your future self will thank you.



# Post-Repair Verification and Long-Term Monitoring for QA/QC

Lets talk about keeping your foundation solid, without always diving headfirst into underpinning. Its like deciding whether to get a root canal or try really, really hard with a good cleaning and some fluoride. Underpinning, thats the root canal – a big, sometimes necessary, but always impactful procedure. And just like with dental work, its worth exploring alternatives first.

So, what else is on the menu? Soil stabilization techniques are a big one. Think of things like injecting grout or expanding polymers into the ground around your foundation. This can help solidify loose or shifting soil, providing better support and preventing further settlement. Its less invasive than underpinning and often quicker, which translates to less disruption and lower initial costs. Another option, particularly for minor settlement issues, might be foundation crack repair. This involves sealing cracks in your foundation walls, preventing water intrusion and further degradation. It wont magically lift a sinking foundation, but it can stop the problem from worsening.

Now, lets get down to brass tacks: return on investment (ROI). When youre weighing up underpinning versus these alternatives, its not just about the upfront price tag. Underpinning, despite being pricier initially, can offer a higher ROI in certain situations. A significantly compromised foundation, left untreated, can lead to structural failure, property damage, and ultimately, a huge hit to your homes value. Underpinning, in this case, is an investment in preserving (or even increasing) your propertys worth.



On the other hand, if the problem is relatively minor, less invasive solutions might offer a better ROI. Spending a smaller amount on soil stabilization or crack repair can prevent further damage and maintain your property value without the hefty cost of underpinning.

Here's the key: it's all about understanding the scope of the problem. Get a thorough assessment of your foundation issues from a qualified structural engineer. They can help you determine the root cause of the problem and recommend the most appropriate solution. Then, crunch the numbers. Consider the initial cost, the long-term impact on your property value, and the potential for future repairs. Only then can you truly calculate the ROI and make an informed decision that's right for your situation. It's not a one-size-fits-all answer; it's about finding the solution that's the best fit for your foundation, and your wallet.



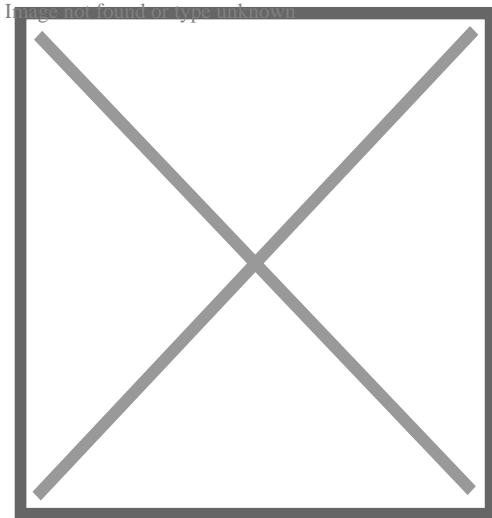
**About Pump**



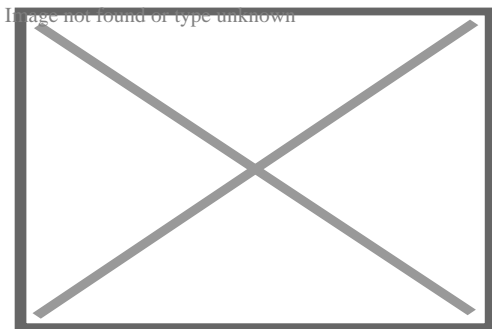


**The accessibility of this article is in question.** The specific issue is: **animation fails MOS, see talk.** Relevant discussion may be found on the talk page. *(April 2025)*

"Water Pump" redirects here. For the community in Pakistan, see Water Pump, Karachi. For other uses of "pump" or "pumps", see Pump (disambiguation).



A small, electrically powered pump



A large, electrically driven pump for waterworks near the Hengsteysee, Germany

A **pump** is a device that moves fluids (liquids or gases), or sometimes slurries,<sup>[1]</sup> by mechanical action, typically converted from electrical energy into hydraulic or pneumatic energy.

Mechanical pumps serve in a wide range of applications such as pumping water from wells, aquarium filtering, pond filtering and aeration, in the car industry for water-cooling and fuel injection, in the energy industry for pumping oil and natural gas or for operating cooling towers and other components of heating, ventilation and air conditioning systems. In the medical industry, pumps are used for biochemical processes in developing and manufacturing medicine, and as artificial replacements for body parts, in particular the artificial heart and penile prosthesis.



When a pump contains two or more pump mechanisms with fluid being directed to flow through them in series, it is called a *multi-stage pump*. Terms such as *two-stage* or *double-stage* may be used to specifically describe the number of stages. A pump that does not fit this description is simply a *single-stage pump* in contrast.

In biology, many different types of chemical and biomechanical pumps have evolved; biomimicry is sometimes used in developing new types of mechanical pumps.

## Types

[edit]

Mechanical pumps may be **submerged** in the fluid they are pumping or be placed **external** to the fluid.

Pumps can be classified by their method of displacement into electromagnetic pumps, positive-displacement pumps, impulse pumps, velocity pumps, gravity pumps, steam pumps and valveless pumps. There are three basic types of pumps: positive-displacement, centrifugal and axial-flow pumps. In centrifugal pumps the direction of flow of the fluid changes by ninety degrees as it flows over an impeller, while in axial flow pumps the direction of flow is unchanged.<sup>[2]</sup><sup>[3]</sup>

See also: Vacuum pump

# Electromagnetic pump

[edit]

This section is an excerpt from Electromagnetic pump.[edit]

An electromagnetic pump is a pump that moves liquid metal, molten salt, brine, or other electrically conductive liquid using electromagnetism.

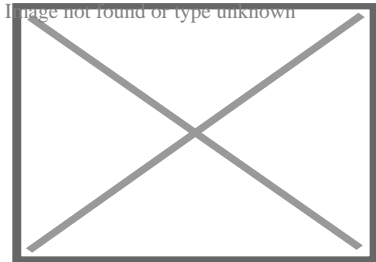
A magnetic field is set at right angles to the direction the liquid moves in, and a current is passed through it. This causes an electromagnetic force that moves the liquid.

Applications include pumping molten solder in many wave soldering machines, pumping liquid-metal coolant, and magnetohydrodynamic drive.

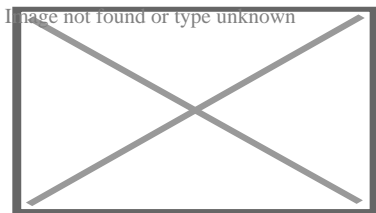


# Positive-displacement pumps

[edit]



Lobe pump internals



Lobe pump internals

A positive-displacement pump makes a fluid move by trapping a fixed amount and forcing (displacing) that trapped volume into the discharge pipe.

Some positive-displacement pumps use an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant through each cycle of operation.

## Positive-displacement pump behavior and safety

[edit]

Positive-displacement pumps, unlike centrifugal, can theoretically produce the same flow at a given rotational speed no matter what the discharge pressure. Thus, positive-displacement pumps are *constant flow machines*. However, a slight increase in internal leakage as the pressure increases prevents a truly constant flow rate.

A positive-displacement pump must not operate against a closed valve on the discharge side of the pump, because it has no shutoff head like centrifugal pumps. A positive-displacement pump operating against a closed discharge valve continues to produce flow and the pressure in the discharge line increases until the line bursts, the pump is



severely damaged, or both.

A relief or safety valve on the discharge side of the positive-displacement pump is therefore necessary. The relief valve can be internal or external. The pump manufacturer normally has the option to supply internal relief or safety valves. The internal valve is usually used only as a safety precaution. An external relief valve in the discharge line, with a return line back to the suction line or supply tank, provides increased safety.

## Positive-displacement types

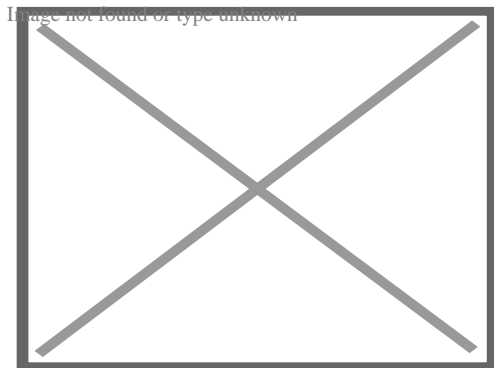
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A positive-displacement pump can be further classified according to the mechanism used to move the fluid:

- *Rotary-type* positive displacement: internal and external gear pump, screw pump, lobe pump, shuttle block, flexible vane and sliding vane, circumferential piston, flexible impeller, helical twisted roots (e.g. the Wendelkolben pump) and liquid-ring pumps
- *Reciprocating-type* positive displacement: piston pumps, plunger pumps and diaphragm pumps
- *Linear-type* positive displacement: rope pumps and chain pumps

## Rotary positive-displacement pumps

[edit]



Rotary vane pump

These pumps move fluid using a rotating mechanism that creates a vacuum that captures and draws in the liquid.<sup>[4]</sup>

*Advantages:* Rotary pumps are very efficient<sup>[5]</sup> because they can handle highly viscous fluids with higher flow rates as viscosity increases.<sup>[6]</sup>



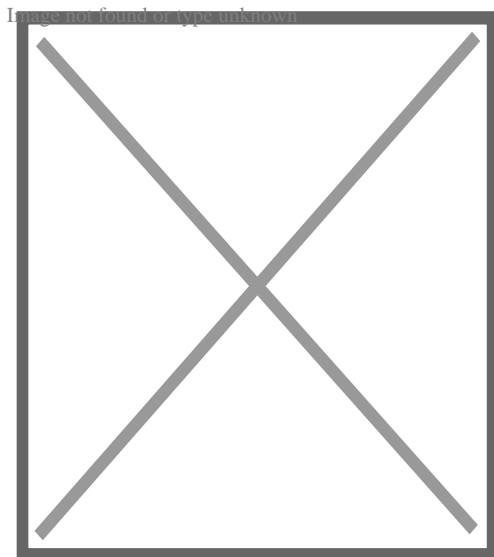
*Drawbacks:* The nature of the pump requires very close clearances between the rotating pump and the outer edge, making it rotate at a slow, steady speed. If rotary pumps are operated at high speeds, the fluids cause erosion, which eventually causes enlarged clearances that liquid can pass through, which reduces efficiency.

Rotary positive-displacement pumps fall into five main types:

- Gear pumps – a simple type of rotary pump where the liquid is pushed around a pair of gears.
- Screw pumps – the shape of the internals of this pump is usually two screws turning against each other to pump the liquid
- Rotary vane pumps
- Hollow disc pumps (also known as eccentric disc pumps or hollow rotary disc pumps), similar to scroll compressors, these have an eccentric cylindrical rotor encased in a circular housing. As the rotor orbits, it traps fluid between the rotor and the casing, drawing the fluid through the pump. It is used for highly viscous fluids like petroleum-derived products, and it can also support high pressures of up to 290 psi.<sup>[7][8][9][10][11][12][13]</sup>
- Peristaltic pumps have rollers which pinch a section of flexible tubing, forcing the liquid ahead as the rollers advance. Because they are very easy to keep clean, these are popular for dispensing food, medicine, and concrete.

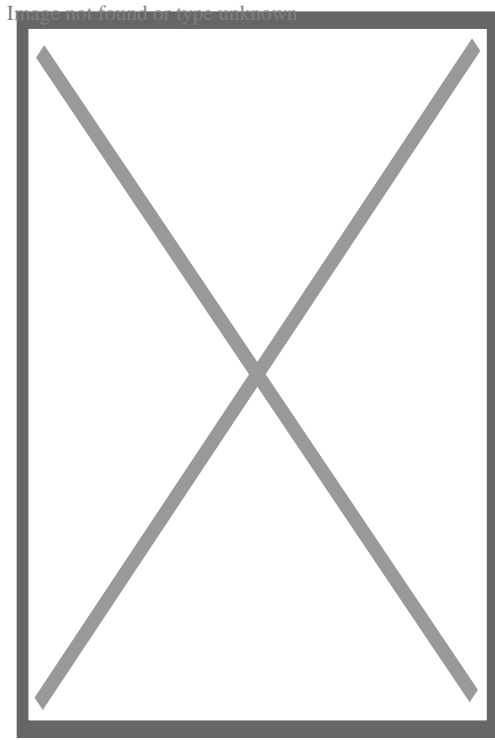
## Reciprocating positive-displacement pumps

[edit]



Simple hand pump





Antique "pitcher" pump (c. 1924) at the Colored School in Alapaha, Georgia, US

See also: Reciprocating pump

Reciprocating pumps move the fluid using one or more oscillating pistons, plungers, or membranes (diaphragms), while valves restrict fluid motion to the desired direction. In order for suction to take place, the pump must first pull the plunger in an outward motion to decrease pressure in the chamber. Once the plunger pushes back, it will increase the chamber pressure and the inward pressure of the plunger will then open the discharge valve and release the fluid into the delivery pipe at constant flow rate and increased pressure.

Pumps in this category range from *simplex*, with one cylinder, to in some cases *quad* (four) cylinders, or more. Many reciprocating-type pumps are *duplex* (two) or *triplex* (three) cylinder. They can be either *single-acting* with suction during one direction of piston motion and discharge on the other, or *double-acting* with suction and discharge in both directions. The pumps can be powered manually, by air or steam, or by a belt driven by an engine. This type of pump was used extensively in the 19th century—in the early days of steam propulsion—as boiler feed water pumps. Now reciprocating pumps typically pump highly viscous fluids like concrete and heavy oils, and serve in special applications that demand low flow rates against high resistance. Reciprocating hand pumps were widely used to pump water from wells. Common bicycle pumps and foot pumps for inflation use reciprocating action.



