HYDRO

Solar Design Manual

Aluminum extrusion,
a world of
opportunities

Aluminum — The material of the future

Aluminum has been described as the "material of opportunity" and more and more companies in the solar industry are realizing the obvious benefits of using aluminum.

A significant benefit of aluminum and the aluminum extrusion process is the almost unlimited opportunity to adapt the shape of the product to optimize performance, maximize stiffness and strength, and reduce the number of parts to assemble and fabricate; all of which contribute to lowering cost. The low density of aluminum can also ease handling and transportation throughout the supply chain by creating lighter weight components and assemblies. And, aluminum is highly durable, almost maintenance-free, and 100% recyclable.

As it relates to solar applications, aluminum's unique properties include:

- High strength-to-weight ratio
- Very cost effective, with proper system design
- Excellent formability and ease of fabrication
- Excellent electrical and thermal conductivity
- Excellent resistance to corrosion
- Attractive surface finish
- Excellent reflector of light and heat
- Easy and economical recycling

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PV and solar thermal collector module frames

Photovoltaic (PV) and solar thermal arrays deliver efficient, environmentally-friendly alternatives to fossil-fuel-based power generation. Technological advances have led to lower production and installation costs. Among these advances is the use of creative design with aluminum extrusion components in the frame structure and other areas of the solar array.

With the number of solar parks and rooftop installations increasing, people are becoming more concerned about the aesthetics and maintenance of the array structure. Owners and operators are looking to solar as a source of energy while remaining as unobtrusive as possible. Architects desire solar systems that blend in with the rest of the building and surrounding area.

Extruded aluminum frame structures meet or exceed the strength and flexibility requirements while delivering a lower lifetime cost compared to steel frames, especially with a properly designed custom solution. Aluminum also provides a high level of aesthetic appeal through anodizing or powder coating to achieve the desired surface finish. And, an aluminum frame structure will remain free of rust and resistant to corrosion for the life of the structure.

Long life, simple design, easy installation, and greater aesthetic appeal over the life of the structure – combined with lower lifetime cost – makes aluminum the metal of choice for solar.

Solar mounting systems

Solar mounting systems attach the solar panel array to either the ground or rooftop for residential and commercial applications. For rooftop installations, a variety of frame designs are used depending on whether the system is mounted to a pitched or flat roof.

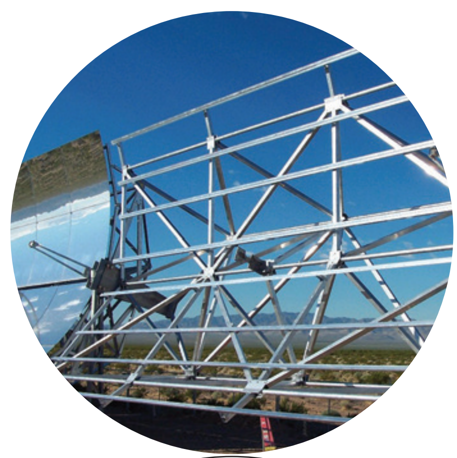
Aluminum ideal for rooftop weight limitations
Existing rooftops typically were not designed to support the weight of a solar installation. But the low density of aluminum helps to make a solar installation feasible, especially on those rooftops that simply cannot handle the high weight of a steel frame structure.

Aluminum extrusions deliver superior design flexibility, high strength-to-weight ratio, excellent corrosion resistance and ease of handling and assembly – all of which are essential for a successful commercial rooftop installation. These characteristics make aluminum the metal choice for solar frame structures installed on carports, commercial buildings and home rooftops.

Ground installation
Aluminum extrusions are ideal for PV and CSP construction because they provide:

- Stiffness to maintain reflector geometry at all times (CSP)
- Strength to withstand the dead and live loads
- Excellent durability and corrosion resistance
- Ease of assembly
- Lower Total Cost of Ownership

With aluminum, you gain a lightweight structure that is easy to handle, transport, and install; a structure which is easy to maintain over a long life and resistant to the corrosive effects of weather. Aluminum is especially desirable for solar parks constructed over landfills or other areas where escaping gases or other environmental impacts may corrode steel frame structures.