These positive-displacement pumps have an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pumps as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant given each cycle of operation and the pump's volumetric efficiency can be achieved through routine maintenance and inspection of its valves.[<sup>14</sup>]

Typical reciprocating pumps are:

- *Plunger pump* – a reciprocating plunger pushes the fluid through one or two open valves, closed by suction on the way back.
- *Diaphragm pump* – similar to plunger pumps, where the plunger pressurizes hydraulic oil which is used to flex a diaphragm in the pumping cylinder. Diaphragm valves are used to pump hazardous and toxic fluids.
- *Piston pump displacement pumps* – *usually simple devices for pumping small amounts of liquid or gel manually. The common hand soap dispenser is such a pump.*
- *Radial piston pump* – a form of hydraulic pump where pistons extend in a radial direction.
- *Vibratory pump or vibration pump* – a particularly low-cost form of plunger pump, popular in low-cost espresso machines.[<sup>15</sup>][<sup>16</sup>] The only moving part is a spring-loaded piston, the armature of a solenoid. Driven by half-wave rectified alternating current, the piston is forced forward while energized, and is retracted by the spring during the other half cycle. Due to their inefficiency, vibratory pumps typically cannot be operated for more than one minute without overheating, so are limited to intermittent duty.

## Various positive-displacement pumps

[edit]

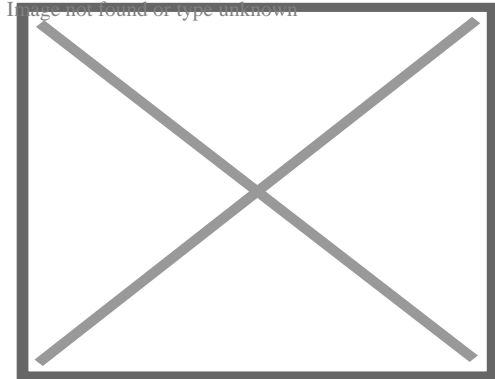
The positive-displacement principle applies in these pumps:

- Rotary lobe pump
- Progressing cavity pump
- Rotary gear pump
- Piston pump
- Diaphragm pump
- Screw pump
- Gear pump
- Hydraulic pump
- Rotary vane pump
- Peristaltic pump
- Rope pump
- Flexible impeller pump



## Gear pump

[edit]



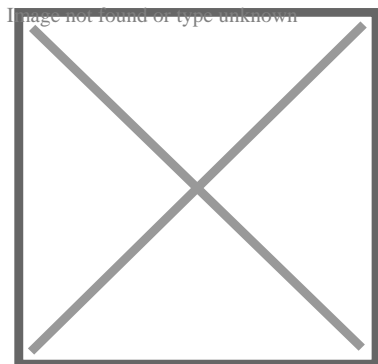
Gear pump

Main article: Gear pump

This is the simplest form of rotary positive-displacement pumps. It consists of two meshed gears that rotate in a closely fitted casing. The tooth spaces trap fluid and force it around the outer periphery. The fluid does not travel back on the meshed part, because the teeth mesh closely in the center. Gear pumps see wide use in car engine oil pumps and in various hydraulic power packs.

## Screw pump

[edit]



Screw pump



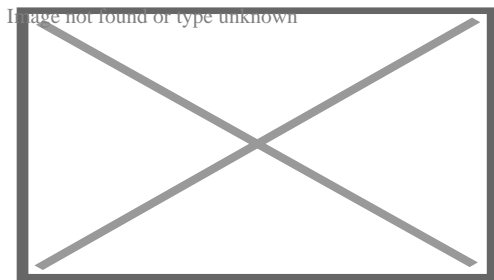
Main article: Screw pump

A screw pump is a more complicated type of rotary pump that uses two or three screws with opposing thread — e.g., one screw turns clockwise and the other counterclockwise. The screws are mounted on parallel shafts that often have gears that mesh so the shafts turn together and everything stays in place. In some cases the driven screw drives the secondary screw, without gears, often using the fluid to limit abrasion. The screws turn on the shafts and drive fluid through the pump. As with other forms of rotary pumps, the clearance between moving parts and the pump's casing is minimal.

## Progressing cavity pump

[edit]

Main article: Progressing cavity pump



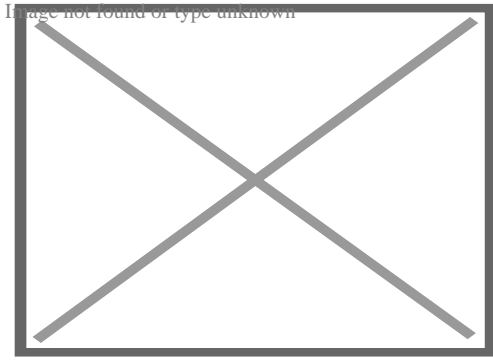
Progressing cavity pump

Widely used for pumping difficult materials, such as sewage sludge contaminated with large particles, a progressing cavity pump consists of a helical rotor, about ten times as long as its width, and a stator, mainly made out of rubber. This can be visualized as a central core of diameter  $x$  with, typically, a curved spiral wound around of thickness half  $x$ , though in reality it is manufactured in a single lobe. This shaft fits inside a heavy-duty rubber sleeve or stator, of wall thickness also typically  $x$ . As the shaft rotates inside the stator, the rotor gradually forces fluid up the rubber cavity. Such pumps can develop very high pressure at low volumes at a rate of 90 PSI per stage on water for standard configurations.

## Roots-type pump

[edit]





A Roots lobe pump

Main article: Roots-type supercharger

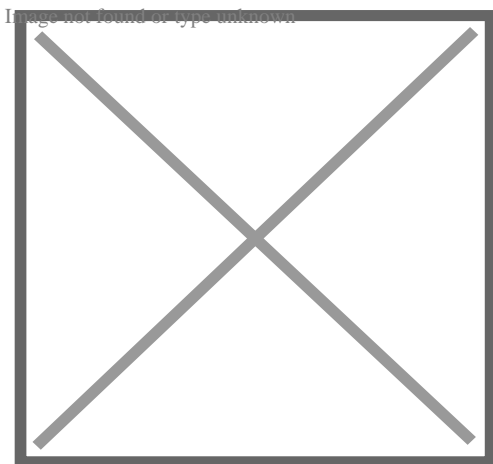
Named after the Roots brothers who invented it, this lobe pump displaces the fluid trapped between two long helical rotors, each fitted into the other when perpendicular at 90°, rotating inside a triangular shaped sealing line configuration, both at the point of suction and at the point of discharge. This design produces a continuous flow with equal volume and no vortex. It can work at low pulsation rates, and offers gentle performance that some applications require.

Applications include:

- High capacity industrial air compressors.
- Roots superchargers on internal combustion engines.
- A brand of civil defense siren, the Federal Signal Corporation's Thunderbolt.

## Peristaltic pump

[edit]



360° peristaltic pump



Main article: Peristaltic pump

A *peristaltic pump* is a type of positive-displacement pump. It contains fluid within a flexible tube fitted inside a circular pump casing (though linear peristaltic pumps have been made). A number of *rollers*, *shoes*, or *wipers* attached to a rotor compress the flexible tube. As the rotor turns, the part of the tube under compression closes (or *occludes*), forcing the fluid through the tube. Additionally, when the tube opens to its natural state after the passing of the cam it draws (*restitution*) fluid into the pump. This process is called *peristalsis* and is used in many biological systems such as the gastrointestinal tract.

## Plunger pumps

[edit]

Main article: Plunger pump

*Plunger pumps* are reciprocating positive-displacement pumps.

These consist of a cylinder with a reciprocating plunger. The suction and discharge valves are mounted in the head of the cylinder. In the suction stroke, the plunger retracts and the suction valves open causing suction of fluid into the cylinder. In the forward stroke, the plunger pushes the liquid out of the discharge valve. Efficiency and common problems: With only one cylinder in plunger pumps, the fluid flow varies between maximum flow when the plunger moves through the middle positions, and zero flow when the plunger is at the end positions. A lot of energy is wasted when the fluid is accelerated in the piping system. Vibration and *water hammer* may be a serious problem. In general, the problems are compensated for by using two or more cylinders not working in phase with each other. Centrifugal pumps are also susceptible to water hammer. Surge analysis, a specialized study, helps evaluate this risk in such systems.

## Triplex-style plunger pump

[edit]

Triplex plunger pumps use three plungers, which reduces the pulsation relative to single reciprocating plunger pumps. Adding a pulsation dampener on the pump outlet can further smooth the *pump ripple*, or ripple graph of a pump transducer. The dynamic relationship of the high-pressure fluid and plunger generally requires high-quality plunger



seals. Plunger pumps with a larger number of plungers have the benefit of increased flow, or smoother flow without a pulsation damper. The increase in moving parts and crankshaft load is one drawback.

Car washes often use these triplex-style plunger pumps (perhaps without pulsation dampers). In 1968, William Bruggeman reduced the size of the triplex pump and increased the lifespan so that car washes could use equipment with smaller footprints. Durable high-pressure seals, low-pressure seals and oil seals, hardened crankshafts, hardened connecting rods, thick ceramic plungers and heavier duty ball and roller bearings improve reliability in triplex pumps. Triplex pumps now are in a myriad of markets across the world.

Triplex pumps with shorter lifetimes are commonplace to the home user. A person who uses a home pressure washer for 10 hours a year may be satisfied with a pump that lasts 100 hours between rebuilds. Industrial-grade or continuous duty triplex pumps on the other end of the quality spectrum may run for as much as 2,080 hours a year.<sup>[17]</sup>

The oil and gas drilling industry uses massive semi-trailer-transported triplex pumps called mud pumps to pump drilling mud, which cools the drill bit and carries the cuttings back to the surface.<sup>[18]</sup> Drillers use triplex or even quintuplex pumps to inject water and solvents deep into shale in the extraction process called *fracking*.<sup>[19]</sup>

## **Diaphragm pump**

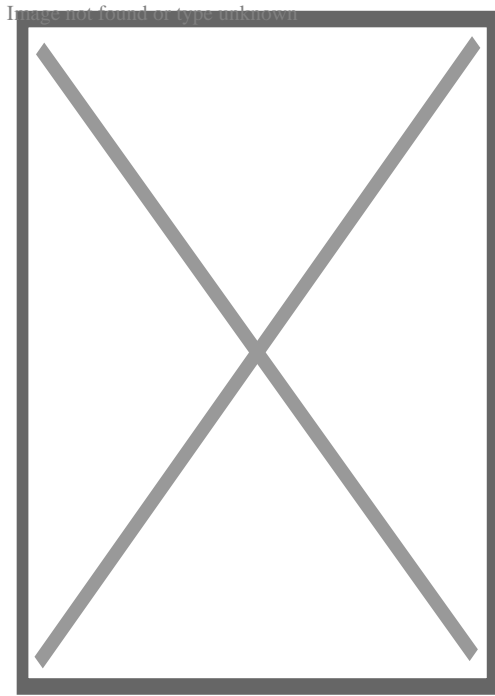
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Typically run on electricity compressed air, diaphragm pumps are relatively inexpensive and can perform a wide variety of duties, from pumping air into an aquarium, to liquids through a filter press. Double-diaphragm pumps can handle viscous fluids and abrasive materials with a gentle pumping process ideal for transporting shear-sensitive media.<sup>[20]</sup>

## **Rope pump**

[edit]





Rope pump schematic

Main article: Rope pump

Devised in China as chain pumps over 1000 years ago, these pumps can be made from very simple materials: A rope, a wheel and a pipe are sufficient to make a simple rope pump. Rope pump efficiency has been studied by grassroots organizations and the techniques for making and running them have been continuously improved.<sup>[21]</sup>

## Impulse pump

[edit]

Impulse pumps use pressure created by gas (usually air). In some impulse pumps the gas trapped in the liquid (usually water), is released and accumulated somewhere in the pump, creating a pressure that can push part of the liquid upwards.

Conventional impulse pumps include:

- *Hydraulic ram pumps* – kinetic energy of a low-head water supply is stored temporarily in an air-bubble hydraulic accumulator, then used to drive water to a higher head.
- *Pulser pumps* – run with natural resources, by kinetic energy only.



- *Airlift pumps* – run on air inserted into pipe, which pushes the water up when bubbles move upward

Instead of a gas accumulation and releasing cycle, the pressure can be created by burning of hydrocarbons. Such combustion driven pumps directly transmit the impulse from a combustion event through the actuation membrane to the pump fluid. In order to allow this direct transmission, the pump needs to be almost entirely made of an elastomer (e.g. silicone rubber). Hence, the combustion causes the membrane to expand and thereby pumps the fluid out of the adjacent pumping chamber. The first combustion-driven soft pump was developed by ETH Zurich.<sup>[22]</sup>

## Hydraulic ram pump

[edit]

A hydraulic ram is a water pump powered by hydropower.<sup>[23]</sup>

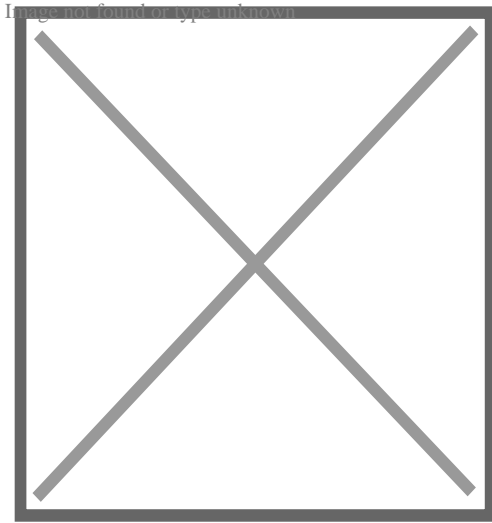
It takes in water at relatively low pressure and high flow-rate and outputs water at a higher hydraulic-head and lower flow-rate. The device uses the water hammer effect to develop pressure that lifts a portion of the input water that powers the pump to a point higher than where the water started.

The hydraulic ram is sometimes used in remote areas, where there is both a source of low-head hydropower, and a need for pumping water to a destination higher in elevation than the source. In this situation, the ram is often useful, since it requires no outside source of power other than the kinetic energy of flowing water.

## Velocity pumps

[edit]





A centrifugal pump uses an impeller with backward-swept arms

Rotodynamic pumps (or dynamic pumps) are a type of velocity pump in which kinetic energy is added to the fluid by increasing the flow velocity. This increase in energy is converted to a gain in potential energy (pressure) when the velocity is reduced prior to or as the flow exits the pump into the discharge pipe. This conversion of kinetic energy to pressure is explained by the *First law of thermodynamics*, or more specifically by *Bernoulli's principle*.

Dynamic pumps can be further subdivided according to the means in which the velocity gain is achieved.<sup>[24]</sup>

These types of pumps have a number of characteristics:

1. Continuous energy
2. Conversion of added energy to increase in kinetic energy (increase in velocity)
3. Conversion of increased velocity (kinetic energy) to an increase in pressure head

A practical difference between dynamic and positive-displacement pumps is how they operate under closed valve conditions. Positive-displacement pumps physically displace fluid, so closing a valve downstream of a positive-displacement pump produces a continual pressure build up that can cause mechanical failure of pipeline or pump. Dynamic pumps differ in that they can be safely operated under closed valve conditions (for short periods of time).

## Radial-flow pump

[edit]

Such a pump is also referred to as a *centrifugal pump*. The fluid enters along the axis or center, is accelerated by the impeller and exits at right angles to the shaft (radially); an



example is the centrifugal fan, which is commonly used to implement a vacuum cleaner. Another type of radial-flow pump is a vortex pump. The liquid in them moves in tangential direction around the working wheel. The conversion from the mechanical energy of motor into the potential energy of flow comes by means of multiple whirls, which are excited by the impeller in the working channel of the pump. Generally, a radial-flow pump operates at higher pressures and lower flow rates than an axial- or a mixed-flow pump.

## Axial-flow pump

[edit]

Main article: Axial-flow pump

These are also referred to as *all-fluid pumps*. The fluid is pushed outward or inward to move fluid axially. They operate at much lower pressures and higher flow rates than radial-flow (centrifugal) pumps. Axial-flow pumps cannot be run up to speed without special precaution. If at a low flow rate, the total head rise and high torque associated with this pipe would mean that the starting torque would have to become a function of acceleration for the whole mass of liquid in the pipe system.<sup>[25]</sup>

Mixed-flow pumps function as a compromise between radial and axial-flow pumps. The fluid experiences both radial acceleration and lift and exits the impeller somewhere between 0 and 90 degrees from the axial direction. As a consequence mixed-flow pumps operate at higher pressures than axial-flow pumps while delivering higher discharges than radial-flow pumps. The exit angle of the flow dictates the pressure head-discharge characteristic in relation to radial and mixed-flow.

## Regenerative turbine pump

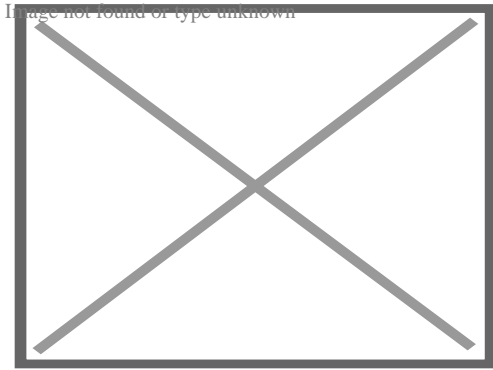
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Regenerative turbine pump animation

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Regenerative turbine pump animation





Close-up of a Regenerative Turbine Pump Impeller

Also known as **drag**, **friction**, **liquid-ring pump**, **peripheral**, **traction**, **turbulence**, or **vortex** pumps, regenerative turbine pumps are a class of rotodynamic pump that operates at high head pressures, typically 4–20 bars (400–2,000 kPa; 58–290 psi).<sup>[26]</sup>

The pump has an impeller with a number of vanes or paddles which spins in a cavity. The suction port and pressure ports are located at the perimeter of the cavity and are isolated by a barrier called a **stripper**, which allows only the **tip channel** (fluid between the blades) to recirculate, and forces any fluid in the **side channel** (fluid in the cavity outside of the blades) through the pressure port. In a regenerative turbine pump, as fluid spirals repeatedly from a vane into the side channel and back to the next vane, kinetic energy is imparted to the periphery,<sup>[26]</sup> thus pressure builds with each spiral, in a manner similar to a regenerative blower.<sup>[27][28][29]</sup>

As regenerative turbine pumps cannot become vapor locked, they are commonly applied to volatile, hot, or cryogenic fluid transport. However, as tolerances are typically tight, they are vulnerable to solids or particles causing jamming or rapid wear. Efficiency is typically low, and pressure and power consumption typically decrease with flow. Additionally, pumping direction can be reversed by reversing direction of spin.<sup>[29][27][30]</sup>

## Side-channel pump

[edit]

A **side-channel** pump has a suction disk, an impeller, and a discharge disk.<sup>[31]</sup>

## Eductor-jet pump

[edit]

Main article: Eductor-jet pump



This uses a jet, often of steam, to create a low pressure. This low pressure sucks in fluid and propels it into a higher-pressure region.

## Gravity pumps

[edit]

Gravity pumps include the *syphon* and *Heron's fountain*. The *hydraulic ram* is also sometimes called a gravity pump. In a gravity pump the fluid is lifted by gravitational force.

## Steam pump

[edit]

Steam pumps have been for a long time mainly of historical interest. They include any type of pump powered by a steam engine and also pistonless pumps such as Thomas Savery's or the Pulsometer steam pump.

Recently there has been a resurgence of interest in low-power solar steam pumps for use in smallholder irrigation in developing countries. Previously small steam engines have not been viable because of escalating inefficiencies as vapour engines decrease in size. However the use of modern engineering materials coupled with alternative engine configurations has meant that these types of system are now a cost-effective opportunity.

## Valveless pumps

[edit]

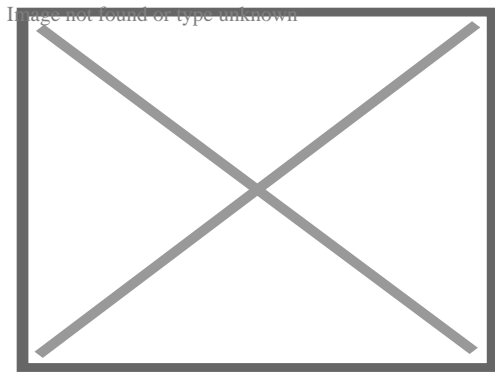
Valveless pumping assists in fluid transport in various biomedical and engineering systems. In a valveless pumping system, no valves (or physical occlusions) are present to regulate the flow direction. The fluid pumping efficiency of a valveless system, however, is not necessarily lower than that having valves. In fact, many fluid-dynamical systems in nature and engineering more or less rely upon valveless pumping to transport the working fluids therein. For instance, blood circulation in the cardiovascular system is maintained to some extent even when the heart's valves fail. Meanwhile, the embryonic



vertebrate heart begins pumping blood long before the development of discernible chambers and valves. Similar to blood circulation in one direction, bird respiratory systems pump air in one direction in rigid lungs, but without any physiological valve. In microfluidics, valveless impedance pumps have been fabricated, and are expected to be particularly suitable for handling sensitive biofluids. Ink jet printers operating on the piezoelectric transducer principle also use valveless pumping. The pump chamber is emptied through the printing jet due to reduced flow impedance in that direction and refilled by capillary action.

## Pump repairs

[edit]



Derelict windmill connected to water pump with water storage tank in the foreground

Examining pump repair records and mean time between failures (MTBF) is of great importance to responsible and conscientious pump users. In view of that fact, the preface to the 2006 Pump User's Handbook alludes to "pump failure" statistics. For the sake of convenience, these failure statistics often are translated into MTBF (in this case, installed life before failure).<sup>[32]</sup>

In early 2005, Gordon Buck, John Crane Inc.'s chief engineer for field operations in Baton Rouge, Louisiana, examined the repair records for a number of refinery and chemical plants to obtain meaningful reliability data for centrifugal pumps. A total of 15 operating plants having nearly 15,000 pumps were included in the survey. The smallest of these plants had about 100 pumps; several plants had over 2000. All facilities were located in the United States. In addition, considered as "new", others as "renewed" and still others as "established". Many of these plants—but not all—had an alliance arrangement with John Crane. In some cases, the alliance contract included having a John Crane Inc. technician or engineer on-site to coordinate various aspects of the program.

Not all plants are refineries, however, and different results occur elsewhere. In chemical plants, pumps have historically been "throw-away" items as chemical attack limits life.



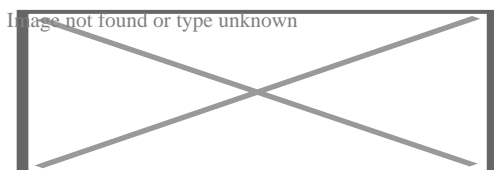
Things have improved in recent years, but the somewhat restricted space available in "old" DIN and ASME-standardized stuffing boxes places limits on the type of seal that fits. Unless the pump user upgrades the seal chamber, the pump only accommodates more compact and simple versions. Without this upgrading, lifetimes in chemical installations are generally around 50 to 60 percent of the refinery values.

Unscheduled maintenance is often one of the most significant costs of ownership, and failures of mechanical seals and bearings are among the major causes. Keep in mind the potential value of selecting pumps that cost more initially, but last much longer between repairs. The MTBF of a better pump may be one to four years longer than that of its non-upgraded counterpart. Consider that published average values of avoided pump failures range from US\$2600 to US\$12,000. This does not include lost opportunity costs. One pump fire occurs per 1000 failures. Having fewer pump failures means having fewer destructive pump fires.

As has been noted, a typical pump failure, based on actual year 2002 reports, costs US\$5,000 on average. This includes costs for material, parts, labor and overhead. Extending a pump's MTBF from 12 to 18 months would save US\$1,667 per year — which might be greater than the cost to upgrade the centrifugal pump's reliability.<sup>[32][1][33]</sup>

## Applications

[edit]



Metering pump for gasoline and additives

Pumps are used throughout society for a variety of purposes. Early applications includes the use of the windmill or watermill to pump water. Today, the pump is used for irrigation, water supply, gasoline supply, air conditioning systems, refrigeration (usually called a compressor), chemical movement, sewage movement, flood control, marine services, etc.

Because of the wide variety of applications, pumps have a plethora of shapes and sizes: from very large to very small, from handling gas to handling liquid, from high pressure to low pressure, and from high volume to low volume.



# Priming a pump

[edit]

Typically, a liquid pump cannot simply draw air. The feed line of the pump and the internal body surrounding the pumping mechanism must first be filled with the liquid that requires pumping: An operator must introduce liquid into the system to initiate the pumping, known as *priming* the pump. Loss of prime is usually due to ingestion of air into the pump, or evaporation of the working fluid if the pump is used infrequently.

Clearances and displacement ratios in pumps for liquids are insufficient for pumping compressible gas, so air or other gasses in the pump can not be evacuated by the pump's action alone. This is the case with most velocity (rotodynamic) pumps — for example, centrifugal pumps. For such pumps, the position of the pump and intake tubing should be lower than the suction point so it is primed by gravity; otherwise the pump should be manually filled with liquid or a secondary pump should be used until all air is removed from the suction line and the pump casing. Liquid ring pumps have a dedicated intake for the priming liquid separate from the intake of the fluid being pumped, as the fluid being pumped may be a gas or mix of gas, liquid, and solids. For these pumps the priming liquid intake must be supplied continuously (either by gravity or pressure), however the intake for the fluid being pumped is capable of drawing a vacuum equivalent to the boiling point of the priming liquid.<sup>[34]</sup>

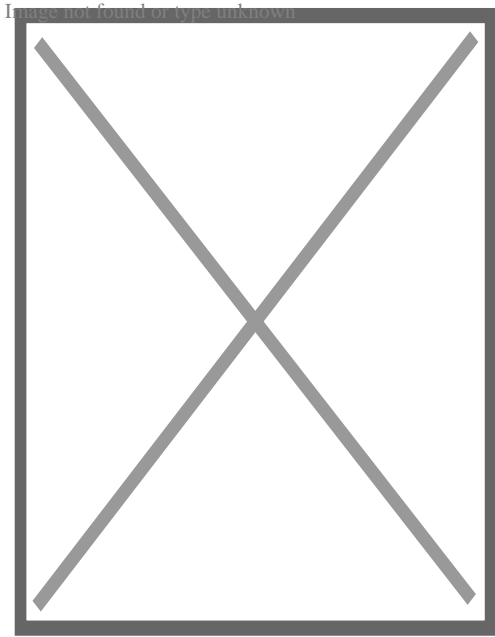
Positive-displacement pumps, however, tend to have sufficiently tight sealing between the moving parts and the casing or housing of the pump that they can be described as *self-priming*. Such pumps can also serve as *priming pumps*, so-called when they are used to fulfill that need for other pumps in lieu of action taken by a human operator.