Solar inverters

A solar inverter changes the direct current (DC) electricity produced by a photovoltaic array into alternating current (AC). AC is the type of current used in commercial and household electrical applications.

Inverter cabinets
Inverter electrical components are housed in a cabinet that can be produced using aluminum extrusions for a cost-effective and highly utilitarian result. Aluminum inverter cabinets are lighter weight and offer greater design flexibility than steel cabinets. Aluminum extrusions deliver a faster prototyping capability.

With aluminum extrusions you gain the ability to create complex enclosures using two or more simpler extrusions. You can simplify assembly and optimize product performance with aluminum. Select your choice of a variety of finish options, like anodizing. Certain finish attributes, like decorative grooves, can be designed into the extrusion. The end result is a lower cost, corrosion resistant, lower weight cabinet that also offers the possibility of adding more components without adding significantly to the original weight.

Heat sinks
Heat sinks are used in inverter cabinets to dissipate heat. The efficiency of a heat sink depends on its ability to transfer heat quickly away from the components that require cooling. Good heat transfer is achieved by using materials of high thermal conductivity that can be shaped to give high surface areas. Aluminum extrusions satisfy all of these requirements, and can be integrated into the structure.

The extrusion process allows you to produce components in many shapes and sizes such as the closely spaced narrow fins required in heat sinks for heat dissipation. In comparison to other materials the combination of aluminum and shape results in lower cost components.

Solar thermal applications

Aluminum extrusions offer a variety of solutions for solar thermal collectors and connecting lines. For all absorbers, substituting copper tubes with aluminum gives immediate cost and weight advantages.

Plate and tube absorbers
Aluminum offers long life, ease of installation, high strength and low corrosion compared to other tube materials such as copper. The aluminum alloys used to produce solar absorber tubes meet or exceed all requirements for the solar absorber market with excellent flow rate and heat transfer properties.

High performance absorbers
Using aluminum in solar absorbers provides the needed flexibility to implement novel design solutions (e.g. combining plate and tube). Micro-channel profiles may be assembled to manifolds and coated to combine the functions of heat absorption and fluid transport.

Connecting lines
With interest in the use of aluminum in absorbers increasing, it is natural to extend this to connecting lines, where the cost advantages are obvious.

Extruded aluminum tubing products have been proven for handling hot liquids in the automotive, trucking, specialty vehicle and defense industries, among others. With aluminum tube connector lines, you will take full advantage of the many proven properties of aluminum, including its ability to resist damage in corrosive conditions, non-magnetic and non-sparking, lightweight and high strength. Aluminum delivers design flexibility, high performance, efficiency, reliability and low cost.

PV solar frame & mounting system design considerations

Ease and speed of assembly
A good solar design optimizes the number of parts that need to be fastened together on site, as well as assembly and training required for the installation team, lowering the total cost. Lower labor costs and fast installation are competitive advantages resulting from a proper design incorporating aluminum extruded components. You also will experience lower heavy equipment costs because lighter weight loads can be handled manually or by smaller machines, saving costs on cranes, front end loaders and other construction machinery. And lightweight aluminum extruded components ship for less.

Coatings and cosmetic appearance
Under normal circumstances, aluminum extruded frame components left unfinished (mill finish) will outlast the 20- to 30-year life expectancy of a commercial or residential roof and current solar panel technology. This is due to aluminum's natural resistance to oxidation and other environmental effects. Where aesthetics is a design concern, the use of a finish will add to the look of the solar installation. Common finishing techniques include powder coat painting and anodizing in the designer's choice of colors, with powder coating being the significantly more affordable option.