## Pumps as public water supplies

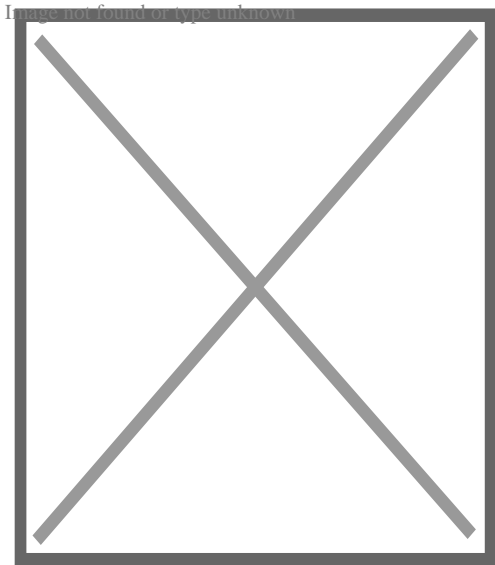
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Main article: Hand pump

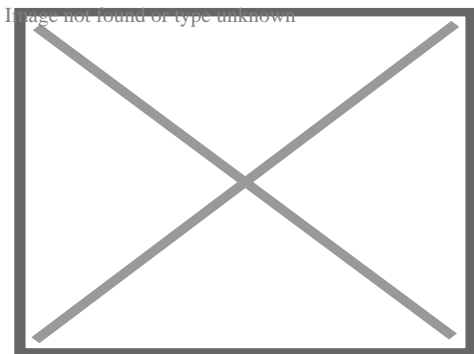




Arabic depiction of a piston pump, by Al-Jazari, c. 1206<sup>[35]</sup><sup>[36]</sup>



First European depiction of a piston pump, by Taccola, c. 1450<sup>[37]</sup>



Irrigation is underway by pump-enabled extraction directly from the Gumti, seen in the background, in Comilla, Bangladesh.



One sort of pump once common worldwide was a hand-powered water pump, or 'pitcher pump'. It was commonly installed over community water wells in the days before piped water supplies.

In parts of the British Isles, it was often called *the parish pump*. Though such community pumps are no longer common, people still used the expression *parish pump* to describe a place or forum where matters of local interest are discussed.<sup>[38]</sup>

Because water from pitcher pumps is drawn directly from the soil, it is more prone to contamination. If such water is not filtered and purified, consumption of it might lead to gastrointestinal or other water-borne diseases. A notorious case is the 1854 Broad Street cholera outbreak. At the time it was not known how cholera was transmitted, but physician John Snow suspected contaminated water and had the handle of the public pump he suspected removed; the outbreak then subsided.

Modern hand-operated community pumps are considered the most sustainable low-cost option for safe water supply in resource-poor settings, often in rural areas in developing countries. A hand pump opens access to deeper groundwater that is often not polluted and also improves the safety of a well by protecting the water source from contaminated buckets. Pumps such as the Afridev pump are designed to be cheap to build and install, and easy to maintain with simple parts. However, scarcity of spare parts for these type of pumps in some regions of Africa has diminished their utility for these areas.

## Sealing multiphase pumping applications

[edit]

Multiphase pumping applications, also referred to as tri-phase, have grown due to increased oil drilling activity. In addition, the economics of multiphase production is attractive to upstream operations as it leads to simpler, smaller in-field installations, reduced equipment costs and improved production rates. In essence, the multiphase pump can accommodate all fluid stream properties with one piece of equipment, which has a smaller footprint. Often, two smaller multiphase pumps are installed in series rather than having just one massive pump.

### Types and features of multiphase pumps

[edit]



## Helico-axial (centrifugal)

[edit]

A rotodynamic pump with one single shaft that requires two mechanical seals, this pump uses an open-type axial impeller. It is often called a *Poseidon pump*, and can be described as a cross between an axial compressor and a centrifugal pump.

## Twin-screw (positive-displacement)

[edit]

The twin-screw pump is constructed of two inter-meshing screws that move the pumped fluid. Twin screw pumps are often used when pumping conditions contain high gas volume fractions and fluctuating inlet conditions. Four mechanical seals are required to seal the two shafts.

## Progressive cavity (positive-displacement)

[edit]

Progressive Cavity Pumps are well suited to pump sludge, slurries, viscous, and shear sensitive fluids. [39] Progressive cavity pumps are single-screw types use in surface and downhole oil production.[40] They serve a vast arrange of industries and applications ranging from Wastewater Treatment,[41] Pulp and Paper, oil and gas, mining, and oil and gas.

## Electric submersible (centrifugal)

[edit]

These pumps are basically multistage centrifugal pumps and are widely used in oil well applications as a method for artificial lift. These pumps are usually specified when the pumped fluid is mainly liquid.

*Buffer tank* A buffer tank is often installed upstream of the pump suction nozzle in case of a slug flow. The buffer tank breaks the energy of the liquid slug, smooths any fluctuations in the incoming flow and acts as a sand trap.



As the name indicates, multiphase pumps and their mechanical seals can encounter a large variation in service conditions such as changing process fluid composition, temperature variations, high and low operating pressures and exposure to abrasive/erosive media. The challenge is selecting the appropriate mechanical seal arrangement and support system to ensure maximized seal life and its overall effectiveness.<sup>[42][43][44]</sup>

## Specifications

[edit]

Pumps are commonly rated by horsepower, volumetric flow rate, outlet pressure in metres (or feet) of head, inlet suction in suction feet (or metres) of head. The head can be simplified as the number of feet or metres the pump can raise or lower a column of water at atmospheric pressure.

From an initial design point of view, engineers often use a quantity termed the specific speed to identify the most suitable pump type for a particular combination of flow rate and head. Net Positive Suction Head (NPSH) is crucial for pump performance. It has two key aspects: 1) NPSHr (Required): The Head required for the pump to operate without cavitation issues. 2) NPSHa (Available): The actual pressure provided by the system (e.g., from an overhead tank). For optimal pump operation, NPSHa must always exceed NPSHr. This ensures the pump has enough pressure to prevent cavitation, a damaging condition.

## Pumping power

[edit]

Main article: Bernoulli's equation

The power imparted into a fluid increases the energy of the fluid per unit volume. Thus the power relationship is between the conversion of the mechanical energy of the pump mechanism and the fluid elements within the pump. In general, this is governed by a series of simultaneous differential equations, known as the Navier–Stokes equations. However a more simple equation relating only the different energies in the fluid, known as Bernoulli's equation can be used. Hence the power, P, required by the pump:

$$P = \frac{\Delta p Q}{\eta}$$

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where  $\Delta p$  is the change in total pressure between the inlet and outlet (in Pa), and Q, the volume flow-rate of the fluid is given in m<sup>3</sup>/s. The total pressure may have gravitational, static pressure and kinetic energy components; i.e. energy is distributed between



change in the fluid's gravitational potential energy (going up or down hill), change in velocity, or change in static pressure.  $\eta$  is the pump efficiency, and may be given by the manufacturer's information, such as in the form of a pump curve, and is typically derived from either fluid dynamics simulation (i.e. solutions to the Navier–Stokes for the particular pump geometry), or by testing. The efficiency of the pump depends upon the pump's configuration and operating conditions (such as rotational speed, fluid density and viscosity etc.)

$$\Delta p = \rho \frac{(v_2^2 - v_1^2)}{2} + \rho \Delta z + \Delta p_{\text{static}}$$

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For a typical "pumping" configuration, the work is imparted on the fluid, and is thus positive. For the fluid imparting the work on the pump (i.e. a turbine), the work is negative. Power required to drive the pump is determined by dividing the output power by the pump efficiency. Furthermore, this definition encompasses pumps with no moving parts, such as a siphon.

## Efficiency

[edit]

Pump efficiency is defined as the ratio of the power imparted on the fluid by the pump in relation to the power supplied to drive the pump. Its value is not fixed for a given pump, efficiency is a function of the discharge and therefore also operating head. For centrifugal pumps, the efficiency tends to increase with flow rate up to a point midway through the operating range (peak efficiency or Best Efficiency Point (BEP) ) and then declines as flow rates rise further. Pump performance data such as this is usually supplied by the manufacturer before pump selection. Pump efficiencies tend to decline over time due to wear (e.g. increasing clearances as impellers reduce in size).

When a system includes a centrifugal pump, an important design issue is matching the *head loss-flow characteristic* with the pump so that it operates at or close to the point of its maximum efficiency.

Pump efficiency is an important aspect and pumps should be regularly tested. Thermodynamic pump testing is one method.

## Minimum flow protection

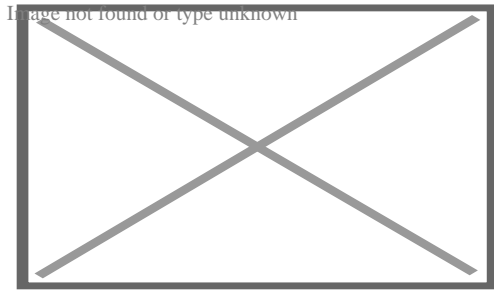
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Most large pumps have a minimum flow requirement below which the pump may be damaged by overheating, impeller wear, vibration, seal failure, drive shaft damage or poor performance.<sup>[45]</sup> A minimum flow protection system ensures that the pump is not



operated below the minimum flow rate. The system protects the pump even if it is shut-in or dead-headed, that is, if the discharge line is completely closed.<sup>[46]</sup>

The simplest minimum flow system is a pipe running from the pump discharge line back to the suction line. This line is fitted with an orifice plate sized to allow the pump minimum flow to pass.<sup>[47]</sup> The arrangement ensures that the minimum flow is maintained, although it is wasteful as it recycles fluid even when the flow through the pump exceeds the minimum flow.



Part of a process flow diagram of pump minimum flow protection arrangement

A more sophisticated, but more costly, system (see diagram) comprises a flow measuring device (FE) in the pump discharge which provides a signal into a flow controller (FIC) which actuates a flow control valve (FCV) in the recycle line. If the measured flow exceeds the minimum flow then the FCV is closed. If the measured flow falls below the minimum flow the FCV opens to maintain the minimum flowrate.<sup>[45]</sup>

As the fluids are recycled the kinetic energy of the pump increases the temperature of the fluid. For many pumps this added heat energy is dissipated through the pipework. However, for large industrial pumps, such as oil pipeline pumps, a recycle cooler is provided in the recycle line to cool the fluids to the normal suction temperature.<sup>[48]</sup> Alternatively the recycled fluids may be returned to upstream of the export cooler in an oil refinery, oil terminal, or offshore installation.

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[edit]

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Machines

### Classical simple machines

### Clocks

### Compressors and pumps

### External combustion engines

### Internal combustion engines

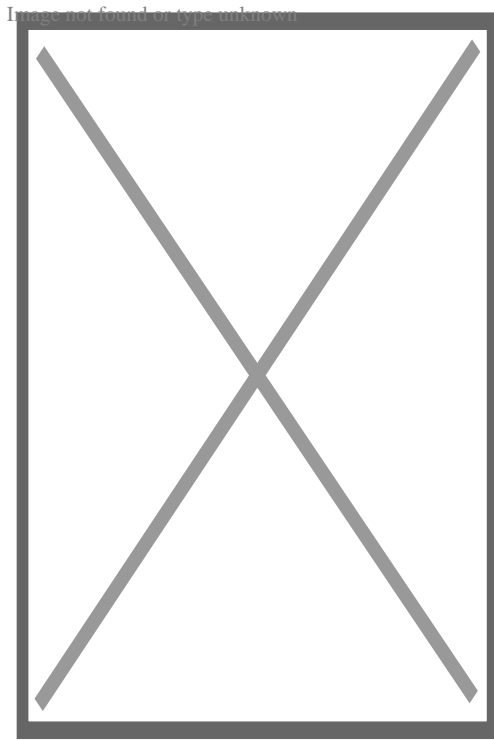
- Inclined plane
- Lever
- Pulley
- Screw
- Wedge
- Wheel and axle
- Atomic clock
- Chronometer
- Pendulum clock
- Quartz clock
- Archimedes' screw
- Eductor-jet pump
- Hydraulic ram
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- Vacuum pump
- Steam engine
- Stirling engine
- Gas turbine
- Reciprocating engine
- Rotary engine
- Nutating disc engine



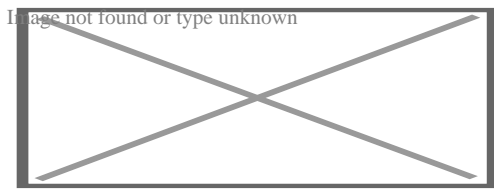




Not to be confused with Concrete.



Cement powder in a bag, ready to be mixed with aggregates and water.<sup>[1]</sup>



Cement block construction examples from the Multiplex Manufacturing Company of Toledo, Ohio, in 1905

A **cement** is a binder, a chemical substance used for construction that sets, hardens, and adheres to other materials to bind them together. Cement is seldom used on its own, but rather to bind sand and gravel (aggregate) together. Cement mixed with fine aggregate produces mortar for masonry, or with sand and gravel, produces concrete. Concrete is the most widely used material in existence and is behind only water as the planet's most-consumed resource.<sup>[2]</sup>

Cements used in construction are usually inorganic, often lime- or calcium silicate-based, and are either **hydraulic** or less commonly **non-hydraulic**, depending on the ability of the cement to set in the presence of water (see hydraulic and non-hydraulic lime plaster).



**Hydraulic cements** (e.g., Portland cement) set and become adhesive through a chemical reaction between the dry ingredients and water. The chemical reaction results in mineral hydrates that are not very water-soluble. This allows setting in wet conditions or under water and further protects the hardened material from chemical attack. The chemical process for hydraulic cement was found by ancient Romans who used volcanic ash (pozzolana) with added lime (calcium oxide).

**Non-hydraulic cement** (less common) does not set in wet conditions or under water. Rather, it sets as it dries and reacts with carbon dioxide in the air. It is resistant to attack by chemicals after setting.

The word "cement" can be traced back to the Ancient Roman term *opus caementicium*, used to describe masonry resembling modern concrete that was made from crushed rock with burnt lime as binder.<sup>[3]</sup> The volcanic ash and pulverized brick supplements that were added to the burnt lime, to obtain a hydraulic binder, were later referred to as *cementum*, *cimentum*, *cāment*, and *cement*. In modern times, organic polymers are sometimes used as cements in concrete.

World production of cement is about 4.4 billion tonnes per year (2021, estimation),<sup>[4]</sup><sup>[5]</sup> of which about half is made in China, followed by India and Vietnam.<sup>[4]</sup><sup>[6]</sup>

The cement production process is responsible for nearly 8% (2018) of global CO<sub>2</sub> emissions,<sup>[5]</sup> which includes heating raw materials in a cement kiln by fuel combustion and release of CO<sub>2</sub> stored in the calcium carbonate (calcination process). Its hydrated products, such as concrete, gradually reabsorb atmospheric CO<sub>2</sub> (carbonation process), compensating for approximately 30% of the initial CO<sub>2</sub> emissions.<sup>[7]</sup>

## Chemistry

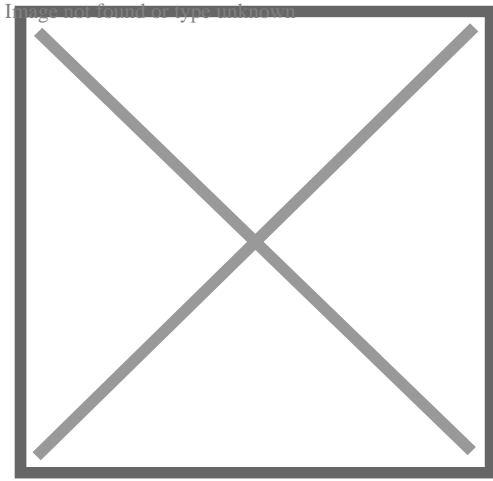
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Cement materials can be classified into two distinct categories: hydraulic cements and non-hydraulic cements according to their respective setting and hardening mechanisms. Hydraulic cement setting and hardening involves hydration reactions and therefore requires water, while non-hydraulic cements only react with a gas and can directly set under air.

## Hydraulic cement

[edit]





Clinker nodules produced by sintering at 1450 °C

By far the most common type of cement is **hydraulic cement**, which hardens by hydration (when water is added) of the clinker minerals. Hydraulic cements (such as Portland cement) are made of a mixture of silicates and oxides, the four main mineral phases of the clinker, abbreviated in the cement chemist notation, being:

$C_3S$ : alite ( $3CaO \cdot SiO_2$ );

$C_2S$ : belite ( $2CaO \cdot SiO_2$ );

$C_3A$ : tricalcium aluminate ( $3CaO \cdot Al_2O_3$ ) (historically, and still occasionally, called *celite*);

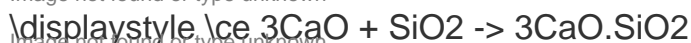
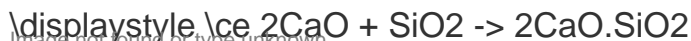
$C_4AF$ : brownmillerite ( $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$ ).

The silicates are responsible for the cement's mechanical properties — the tricalcium aluminate and brownmillerite are essential for the formation of the liquid phase during the sintering (firing) process of clinker at high temperature in the kiln. The chemistry of these reactions is not completely clear and is still the object of research.<sup>[8]</sup>

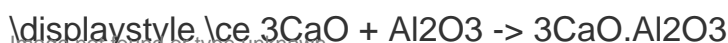
First, the limestone (calcium carbonate) is burned to remove its carbon, producing lime (calcium oxide) in what is known as a calcination reaction. This single chemical reaction is a major emitter of global carbon dioxide emissions.<sup>[9]</sup>



The lime reacts with silicon dioxide to produce dicalcium silicate and tricalcium silicate.

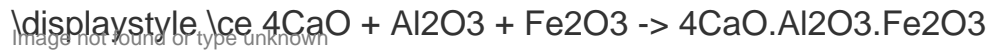


The lime also reacts with aluminium oxide to form tricalcium aluminate.



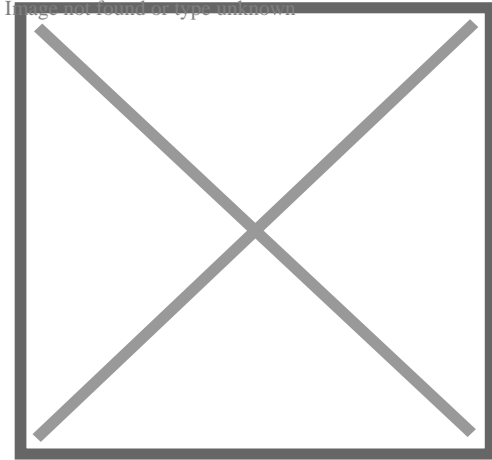


In the last step, calcium oxide, aluminium oxide, and ferric oxide react together to form brownmillerite.



## Non-hydraulic cement

[edit]



Calcium oxide obtained by thermal decomposition of calcium carbonate at high temperature (above 825 °C).

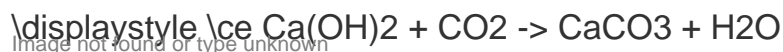
A less common form of cement is **non-hydraulic cement**, such as slaked lime (calcium oxide mixed with water), which hardens by carbonation in contact with carbon dioxide, which is present in the air (~ 412 vol. ppm  $\hat{A}f\hat{A}c\hat{A}c\hat{A},-\hat{A}^{\circ}\hat{A}\hat{A}^{\text{TM}}$  0.04 vol. %). First calcium oxide (lime) is produced from calcium carbonate (limestone or chalk) by calcination at temperatures above 825 °C (1,517 °F) for about 10 hours at atmospheric pressure:



The calcium oxide is then *spent* (slaked) by mixing it with water to make slaked lime (calcium hydroxide):



Once the excess water is completely evaporated (this process is technically called *setting*), the carbonation starts:





This reaction is slow, because the partial pressure of carbon dioxide in the air is low (~ 0.4 millibar). The carbonation reaction requires that the dry cement be exposed to air, so the slaked lime is a non-hydraulic cement and cannot be used under water. This process is called the *lime cycle*.

## History

[edit]

Perhaps the earliest known occurrence of cement is from twelve million years ago. A deposit of cement was formed after an occurrence of oil shale located adjacent to a bed of limestone burned by natural causes. These ancient deposits were investigated in the 1960s and 1970s.<sup>[10]</sup>

## Alternatives to cement used in antiquity

[edit]

Cement, chemically speaking, is a product that includes lime as the primary binding ingredient, but is far from the first material used for cementation. The Babylonians and Assyrians used bitumen (asphalt or pitch) to bind together burnt brick or alabaster slabs. In Ancient Egypt, stone blocks were cemented together with a mortar made of sand and roughly burnt gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), which is plaster of Paris, which often contained calcium carbonate ( $\text{CaCO}_3$ ).<sup>[11]</sup>

## Ancient Greece and Rome

[edit]

Lime (calcium oxide) was used on Crete and by the Ancient Greeks. There is evidence that the Minoans of Crete used crushed potsherds as an artificial pozzolan for hydraulic cement.<sup>[11]</sup> Nobody knows who first discovered that a combination of hydrated non-hydraulic lime and a pozzolan produces a hydraulic mixture (see also: Pozzolanic reaction), but such concrete was used by the Greeks, specifically the Ancient Macedonians,<sup>[12][13]</sup> and three centuries later on a large scale by Roman engineers.<sup>[14][15][16]</sup>



There is... a kind of powder which from natural causes produces astonishing results. It is found in the neighborhood of Baiae and in the country belonging to the towns round about Mount Vesuvius. This substance when mixed with lime and rubble not only lends strength to buildings of other kinds but even when piers of it are constructed in the sea, they set hard underwater.

—*Marcus Vitruvius Pollio, Liber II, De Architectura, Chapter VI "Pozzolana" Sec. 1*

The Greeks used volcanic tuff from the island of Thera as their pozzolan and the Romans used crushed volcanic ash (activated aluminium silicates) with lime. This mixture could set under water, increasing its resistance to corrosion like rust.<sup>[17]</sup> The material was called *pozzolana* from the town of Pozzuoli, west of Naples where volcanic ash was extracted.<sup>[18]</sup> In the absence of pozzolanic ash, the Romans used powdered brick or pottery as a substitute and they may have used crushed tiles for this purpose before discovering natural sources near Rome.<sup>[11]</sup> The huge dome of the Pantheon in Rome and the massive Baths of Caracalla are examples of ancient structures made from these concretes, many of which still stand.<sup>[19]</sup><sup>[2]</sup> The vast system of Roman aqueducts also made extensive use of hydraulic cement.<sup>[20]</sup> Roman concrete was rarely used on the outside of buildings. The normal technique was to use brick facing material as the formwork for an infill of mortar mixed with an aggregate of broken pieces of stone, brick, potsherds, recycled chunks of concrete, or other building rubble.<sup>[21]</sup>

## Mesoamerica

[edit]

Lightweight concrete was designed and used for the construction of structural elements by the pre-Columbian builders who lived in a very advanced civilisation in El Tajin near Mexico City, in Mexico. A detailed study of the composition of the aggregate and binder show that the aggregate was pumice and the binder was a pozzolanic cement made with volcanic ash and lime.<sup>[22]</sup>

## Middle Ages

[edit]



Any preservation of this knowledge in literature from the Middle Ages is unknown, but medieval masons and some military engineers actively used hydraulic cement in structures such as canals, fortresses, harbors, and shipbuilding facilities.<sup>[23][24]</sup> A mixture of lime mortar and aggregate with brick or stone facing material was used in the Eastern Roman Empire as well as in the West into the Gothic period. The German Rhineland continued to use hydraulic mortar throughout the Middle Ages, having local pozzolana deposits called trass.<sup>[21]</sup>

## 16th century

[edit]

Tabby is a building material made from oyster shell lime, sand, and whole oyster shells to form a concrete. The Spanish introduced it to the Americas in the sixteenth century.<sup>[25]</sup>

## 18th century

[edit]

The technical knowledge for making hydraulic cement was formalized by French and British engineers in the 18th century.<sup>[23]</sup>

John Smeaton made an important contribution to the development of cements while planning the construction of the third Eddystone Lighthouse (1755–59) in the English Channel now known as Smeaton's Tower. He needed a hydraulic mortar that would set and develop some strength in the twelve-hour period between successive high tides. He performed experiments with combinations of different limestones and additives including trass and pozzolanas<sup>[11]</sup> and did exhaustive market research on the available hydraulic limes, visiting their production sites, and noted that the "hydraulicity" of the lime was directly related to the clay content of the limestone used to make it. Smeaton was a civil engineer by profession, and took the idea no further.

In the South Atlantic seaboard of the United States, tabby relying on the oyster-shell middens of earlier Native American populations was used in house construction from the 1730s to the 1860s.<sup>[25]</sup>

In Britain particularly, good quality building stone became ever more expensive during a period of rapid growth, and it became a common practice to construct prestige buildings



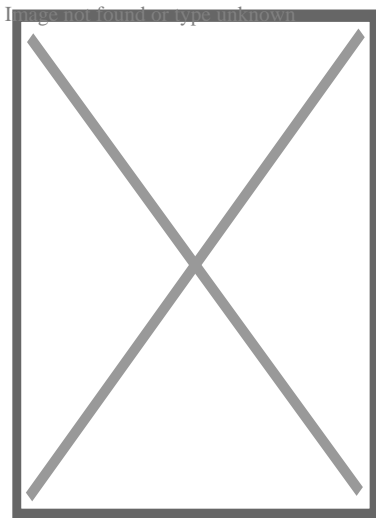
from the new industrial bricks, and to finish them with a stucco to imitate stone. Hydraulic limes were favored for this, but the need for a fast set time encouraged the development of new cements. Most famous was Parker's "Roman cement".<sup>[26]</sup> This was developed by James Parker in the 1780s, and finally patented in 1796. It was, in fact, nothing like material used by the Romans, but was a "natural cement" made by burning septaria – nodules that are found in certain clay deposits, and that contain both clay minerals and calcium carbonate. The burnt nodules were ground to a fine powder. This product, made into a mortar with sand, set in 5–15 minutes. The success of "Roman cement" led other manufacturers to develop rival products by burning artificial hydraulic lime cements of clay and chalk. Roman cement quickly became popular but was largely replaced by Portland cement in the 1850s.<sup>[11]</sup>

## 19th century

[edit]

Apparently unaware of Smeaton's work, the same principle was identified by Frenchman Louis Vicat in the first decade of the nineteenth century. Vicat went on to devise a method of combining chalk and clay into an intimate mixture, and, burning this, produced an "artificial cement" in 1817<sup>[27]</sup> considered the "principal forerunner"<sup>[11]</sup> of Portland cement and "...Edgar Dobbs of Southwark patented a cement of this kind in 1811."<sup>[11]</sup>

In Russia, Egor Cheliev created a new binder by mixing lime and clay. His results were published in 1822 in his book *A Treatise on the Art to Prepare a Good Mortar* published in St. Petersburg. A few years later in 1825, he published another book, which described various methods of making cement and concrete, and the benefits of cement in the construction of buildings and embankments.<sup>[28][29]</sup>



William Aspdin is considered the inventor of "modern" Portland cement.<sup>[30]</sup>



Portland cement, the most common type of cement in general use around the world as a basic ingredient of concrete, mortar, stucco, and non-speciality grout, was developed in England in the mid 19th century, and usually originates from limestone. James Frost produced what he called "British cement" in a similar manner around the same time, but did not obtain a patent until 1822.<sup>[31]</sup> In 1824, Joseph Aspdin patented a similar material, which he called *Portland cement*, because the render made from it was in color similar to the prestigious Portland stone quarried on the Isle of Portland, Dorset, England. However, Aspdins' cement was nothing like modern Portland cement but was a first step in its development, called a *proto-Portland cement*.<sup>[11]</sup> Joseph Aspdins' son William Aspdin had left his father's company and in his cement manufacturing apparently accidentally produced calcium silicates in the 1840s, a middle step in the development of Portland cement. William Aspdin's innovation was counterintuitive for manufacturers of "artificial cements", because they required more lime in the mix (a problem for his father), a much higher kiln temperature (and therefore more fuel), and the resulting clinker was very hard and rapidly wore down the millstones, which were the only available grinding technology of the time. Manufacturing costs were therefore considerably higher, but the product set reasonably slowly and developed strength quickly, thus opening up a market for use in concrete. The use of concrete in construction grew rapidly from 1850 onward, and was soon the dominant use for cements. Thus Portland cement began its predominant role. Isaac Charles Johnson further refined the production of *meso-Portland cement* (middle stage of development) and claimed he was the real father of Portland cement.<sup>[32]</sup>

Setting time and "early strength" are important characteristics of cements. Hydraulic limes, "natural" cements, and "artificial" cements all rely on their belite ( $2 \text{ CaO} \cdot \text{SiO}_2$ , abbreviated as  $\text{C}_2\text{S}$ ) content for strength development. Belite develops strength slowly. Because they were burned at temperatures below  $1,250^\circ\text{C}$  ( $2,280^\circ\text{F}$ ), they contained no alite ( $3 \text{ CaO} \cdot \text{SiO}_2$ , abbreviated as  $\text{C}_3\text{S}$ ), which is responsible for early strength in modern cements. The first cement to consistently contain alite was made by William Aspdin in the early 1840s: This was what we call today "modern" Portland cement. Because of the air of mystery with which William Aspdin surrounded his product, others (e.g., Vicat and Johnson) have claimed precedence in this invention, but recent analysis<sup>[33]</sup> of both his concrete and raw cement have shown that William Aspdin's product made at Northfleet, Kent was a true alite-based cement. However, Aspdin's methods were "rule-of-thumb": Vicat is responsible for establishing the chemical basis of these cements, and Johnson established the importance of sintering the mix in the kiln.