Tight tolerance for mitering and corner joints
Design your frame structure so that it snaps together without gaps that would allow moisture penetration. Aluminum extruded components can be designed for quick, easy snap-together construction with tight fitting joints.

Adjustable PV frame design
Because the industry has not developed a standard size for solar panels, design your frame structure to be adaptable for different size panels. An adjustable frame design gives your solar panel vendor selection flexibility as well as design adaptability. One of the strengths of aluminum extrusion frame components is the ease with which they can be adapted to different size requirements. For example, the same extrusion profile can be fabricated to different lengths and assembly requirements (holes, notches, etc.) at the plant for ready-to-assemble delivery.

Racking and mounting
Design your racking and mounting structures that work with your frame to form a complete, unified structure. With a proper design, your solar system will work great and cost less.

Roof- and ground-mounted solar systems each have their own design issues.

Roof-Mounted Systems: Decide whether to use a penetration or ballast mount. A penetration system places less weight on the roof structure and is suitable where weight is an issue. Your design needs to be consistent with the requirements of the roof warranty to assure that the design doesn't void the warranty. For these reasons, penetration designs should be avoided unless a ballast mount design is not possible. Ballast mount does not require penetration of

the existing roof structure, but the ballasts do add significant weight. Design considerations include:

- Roof pitch
- Frame structure angle
- Ease of access to the roof for installation
- Ease of access to the frame system for maintenance and repair after installation
- Existing roof hazards such as cables and other obstacles

For most applications, the preferred roof design for solar is a ballast mount system with a low angle to minimize wind exposure.

Ground-Mounted Systems: Design your ground mount solar system to be adjustable for differences in land contours. In many cases, you may want your system to be be self-leveling, especially for uneven areas like landfills where the ground will shift significantly over time.

Modularity & scalability
Design your solar system to fit the space available and to expand as additional space becomes available. A modular system is easier to install and allows you to expand over time.

Clips, connectors, and fasteners
In your design, include a method for fastening modules to the frame and rack system. Also consider how you will attach your system to a ground post. Include a way to connect your frame components together appropriate to the overall design of your solar frame system. Since speed and ease of assembly are major cost considerations, choose a joining method that supports quick installation with a minimum of labor. Clips and connectors that facilitate quick, easy assembly can be included in your custom design with aluminum extruded profiles fabricated to your requirements.

Environment
Aluminum is "the green metal" and offers a number of advantages over steel for solar structures. An aluminum frame will outlast the life of the solar panel modules yet is cost competitive with steel structures that will rust out before the solar panels wear out. This frees you to design your solar installation for the life of the panels rather than the frame structure, giving you a significant competitive advantage.

When it's time to replace your solar structure, aluminum is 100 percent recyclable. But, environmental considerations start at the beginning of the process with the raw material used to extrude your components. Using recycled aluminum billet from Hydro reduces the environmental impact of your project by reducing the impact of sourcing and processing raw metal out of the ground.

IBIS PV mounting structure analysis

Using information available in the public domain, IBIS Associates, an independent 3rd party consultant, determined what it costs to fabricate, assemble, ship, and install PV mounting structures for two separate material systems; aluminum extrusions and galvanized steel. IBIS focuses on competitive position assessments of traditional and advanced materials and manufacturing technologies. Specific installation scenarios considered in the analysis include:

- Residential sloped roof-top system
- Commercial flat roof-top system
- Small utility-scale ground-mount systems
- Large utility-scale ground-mount systems

Three specific cost factors were considered; system selection and components (rails, footings, clamps, etc.), fully burdened installation labor, and shipping costs. Cost of land and site preparation was not considered in ground-mounted scenarios.

Conclusions

When taking into account the total cost of materials, other components, shipping, and installation, **aluminum is a more economical alternative to steel in PV mounting structures, across all market segments**. In addition to this demonstrated "initial" cost advantage, you can expect structures built with aluminum extrusions to have a **lower Total Cost of Ownership**, primarily as the result of lower on-going maintenance costs and substantially higher residual value.

Other advantages of using aluminum extrusions for PV structures include:

- Low density & high strength-to-weight ratio
- Low tooling costs and unlimited design flexibility to optimize performance and reduce fabrication steps
- High corrosion resistance for superior durability, even in extreme environments
- Ease of recycling and high scrap value

Recycling value comparison

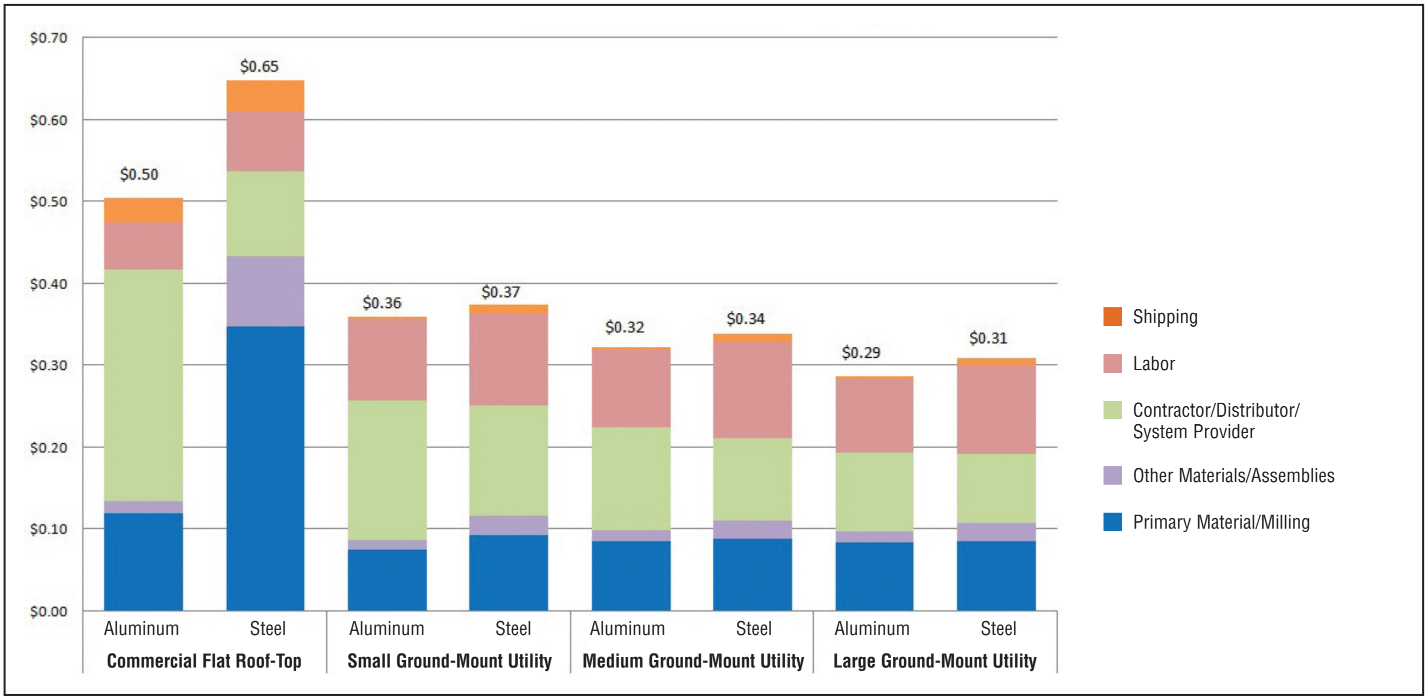
The aluminum system is nearly one-third the mass of the steel design, but it has three times the residual scrap value upon decommissioning (see table).