In the US the first large-scale use of cement was Rosendale cement, a natural cement mined from a massive deposit of dolomite discovered in the early 19th century near Rosendale, New York. Rosendale cement was extremely popular for the foundation of buildings (e.g., Statue of Liberty, Capitol Building, Brooklyn Bridge) and lining water pipes.<sup>[34]</sup> Sorel cement, or magnesia-based cement, was patented in 1867 by the Frenchman Stanislas Sorel.<sup>[35]</sup> It was stronger than Portland cement but its poor water resistance (leaching) and corrosive properties (pitting corrosion due to the presence of

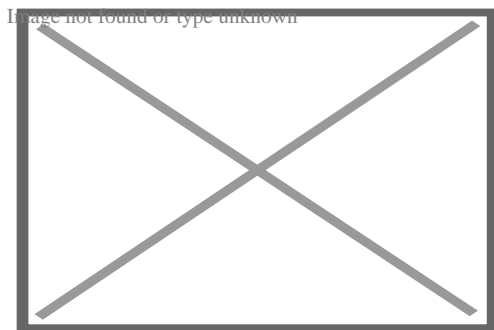


leachable chloride anions and the low pH (8.5–9.5) of its pore water) limited its use as reinforced concrete for building construction.[<sup>36</sup>]

The next development in the manufacture of Portland cement was the introduction of the rotary kiln. It produced a clinker mixture that was both stronger, because more alite ( $C_3S$ ) is formed at the higher temperature it achieved (1450 °C), and more homogeneous. Because raw material is constantly fed into a rotary kiln, it allowed a continuous manufacturing process to replace lower capacity batch production processes.[<sup>11</sup>]

## 20th century

[edit]



The National Cement Share Company of Ethiopia's new plant in Dire Dawa

Calcium aluminate cements were patented in 1908 in France by Jules Bied for better resistance to sulfates.[<sup>37</sup>] Also in 1908, Thomas Edison experimented with pre-cast concrete in houses in Union, N.J.[<sup>38</sup>]

In the US, after World War One, the long curing time of at least a month for Rosendale cement made it unpopular for constructing highways and bridges, and many states and construction firms turned to Portland cement. Because of the switch to Portland cement, by the end of the 1920s only one of the 15 Rosendale cement companies had survived. But in the early 1930s, builders discovered that, while Portland cement set faster, it was not as durable, especially for highways—to the point that some states stopped building highways and roads with cement. Bertrain H. Wait, an engineer whose company had helped construct the New York City's Catskill Aqueduct, was impressed with the durability of Rosendale cement, and came up with a blend of both Rosendale and Portland cements that had the good attributes of both. It was highly durable and had a much faster setting time. Wait convinced the New York Commissioner of Highways to construct an experimental section of highway near New Paltz, New York, using one sack of Rosendale to six sacks of Portland cement. It was a success, and for decades the Rosendale-Portland cement blend was used in concrete highway and concrete bridge construction.[<sup>34</sup>]



Cementitious materials have been used as a nuclear waste immobilizing matrix for more than a half-century.<sup>[39]</sup> Technologies of waste cementation have been developed and deployed at industrial scale in many countries. Cementitious wastefoms require a careful selection and design process adapted to each specific type of waste to satisfy the strict waste acceptance criteria for long-term storage and disposal.<sup>[40]</sup>

## Types

[edit]

Components of cement: comparison of chemical and physical characteristics <sup>[a]</sup> <sup>[41]</sup> <sup>[42]</sup> <sup>[43]</sup>						
Property	Portland cement	Siliceous <sup>[b]</sup> fly ash	Calcareous <sup>[c]</sup> fly ash	Slag cement	Silica fume	
Proportion by mass (%)	SiO <sub>2</sub>	21.9	52	35	35	85–97
	Al <sub>2</sub> O <sub>3</sub>	6.9	23	18	12	—
	Fe <sub>2</sub> O <sub>3</sub>	3	11	6	1	—
	CaO	63	5	21	40	< 1
	MgO	2.5	—	—	—	—
	SO <sub>3</sub>	1.7	—	—	—	—
	Specific surface (m <sup>2</sup> /kg) <sup>[d]</sup>	370	420	420	400	15,000 – 30,000
Specific gravity	3.15	2.38	2.65	2.94	2.22	
General purpose	Primary binder	Cement replacement	Cement replacement	Cement replacement	Property enhancer	

- <sup>1</sup> ^ Values shown are approximate: those of a specific material may vary.
- <sup>2</sup> ^ ASTM C618 Class F
- <sup>3</sup> ^ ASTM C618 Class C
- <sup>4</sup> ^ Specific surface measurements for silica fume by nitrogen adsorption (BET) method, others by air permeability method (Blaine).

Modern development of hydraulic cement began with the start of the Industrial Revolution (around 1800), driven by three main needs:

- Hydraulic cement render (stucco) for finishing brick buildings in wet climates



- Hydraulic mortars for masonry construction of harbor works, etc., in contact with sea water
- Development of strong concretes

Modern cements are often Portland cement or Portland cement blends, but other cement blends are used in some industrial settings.

## Portland cement

[edit]

Main article: Portland cement

Portland cement, a form of hydraulic cement, is by far the most common type of cement in general use around the world. This cement is made by heating limestone (calcium carbonate) with other materials (such as clay) to 1,450 °C (2,640 °F) in a kiln, in a process known as calcination that liberates a molecule of carbon dioxide from the calcium carbonate to form calcium oxide, or quicklime, which then chemically combines with the other materials in the mix to form calcium silicates and other cementitious compounds. The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum (  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) into a powder to make *ordinary Portland cement*, the most commonly used type of cement (often referred to as OPC). Portland cement is a basic ingredient of concrete, mortar, and most non-specialty grout. The most common use for Portland cement is to make concrete. Portland cement may be grey or white.

## Portland cement blend

[edit]

Portland cement blends are often available as inter-ground mixtures from cement producers, but similar formulations are often also mixed from the ground components at the concrete mixing plant.

**Portland blast-furnace slag cement, or blast furnace** cement (ASTM C595 and EN 197-1 nomenclature respectively), contains up to 95% ground granulated blast furnace slag, with the rest Portland clinker and a little gypsum. All compositions produce high ultimate strength, but as slag content is increased, early strength is reduced, while sulfate resistance increases and heat evolution diminishes. Used as an economic alternative to Portland sulfate-resisting and low-heat cements.



**Portland-fly ash** cement contains up to 40% fly ash under ASTM standards (ASTM C595), or 35% under EN standards (EN 197–1). The fly ash is pozzolanic, so that ultimate strength is maintained. Because fly ash addition allows a lower concrete water content, early strength can also be maintained. Where good quality cheap fly ash is available, this can be an economic alternative to ordinary Portland cement.<sup>[44]</sup>

**Portland pozzolan** cement includes fly ash cement, since fly ash is a pozzolan, but also includes cements made from other natural or artificial pozzolans. In countries where volcanic ashes are available (e.g., Italy, Chile, Mexico, the Philippines), these cements are often the most common form in use. The maximum replacement ratios are generally defined as for Portland-fly ash cement.

**Portland silica fume** cement. Addition of silica fume can yield exceptionally high strengths, and cements containing 5–20% silica fume are occasionally produced, with 10% being the maximum allowed addition under EN 197–1. However, silica fume is more usually added to Portland cement at the concrete mixer.<sup>[45]</sup>

**Masonry** cements are used for preparing bricklaying mortars and stuccos, and must not be used in concrete. They are usually complex proprietary formulations containing Portland clinker and a number of other ingredients that may include limestone, hydrated lime, air entrainers, retarders, waterproofers, and coloring agents. They are formulated to yield workable mortars that allow rapid and consistent masonry work. Subtle variations of masonry cement in North America are plastic cements and stucco cements. These are designed to produce a controlled bond with masonry blocks.

**Expansive** cements contain, in addition to Portland clinker, expansive clinkers (usually sulfoaluminate clinkers), and are designed to offset the effects of drying shrinkage normally encountered in hydraulic cements. This cement can make concrete for floor slabs (up to 60 m square) without contraction joints.

**White blended** cements may be made using white clinker (containing little or no iron) and white supplementary materials such as high-purity metakaolin. **Colored** cements serve decorative purposes. Some standards allow the addition of pigments to produce colored Portland cement. Other standards (e.g., ASTM) do not allow pigments in Portland cement, and colored cements are sold as blended hydraulic cements.

**Very finely ground** cements are cement mixed with sand or with slag or other pozzolan type minerals that are extremely finely ground together. Such cements can have the same physical characteristics as normal cement but with 50% less cement, particularly because there is more surface area for the chemical reaction. Even with intensive grinding they can use up to 50% less energy (and thus less carbon emissions) to fabricate than ordinary Portland cements.<sup>[46]</sup>



# Other

[edit]

**Pozzolan-lime** cements are mixtures of ground pozzolan and lime. These are the cements the Romans used, and are present in surviving Roman structures like the Pantheon in Rome. They develop strength slowly, but their ultimate strength can be very high. The hydration products that produce strength are essentially the same as those in Portland cement.

**Slag-lime** cements—ground granulated blast-furnace slag—are not hydraulic on their own, but are "activated" by addition of alkalis, most economically using lime. They are similar to pozzolan lime cements in their properties. Only granulated slag (i.e., water-quenched, glassy slag) is effective as a cement component.

**Supersulfated** cements contain about 80% ground granulated blast furnace slag, 15% gypsum or anhydrite and a little Portland clinker or lime as an activator. They produce strength by formation of ettringite, with strength growth similar to a slow Portland cement. They exhibit good resistance to aggressive agents, including sulfate.

**Calcium aluminate** cements are hydraulic cements made primarily from limestone and bauxite. The active ingredients are monocalcium aluminate  $\text{CaAl}_2\text{O}_4$  ( $\text{CaO} \cdot \text{Al}_2\text{O}_3$  or CA in cement chemist notation, CCN) and mayenite  $\text{Ca}_{12}\text{Al}_{14}\text{O}_{33}$  ( $12 \text{ CaO} \cdot 7 \text{ Al}_2\text{O}_3$ , or  $\text{C}_{12}\text{A}_7$  in CCN). Strength forms by hydration to calcium aluminate hydrates. They are well-adapted for use in refractory (high-temperature resistant) concretes, e.g., for furnace linings.

**Calcium sulfoaluminate** cements are made from clinkers that include ye'elimite ( $\text{Ca}_4(\text{AlO}_2)_6\text{SO}_4$  or  $\text{C}_4\text{A}_3\bar{\text{S}}$  in Cement chemist's notation) as a primary phase. They are used in expansive cements, in ultra-high early strength cements, and in "low-energy" cements. Hydration produces ettringite, and specialized physical properties (such as expansion or rapid reaction) are obtained by adjustment of the availability of calcium and sulfate ions. Their use as a low-energy alternative to Portland cement has been pioneered in China, where several million tonnes per year are produced.<sup>[47][48]</sup> Energy requirements are lower because of the lower kiln temperatures required for reaction, and the lower amount of limestone (which must be endothermically decarbonated) in the mix. In addition, the lower limestone content and lower fuel consumption leads to a  $\text{CO}_2$  emission around half that associated with Portland clinker. However,  $\text{SO}_2$  emissions are usually significantly higher.

**"Natural"** cements corresponding to certain cements of the pre-Portland era, are produced by burning argillaceous limestones at moderate temperatures. The level of



clay components in the limestone (around 30–35%) is such that large amounts of belite (the low-early strength, high-late strength mineral in Portland cement) are formed without the formation of excessive amounts of free lime. As with any natural material, such cements have highly variable properties.

**Geopolymer** cements are made from mixtures of water-soluble alkali metal silicates, and aluminosilicate mineral powders such as fly ash and metakaolin.

**Polymer** cements are made from organic chemicals that polymerise. Producers often use thermoset materials. While they are often significantly more expensive, they can give a water proof material that has useful tensile strength.