A mere 5% of the original energy used in primary aluminum production is needed to remelt aluminum products. Recycling aluminum saves nearly 95% of the greenhouse gas emissions associated with primary aluminum production. And, aluminum can be recycled time and time again. Hydro uses primary-quality billet from their own casthouses with 70+% post-industrial recycled content. In contrast to steel, aluminum's properties never change.

50 Mega Watt System	Aluminum	Steel
Total Mass of Structure (lbs)	2,473,348	6,835,683
Scrap Price ($/lb)*	$0.79	$0.09
Total Recycled Value	**$1,961,365**	**$635,719**

* USGS Minerals Yearbook 2009 - Recycling Statistics

PV Mounting Structure Cost ($/W)



For all systems compared, aluminum is the lower cost option

Concentrating Solar Power (CSP)

CSP system
A CSP system is generally comprised of a reflector, a receiver for collecting/absorbing the reflected and refocused solar radiation, along with support structures for the reflectors and collector, and a suitable mechanism for tracking the sun. In utility-scale CSP generation, the solar field accounts for at least 50 percent of the power plant's total cost.

Solar Collector Assemblies (SCA), consisting of a rigid truss assembly, or space frame structure, to support the reflectors, receivers, and system for tracking the sun, constitute approximately 25 percent of those costs.

While concentrating the sun's rays relies on reflectors, it is the supporting metal architecture — trusses, frames, arches, etc. — that assures reflector alignments and provides the strength needed to withstand common forces, stresses, movements, and wind loads, both for parabola shaped reflectors in troughs, and flat reflectors for solar towers.

Steel was used in the 1980's for SCA support structures. However, new designs and fabrication techniques for aluminum have provided viable alternatives. State-of-the-art aluminum space frames in commercial operations have achieved the multiple goals of much higher optical efficiency, lower life-cycle cost, and minimal ecosystem disruption.

Although steel generally has a lower initial material cost, aluminum outperforms steel in terms of total cost; it is less expensive to transport and assemble and has advantages in operations and salvaging. Advantages include:

- Ability to design extrusion to final shape
- Lower cost and more precise machining
- High strength-to-weight ratio
- Ability to provide suitable support using fewer parts
- Reduced transportation and assembly costs
- Faster assembly with accurate alignment and movement in the field
- High recycled content
- Full recyclability at end of life

Structural needs
A sturdy frame is essential to maintaining proper reflector alignment while supporting the solar array structure against environmental and operational stresses such as corrosion, movement and wind loads. In designing the solar frame structure keep in mind the necessity of maintaining optical accuracy with design efficiency. This requires a frame design that incorporates the best practices including minimal raw material consumption, lean manufacturing practices, easy transportation and assembly, long life-cycle and minimized life-cycle costs. Your design should also consider the structure's impact on local environment.

The frame structure needs to incorporate the following characteristics:

Stiffness – rigid frame structure for high optical efficiency

Motion – high angular tolerance consistent with tracking requirements

Strength – to withstand dead weight and loads required for tracking the sun's movement

Modularity –with an optimized number of components consistent with size, transportation, assembly, and site conditions

Ease of fabrication –lightweight design that considers transportation and assembly on site

O&M – high mean time between repairs or replacement of components

All forces acting on a collector must be transmitted through the support framework or auxiliary structures and be dissipated into the ground. In early support designs, it was deemed imperative to use heavy steel structural members to maintain the stiffness and geometry of the collector at all times. Recent advancements in aluminum space frame design have, however, debunked that notion.

Life-cycle cost

While support-structure designs, strategies and technology advancements have pursued the goal of lowering the cost of the solar collector assembly, many solar developers have been reluctant to move away from using steel in the support structures.

This reluctance can be attributed to the assumption that steel is cheaper than aluminum, or other materials, and that heavy weights are needed to combat the various loads that can impact collectors. Though material costs to produce solar mounting systems in steel are generally lower than those of aluminum, the initial cost advantage is mitigated by several factors. Aluminum made with recycled content uses significantly less energy to produce, yet the product shows no loss in performance characteristics. The lighter, rigid aluminum alternatives provide significant savings in terms of design flexibility, labor, transportation, time to install, accuracy, and related gains in electricity generation.

Frame design history

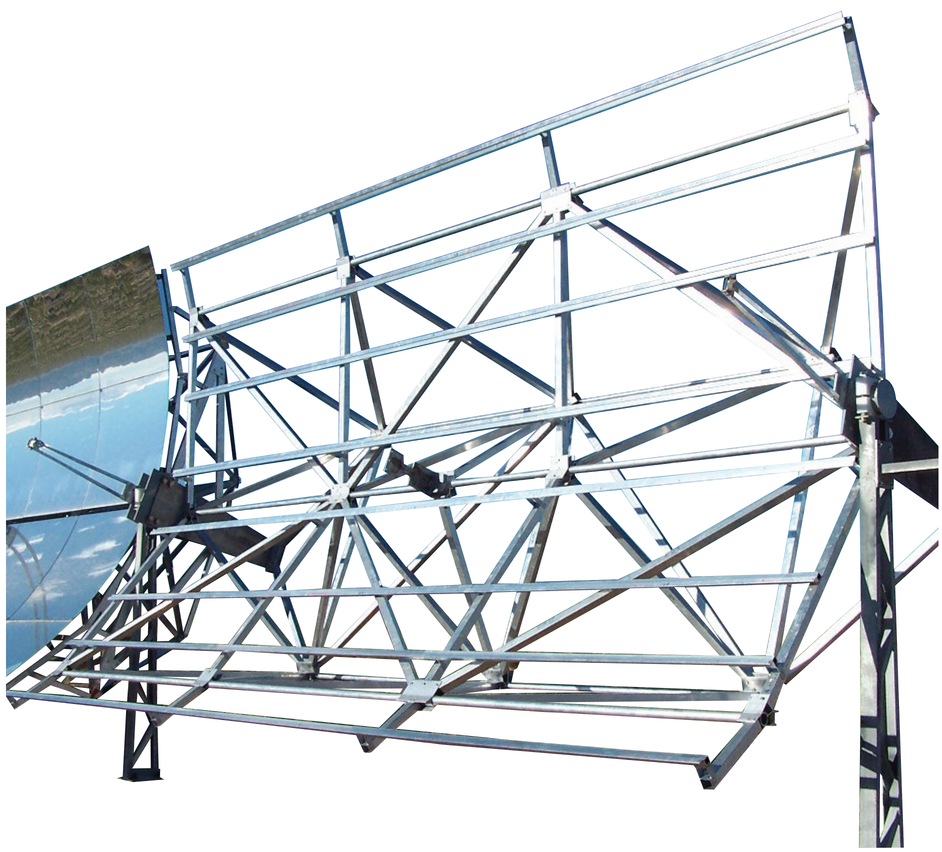
It wasn't until 1981 and 1982 that IEA demonstrated a larger solar-electric parabolic trough. Luz pioneered two steel-based architectures for supporting trough collectors, a torque tube and a V-truss structure.

A torque tube-based structure consists of a long tubular substructure to provide torsion and tension stiffness, connected to a cantilever substructure mounted to and supporting the reflectors. The torque tube design provided adequate optical performance and torsion resistance, but the raw materials, transportation and assembly (including welding and specialty jigs) resulted in higher cost.

The V-truss structure provided the rigidity and strength to withstand loads, compression and twisting forces, but it did not significantly improve optical performance. It also displayed inadequate torsion resistance and did not lower manufacturing costs as much as expected.

Sener and a EuroTrough consortium independently evolved second-generation systems in an attempt to improve optical efficiency, manufacturability and costs. The Sener design used stamped cantilever arms to connect to the torque tube instead of welded tube profiles. Stamping helped Sener lower manufacturing and mounting costs, but assembly still required costly welding of auxiliary components to the tube, thereby diminishing the gains.