**Sorel** cement is a hard, durable cement made by combining magnesium oxide and a magnesium chloride solution

**Fiber mesh** cement or fiber reinforced concrete is cement that is made up of fibrous materials like synthetic fibers, glass fibers, natural fibers, and steel fibers. This type of mesh is distributed evenly throughout the wet concrete. The purpose of fiber mesh is to reduce water loss from the concrete as well as enhance its structural integrity.<sup>[49]</sup> When used in plasters, fiber mesh increases cohesiveness, tensile strength, impact resistance, and to reduce shrinkage; ultimately, the main purpose of these combined properties is to reduce cracking.<sup>[50]</sup>

**Electric** cement is proposed to be made by recycling cement from demolition wastes in an electric arc furnace as part of a steelmaking process. The recycled cement is intended to be used to replace part or all of the lime used in steelmaking, resulting in a slag-like material that is similar in mineralogy to Portland cement, eliminating most of the associated carbon emissions.<sup>[51]</sup>

## Setting, hardening and curing

[edit]

Cement starts to set when mixed with water, which causes a series of hydration chemical reactions. The constituents slowly hydrate and the mineral hydrates solidify and harden. The interlocking of the hydrates gives cement its strength. Contrary to popular belief, hydraulic cement does not set by drying out — proper curing requires maintaining the appropriate moisture content necessary for the hydration reactions during the setting and the hardening processes. If hydraulic cements dry out during the curing phase, the resulting product can be insufficiently hydrated and significantly weakened. A minimum temperature of 5 °C is recommended, and no more than 30 °C<sup>[52]</sup> The concrete at young age must be protected against water evaporation due to direct insolation, elevated temperature, low relative humidity and wind.



The *interfacial transition zone* (ITZ) is a region of the cement paste around the aggregate particles in concrete. In the zone, a gradual transition in the microstructural features occurs.<sup>[53]</sup> This zone can be up to 35 micrometer wide.<sup>[54]</sup> Other studies have shown that the width can be up to 50 micrometer. The average content of unreacted clinker phase decreases and porosity decreases towards the aggregate surface. Similarly, the content of ettringite increases in ITZ. <sup>[54]</sup>

## Safety issues

[edit]

Bags of cement routinely have health and safety warnings printed on them because not only is cement highly alkaline, but the setting process is exothermic. As a result, wet cement is strongly caustic ( $\text{pH} = 13.5$ ) and can easily cause severe skin burns if not promptly washed off with water. Similarly, dry cement powder in contact with mucous membranes can cause severe eye or respiratory irritation. Some trace elements, such as chromium, from impurities naturally present in the raw materials used to produce cement may cause allergic dermatitis.<sup>[55]</sup> Reducing agents such as ferrous sulfate ( $\text{FeSO}_4$ ) are often added to cement to convert the carcinogenic hexavalent chromate ( $\text{CrO}_4^{2-}$ ) into trivalent chromium ( $\text{Cr}^{3+}$ ), a less toxic chemical species. Cement users need also to wear appropriate gloves and protective clothing.<sup>[56]</sup>

## Cement industry in the world

[edit]

Global cement production (2022)

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Global cement production in 2022



## Global cement capacity (2022)

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### Global cement capacity in 2022

See also: List of countries by cement production and Cement industry in the United States

In 2010, the world production of hydraulic cement was 3,300 megatonnes ( $3,600 \times 10^6$  short tons). The top three producers were China with 1,800, India with 220, and the United States with 63.5 million tonnes for a total of over half the world total by the world's three most populated states.<sup>[57]</sup>

For the world capacity to produce cement in 2010, the situation was similar with the top three states (China, India, and the US) accounting for just under half the world total capacity.<sup>[58]</sup>

Over 2011 and 2012, global consumption continued to climb, rising to 3585 Mt in 2011 and 3736 Mt in 2012, while annual growth rates eased to 8.3% and 4.2%, respectively.

China, representing an increasing share of world cement consumption, remains the main engine of global growth. By 2012, Chinese demand was recorded at 2160 Mt, representing 58% of world consumption. Annual growth rates, which reached 16% in 2010, appear to have softened, slowing to 5–6% over 2011 and 2012, as China's economy targets a more sustainable growth rate.

Outside of China, worldwide consumption climbed by 4.4% to 1462 Mt in 2010, 5% to 1535 Mt in 2011, and finally 2.7% to 1576 Mt in 2012.

Iran is now the 3rd largest cement producer in the world and has increased its output by over 10% from 2008 to 2011.<sup>[59]</sup> Because of climbing energy costs in Pakistan and other major cement-producing countries, Iran is in a unique position as a trading partner, utilizing its own surplus petroleum to power clinker plants. Now a top producer in the Middle-East, Iran is further increasing its dominant position in local markets and abroad.<sup>[60]</sup>

The performance in North America and Europe over the 2010–12 period contrasted strikingly with that of China, as the global financial crisis evolved into a sovereign debt crisis for many economies in this region<sup>[clarification needed]</sup> and recession. Cement consumption levels for this region fell by 1.9% in 2010 to 445 Mt, recovered by 4.9% in



2011, then dipped again by 1.1% in 2012.

The performance in the rest of the world, which includes many emerging economies in Asia, Africa and Latin America and representing some 1020 Mt cement demand in 2010, was positive and more than offset the declines in North America and Europe. Annual consumption growth was recorded at 7.4% in 2010, moderating to 5.1% and 4.3% in 2011 and 2012, respectively.

As at year-end 2012, the global cement industry consisted of 5673 cement production facilities, including both integrated and grinding, of which 3900 were located in China and 1773 in the rest of the world.

Total cement capacity worldwide was recorded at 5245 Mt in 2012, with 2950 Mt located in China and 2295 Mt in the rest of the world.<sup>[6]</sup>

## China

[edit]

Main article: Cement industry in China

"For the past 18 years, China consistently has produced more cement than any other country in the world. [...] (However,) China's cement export peaked in 1994 with 11 million tonnes shipped out and has been in steady decline ever since. Only 5.18 million tonnes were exported out of China in 2002. Offered at \$34 a ton, Chinese cement is pricing itself out of the market as Thailand is asking as little as \$20 for the same quality."<sup>[61]</sup>

In 2006, it was estimated that China manufactured 1.235 billion tonnes of cement, which was 44% of the world total cement production.<sup>[62]</sup> "Demand for cement in China is expected to advance 5.4% annually and exceed 1 billion tonnes in 2008, driven by slowing but healthy growth in construction expenditures. Cement consumed in China will amount to 44% of global demand, and China will remain the world's largest national consumer of cement by a large margin."<sup>[63]</sup>

In 2010, 3.3 billion tonnes of cement was consumed globally. Of this, China accounted for 1.8 billion tonnes.<sup>[64]</sup>

### Environmental impacts

[edit]

Further information: Environmental impact of concrete



Cement manufacture causes environmental impacts at all stages of the process. These include emissions of airborne pollution in the form of dust, gases, noise and vibration when operating machinery and during blasting in quarries, and damage to countryside from quarrying. Equipment to reduce dust emissions during quarrying and manufacture of cement is widely used, and equipment to trap and separate exhaust gases are coming into increased use. Environmental protection also includes the re-integration of quarries into the countryside after they have been closed down by returning them to nature or re-cultivating them.

## CO<sub>2</sub> emissions

[edit]

Global carbon emission by type to 2018

Image not found or type unknown

Global carbon emission by type to 2018

Carbon concentration in cement spans from 5% in cement structures to 8% in the case of roads in cement.<sup>[65]</sup> Cement manufacturing releases CO<sub>2</sub> in the atmosphere both directly when calcium carbonate is heated, producing lime and carbon dioxide,<sup>[66]</sup><sup>[67]</sup> and also indirectly through the use of energy if its production involves the emission of CO

2. The cement industry produces about 10% of global human-made CO<sub>2</sub> emissions, of which 60% is from the chemical process, and 40% from burning fuel.<sup>[68]</sup> A Chatham House study from 2018 estimates that the 4 billion tonnes of cement produced annually account for 8% of worldwide CO<sub>2</sub> emissions.<sup>[5]</sup>



Nearly 900 kg of CO

<sub>2</sub> are emitted for every 1000 kg of Portland cement produced. In the European Union, the specific energy consumption for the production of cement clinker has been reduced by approximately 30% since the 1970s. This reduction in primary energy requirements is equivalent to approximately 11 million tonnes of coal per year with corresponding benefits in reduction of CO

<sub>2</sub> emissions. This accounts for approximately 5% of anthropogenic CO<sub>2</sub>.<sup>[69]</sup>

The majority of carbon dioxide emissions in the manufacture of Portland cement (approximately 60%) are produced from the chemical decomposition of limestone to lime, an ingredient in Portland cement clinker. These emissions may be reduced by lowering the clinker content of cement. They can also be reduced by alternative fabrication methods such as the intergrinding cement with sand or with slag or other pozzolan type minerals to a very fine powder.<sup>[70]</sup>

To reduce the transport of heavier raw materials and to minimize the associated costs, it is more economical to build cement plants closer to the limestone quarries rather than to the consumer centers.<sup>[71]</sup>

As of 2019 carbon capture and storage is about to be trialed, but its financial viability is uncertain.<sup>[72]</sup>

CO

## <sub>2</sub> absorption

[edit]

Hydrated products of Portland cement, such as concrete and mortars, slowly reabsorb atmospheric CO<sub>2</sub> gas, which has been released during calcination in a kiln. This natural process, reversed to calcination, is called carbonation.<sup>[73]</sup> As it depends on CO<sub>2</sub> diffusion into the bulk of concrete, its rate depends on many parameters, such as environmental conditions and surface area exposed to the atmosphere.<sup>[74][75]</sup> Carbonation is particularly significant at the latter stages of the concrete life - after demolition and crushing of the debris. It was estimated that during the whole life-cycle of cement products, it can be reabsorbed nearly 30% of atmospheric CO<sub>2</sub> generated by cement production.<sup>[75]</sup>

Carbonation process is considered as a mechanism of concrete degradation. It reduces pH of concrete that promotes reinforcement steel corrosion.<sup>[73]</sup> However, as the product of Ca(OH)<sub>2</sub> carbonation, CaCO<sub>3</sub>, occupies a greater volume, porosity of concrete reduces. This increases strength and hardness of concrete.<sup>[76]</sup>



There are proposals to reduce carbon footprint of hydraulic cement by adopting non-hydraulic cement, lime mortar, for certain applications. It reabsorbs some of the  $\text{CO}_2$  during hardening, and has a lower energy requirement in production than Portland cement.[<sup>77</sup>]

A few other attempts to increase absorption of carbon dioxide include cements based on magnesium (Sorel cement).[<sup>78</sup>][<sup>79</sup>][<sup>80</sup>]

## Heavy metal emissions in the air

[edit]

In some circumstances, mainly depending on the origin and the composition of the raw materials used, the high-temperature calcination process of limestone and clay minerals can release in the atmosphere gases and dust rich in volatile heavy metals, e.g. thallium, [<sup>81</sup>] cadmium and mercury are the most toxic. Heavy metals (Tl, Cd, Hg, ...) and also selenium are often found as trace elements in common metal sulfides (pyrite ( $\text{FeS}_2$ ), zinc blende ( $\text{ZnS}$ ), galena ( $\text{PbS}$ ), ...) present as secondary minerals in most of the raw materials. Environmental regulations exist in many countries to limit these emissions. As of 2011 in the United States, cement kilns are "legally allowed to pump more toxins into the air than are hazardous-waste incinerators." [<sup>82</sup>]

## Heavy metals present in the clinker

[edit]

The presence of heavy metals in the clinker arises both from the natural raw materials and from the use of recycled by-products or alternative fuels. The high pH prevailing in the cement porewater ( $12.5 < \text{pH} < 13.5$ ) limits the mobility of many heavy metals by decreasing their solubility and increasing their sorption onto the cement mineral phases. Nickel, zinc and lead are commonly found in cement in non-negligible concentrations. Chromium may also directly arise as natural impurity from the raw materials or as secondary contamination from the abrasion of hard chromium steel alloys used in the ball mills when the clinker is ground. As chromate ( $\text{CrO}_4^{2-}$ ) is toxic and may cause severe skin allergies at trace concentration, it is sometimes reduced into trivalent Cr(III) by addition of ferrous sulfate ( $\text{FeSO}_4$ ).



# Use of alternative fuels and by-products materials

[edit]

A cement plant consumes 3 to 6 GJ of fuel per tonne of clinker produced, depending on the raw materials and the process used. Most cement kilns today use coal and petroleum coke as primary fuels, and to a lesser extent natural gas and fuel oil. Selected waste and by-products with recoverable calorific value can be used as fuels in a cement kiln (referred to as co-processing), replacing a portion of conventional fossil fuels, like coal, if they meet strict specifications. Selected waste and by-products containing useful minerals such as calcium, silica, alumina, and iron can be used as raw materials in the kiln, replacing raw materials such as clay, shale, and limestone. Because some materials have both useful mineral content and recoverable calorific value, the distinction between alternative fuels and raw materials is not always clear. For example, sewage sludge has a low but significant calorific value, and burns to give ash containing minerals useful in the clinker matrix.<sup>[83]</sup> Scrap automobile and truck tires are useful in cement manufacturing as they have high calorific value and the iron embedded in tires is useful as a feed stock.<sup>[84]</sup>

Clinker is manufactured by heating raw materials inside the main burner of a kiln to a temperature of 1,450 °C. The flame reaches temperatures of 1,800 °C. The material remains at 1,200 °C for 12–15 seconds at 1,800 °C or sometimes for 5–8 seconds (also referred to as residence time). These characteristics of a clinker kiln offer numerous benefits and they ensure a complete destruction of organic compounds, a total neutralization of acid gases, sulphur oxides and hydrogen chloride. Furthermore, heavy metal traces are embedded in the clinker structure and no by-products, such as ash or residues, are produced.<sup>[85]</sup>

The EU cement industry already uses more than 40% fuels derived from waste and biomass in supplying the thermal energy to the grey clinker making process. Although the choice for this so-called alternative fuels (AF) is typically cost driven, other factors are becoming more important. Use of alternative fuels provides benefits for both society and the company: CO

2-emissions are lower than with fossil fuels, waste can be co-processed in an efficient and sustainable manner and the demand for certain virgin materials can be reduced. Yet there are large differences in the share of alternative fuels used between the European Union (EU) member states. The societal benefits could be improved if more member states increase their alternative fuels share. The Ecofys study<sup>[86]</sup> assessed the barriers and opportunities for further uptake of alternative fuels in 14 EU member states. The Ecofys study found that local factors constrain the market potential to a much larger



extent than the technical and economic feasibility of the cement industry itself.

## Reduced-footprint cement

[edit]

Growing environmental concerns and the increasing cost of fossil fuels have resulted, in many countries, in a sharp reduction of the resources needed to produce cement, as well as effluents (dust and exhaust gases).<sup>[87]</sup> Reduced-footprint cement is a cementitious material that meets or exceeds the functional performance capabilities of Portland cement. Various techniques are under development. One is geopolymers cement, which incorporates recycled materials, thereby reducing consumption of raw materials, water, and energy. Another approach is to reduce or eliminate the production and release of damaging pollutants and greenhouse gases, particularly CO<sub>2</sub>.<sup>[88]</sup> Recycling old cement in electric arc furnaces is another approach.<sup>[89]</sup> Also, a team at the University of Edinburgh has developed the 'DUPE' process based on the microbial activity of *Sporosarcina pasteurii*, a bacterium precipitating calcium carbonate, which, when mixed with sand and urine, can produce mortar blocks with a compressive strength 70% of that of concrete.<sup>[90]</sup> An overview of climate-friendly methods for cement production can be found here.<sup>[91]</sup>

## See also

[edit]

- Asphalt concrete
- Calcium aluminate cements
- Cement chemist notation
- Cement render
- Cenocell
- Energetically modified cement (EMC)
- Fly ash
- Geopolymer cement
- Portland cement
- Rosendale cement
- Sulfate attack in concrete and mortar
- Sulfur concrete
- Tiocem
- List of countries by cement production

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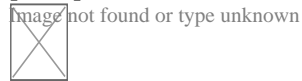


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## External links

[edit]



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Technology and related concepts



## Major technologies

### Necessities

- Agriculture
  - Domestication
  - Grafting
  - Working animal
- Clothing
  - Sewing machine
- Cooking
  - Beer
  - Bread
  - Cheese
  - Milling
  - Wine
- Food storage
  - Pottery
- Sanitation
  - Plumbing
  - Toilet
- Tool / Equipment
  - Blade
  - Hammer
  - Plough
  - Wedge
- Weapon
  - Gun
- Accounting
- Calculation
  - Abacus
  - Calendar
- Cryptography
- Lock and key
- Money
  - Banknote
  - Coin

### Social

- Musical instrument
  - Phonograph
- Toy
  - Game
  - Video game
- Writing
  - Book
  - Map
  - Printing press
  - Typewriter
- Aqueduct
  - Canal
  - Irrigation



## **Perspectives**

- Criticism**
  - Appropriate technology
    - Low technology
  - Luddite
    - Neo-Luddism
  - Precautionary principle
  - Environmental technology
    - Clean technology
- Ecotechnology**
  - Sustainable design
    - Sustainable engineering
  - Government by algorithm
  - Intellectual property
    - Patent
    - Trade secret
- Policy & politics**
  - Persuasive technology
  - Science policy
  - Strategy of Technology
  - Technology assessment
  - Technorealism
  - Futures studies
    - Technology forecasting
- Progressivism**
  - Technological utopianism
    - Technocracy movement
    - Technological singularity
    - Transhumanism
  - Diffusion of innovations
    - Technology transfer
- Studies**
  - History
    - Timeline of historic inventions
  - Philosophy
    - Social construction of technology
    - Technological determinism
  - Technology acceptance model






## Related concepts

### Applied science

- Agronomy
- Architecture
- Construction
- Engineering
- Forensics
- Forestry
- Logistics
- Medicine
- Mining
- Navigation
- Surveying
- Design
- High tech
- Invention

### Innovation

- Mature technology
- Research and development
- Technological convergence
- Technology lifecycle

-  **Category**
-  **Outline**
-  **Portal**

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Concrete

### History

- Ancient Roman architecture
- Roman architectural revolution
- Roman concrete
- Roman engineering
- Roman technology



	<ul style="list-style-type: none"> <li>○ Cement <ul style="list-style-type: none"> <li>○ Calcium aluminate</li> <li>○ Energetically modified</li> <li>○ Portland</li> <li>○ Rosendale</li> </ul> </li> </ul>
<b>Composition</b>	<ul style="list-style-type: none"> <li>○ Water</li> <li>○ Water–cement ratio</li> <li>○ Aggregate</li> <li>○ Reinforcement</li> <li>○ Fly ash</li> <li>○ Ground granulated blast-furnace slag</li> <li>○ Silica fume</li> <li>○ Metakaolin</li> <li>○ Plant</li> <li>○ Concrete mixer</li> <li>○ Volumetric mixer</li> <li>○ Reversing drum mixer</li> </ul>
<b>Production</b>	<ul style="list-style-type: none"> <li>○ Slump test</li> <li>○ Flow table test</li> <li>○ Curing</li> <li>○ Concrete cover</li> <li>○ Cover meter</li> <li>○ Rebar</li> <li>○ Precast</li> <li>○ Cast-in-place</li> <li>○ Formwork</li> <li>○ Climbing formwork</li> <li>○ Slip forming</li> <li>○ Screed</li> </ul>
<b>Construction</b>	<ul style="list-style-type: none"> <li>○ Power screed</li> <li>○ Finisher</li> <li>○ Grinder</li> <li>○ Power trowel</li> <li>○ Pump</li> <li>○ Float</li> <li>○ Sealer</li> <li>○ Tremie</li> <li>○ Properties</li> <li>○ Durability</li> <li>○ Degradation</li> </ul>
<b>Science</b>	<ul style="list-style-type: none"> <li>○ Environmental impact</li> <li>○ Recycling</li> <li>○ Segregation</li> <li>○ Alkali–silica reaction</li> </ul>



<b>Types</b>	<ul style="list-style-type: none"> <li>○ AstroCrete</li> <li>○ Fiber-reinforced</li> <li>○ Filigree</li> <li>○ Foam</li> <li>○ Lunarcrete</li> <li>○ Mass</li> <li>○ Nanoconcrete</li> <li>○ Pervious</li> <li>○ Polished</li> <li>○ Polymer</li> <li>○ Prestressed</li> <li>○ Ready-mix</li> <li>○ Reinforced</li> <li>○ Roller-compacting</li> <li>○ Self-consolidating</li> <li>○ Self-leveling</li> <li>○ Sulfur</li> <li>○ Tabby</li> <li>○ Translucent</li> <li>○ Waste light</li> <li>○ Aerated <ul style="list-style-type: none"> <li>○ AAC</li> <li>○ RAAC</li> </ul> </li> <li>○ Slab <ul style="list-style-type: none"> <li>○ waffle</li> <li>○ hollow-core</li> <li>○ voided biaxial</li> <li>○ slab on grade</li> </ul> </li> </ul>
<b>Applications</b>	<ul style="list-style-type: none"> <li>○ Concrete block</li> <li>○ Step barrier</li> <li>○ Roads</li> <li>○ Columns</li> <li>○ Structures</li> <li>○ American Concrete Institute</li> <li>○ Concrete Society</li> </ul>
<b>Organizations</b>	<ul style="list-style-type: none"> <li>○ Institution of Structural Engineers</li> <li>○ Indian Concrete Institute</li> <li>○ Nanocem</li> <li>○ Portland Cement Association</li> <li>○ International Federation for Structural Concrete</li> </ul>
<b>Standards</b>	<ul style="list-style-type: none"> <li>○ Eurocode 2</li> <li>○ EN 197-1</li> <li>○ EN 206-1</li> <li>○ EN 10080</li> </ul>



**See also**

- Hempcrete
-  Category:Concrete

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Major industries



## Natural sector

### Agriculture

- Arable farming
  - Cereals
  - Legumes
  - Vegetables
  - Fiber crops
  - Oilseeds
  - Sugar
  - Tobacco
- Permanent crops
  - Apples et al.
  - Berries
  - Citrus
  - Stone fruits
  - Tropical fruit
  - Viticulture
  - Cocoa
  - Coffee
  - Tea
  - Nuts
  - Olives
  - Medicinal plants
  - Spices
- Horticulture
  - Flowers
  - Seeds
- Animal husbandry
  - Beef cattle
  - Dairy farming
  - Fur farming
  - Horses
  - Other livestock
  - Pig
  - Wool
  - Poultry
  - Beekeeping
  - Cochineal
  - Shellac
  - Silk
- Hunting
  - Fur trapping
- Silviculture
  - Bamboo
- Logging
  - Firewood
- Batten

### Biotic



## **Industrial sector**

- Food
  - Animal feed
  - Baking
  - Canning
  - Dairy products
  - Flour
  - Meat
  - Prepared
  - Preserved
  - Sweets
  - Vegetable oils
- Beverages
  - Beer
  - Bottled water
  - Liquor
  - Soft drinks
  - Wine
- Textiles
  - Carding
  - Dyeing
  - Prints
  - Spinning
  - Weaving
  - Carpets
  - Lace
  - Linens
  - Rope
- Clothing
  - Accessories
  - Dressmaking
  - Furs
  - Hatmaking
  - Sewing
  - Shoemaking
  - Tailoring
- Printing
  - Bookbinding
  - Embossing
  - Engraving
  - Secure
  - Typesetting

## **Light industry**

- Media reproduction
  - Cassette tapes
  - Phonographs
  - Optical discs



## **Service sector**

<b>Sales</b>	○ Retail <ul style="list-style-type: none"><li>○ Car dealership</li><li>○ Consumer goods</li><li>○ General store</li><li>○ Grocery store</li><li>○ Department store</li><li>○ Mail order</li><li>○ Online shopping</li><li>○ Specialty store</li></ul>
	○ Wholesale <ul style="list-style-type: none"><li>○ Auction</li><li>○ Brokerage</li><li>○ Distribution</li></ul>
	○ Cargo <ul style="list-style-type: none"><li>○ Air cargo</li><li>○ Intermodal</li><li>○ Mail</li><li>○ Moving company</li><li>○ Rail</li><li>○ Trucking</li></ul>
<b>Transport &amp; Storage</b>	○ Passenger transport <ul style="list-style-type: none"><li>○ Airlines</li><li>○ Car rentals</li><li>○ Passenger rail</li><li>○ Ridesharing</li><li>○ Taxis</li></ul>
	○ Warehousing <ul style="list-style-type: none"><li>○ Self storage</li></ul>
<b>Hospitality</b>	○ Foodservice <ul style="list-style-type: none"><li>○ Drink service</li><li>○ Cafés</li><li>○ Catering</li><li>○ Fast food</li><li>○ Food delivery</li><li>○ Restaurants</li><li>○ Teahouses</li></ul>
	○ Hotels
	○ Financial services <ul style="list-style-type: none"><li>○ Banking</li><li>○ Credit</li><li>○ Financial advice</li><li>○ Holding company</li><li>○ Money transfer</li><li>○ Payment cards</li><li>○ Risk management</li><li>○ Securities</li></ul>




## Related

### Classification standards

- Production-based
  - ANZSIC
  - **ISIC**
  - NACE
  - NAICS
  - SIC
  - UKSIC
- Market-based
  - GICS
  - ICB
  - TRBC
- Other
  - Aftermarket
  - Generic
  - OEM
- Externalities
  - Community
  - Crime
  - Culture
  - Pollution
  - Well-being
- Funding
- Goods
  - Commodities
  - Final
  - Intermediate
  - Raw material
- Innovation
- Primary inputs
  - Labor
  - Natural resources
  - Physical capital
- Services
- Technology
- Centralization
  - Cartel
  - Conglomerate
  - Horizontal integration
  - Mergers and acquisitions
  - Monopoly
  - Monopsony
  - Vertical integration
- Decentralization
  - Enforced breakup
  - Freelancing
  - Homesteading

### Inputs & outputs



-  **Category**
-  **Commons**
-  **Outline**

## Authority control databases Edit this at Wikidata

<b>International</b>	<ul style="list-style-type: none"> <li>○ FAST</li> <li>○ Germany</li> <li>○ United States</li> <li>○ France</li> <li>○ BnF data</li> </ul>
<b>National</b>	<ul style="list-style-type: none"> <li>○ Japan</li> <li>○ Czech Republic</li> <li>○ Spain</li> <li>○ Latvia</li> <li>○ Israel</li> </ul>
<b>Other</b>	<ul style="list-style-type: none"> <li>○ IdRef</li> <li>○ Historical Dictionary of Switzerland</li> </ul>

## About Cook County

## Driving Directions in Cook County

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Driving Directions From 42.088525008778, -88.079435634324 to

Driving Directions From 42.021124436568, -88.109125186152 to

Driving Directions From 42.017845685371, -88.11591807218 to

Driving Directions From 42.084324223519, -88.137710099374 to

Driving Directions From 42.10843482977, -88.114090738222 to



Driving Directions From 42.086153671225, -88.19640031169 to

Driving Directions From 42.051159627372, -88.202951526236 to

Driving Directions From 42.008657936699, -88.152725208607 to

Driving Directions From 42.007242948498, -88.153060682778 to

Driving Directions From 42.073881347839, -88.179224443136 to

<https://www.google.com/maps/place/@42.050000207566,-88.075050390596,25.2z/data=!4m6!3m5!1sNone!8m2!3d42.0637725!4d-88.1396465!16s%2F>

<https://www.google.com/maps/place/@42.087798734568,-88.063295005626,25.2z/data=!4m6!3m5!1sNone!8m2!3d42.0637725!4d-88.1396465!16s%2F>

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88.1396465!16s%2F

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United Structural Systems of Illinois, Inc

Phone : +18473822882

City : Hoffman Estates

State : IL

Zip : 60169

Address : 2124 Stonington Ave

### **Google Business Profile**

Company Website : <https://www.unitedstructuralsystems.com/>

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