The EuroTrough torque box design utilized a rectangular central frame with a square cross-section and cantilever arms to resist bending, twisting and various load stresses while maintaining reasonable optical performance. This design provided torsional rigidity that allowed longer troughs to be developed and allowed longer collectors operated by a single drive.



These two second-generation designs have achieved reasonable optical performance and less collector deformation, but manufacturing, transportation, and erection costs have not dropped significantly. Steel frame construction still requires huge cranes, welding, special jigs, and many man-hours.

State-of-the-art aluminum frame design

The newest generation trough support structures with dramatic improvements in all aspects of the design and operation requirements is the Solargenix (later Acciona)-Gossamer-Hydro all-aluminum space frame with hub connectors that was first put in operation on Nevada Solar One.

The first generation all-aluminum space frame was envisioned by Solargenix under the U.S. Department of Energy's USA Trough Initiative and through a cost-shared R&D contract with NREL. The resulting collector and supporting structure provided valuable insights and led to the second-generation design, which was commercialized.

Located 30 miles outside Las Vegas, NS1 has a nominal production capacity of 64 MW with a maximum capacity of 75 MW. Its annual production is 130,000 MW. It was built in just 16 months at a cost of $266 million. It came online in June 2007.

It's 300 acres of solar fields comprise 9,120 space frames supporting 760 parabolic concentrators with more than 180,000 mirrors that concentrate the sun's rays onto 18,240 solar receiver tubes located on their focal line.
The frames were manufactured from more than 7 million pounds of extruded aluminum with 70-80 percent recycled content.

The performance facts as reported by NREL for the extruded aluminum trough versus the most advanced competitive design includes:

- 50% fewer parts
- 30% less weight
- 1/3 assembly time required compared to conventional frame systems
- No post-construction frame or mirror alignment required

Performance assessments showed a combined "slope error" (mirror error plus frame alignment error) standard deviation of less than 2.0 milliradian, enabling improvement in focusing of up to 38 percent over NREL's recommended 3.0. This means the collector troughs are operating near theoretically perfect performance. The net effect is an annual output increase of 4 percent, or approximately 2.5 MW.

IBIS CSP frame structure analysis

Using information available in the public domain, IBIS Associates performed an independent detailed analysis of various existing parabolic trough CSP (Concentrated Solar Power) frame designs from steel and aluminum used for utility scale solar power applications.

Material, fabrication, transportation and field assembly costs were estimated and vetted for use in this study. The included excerpts from the IBIS analysis are useful in understanding why aluminum extrusions represent a competitive advantages in both total installed cost and performance.

- IBIS focuses on competitive position assessments of traditional and advanced materials and manufacturing technologies
- The Eurotrough, Skal-ET 150, HelioTrough, and SenerTrough steel-based systems were compared to a "standardized" aluminum-extrusion design using public data available for the Acciona/FP&L CSP structures
- IBIS created parts and material processing models for the aluminum extruded and galvanized steel frame designs, detailing components/materials/processes and modeling the costs associated with these elements
- The results were validated via external expert review
- The results are a strategic cost analysis (not a final "price" analysis, as it does not include SG&A costs nor profit)

Design comparisons

Eurotrough/Skal-ET 150
Developed by a consortium of industry partners and supported by the European commission, the Skall-ET 150 is a scaled-up design which replaces square tube sections with angle sections.

Collector length: 12 m
Aperture width: 5.77 m
Total aperture area: 69.2 m^2

HelioTrough
A torque-tube design with the center of gravity below the mirror surface provides gapless SCA (no mirror gap across the pylons)

Collector length: 19.1 m
Aperture width: 6.77 m
Total aperture area: 129.3 m^2

SenerTrough
A torque tube design utilizing stamped cantilever arms made from electrogalvanized sheet (reducing galavanting costs)

Collector length: 12 m
Aperture width: 5.77 m
Total aperture area: 69.2 m^2

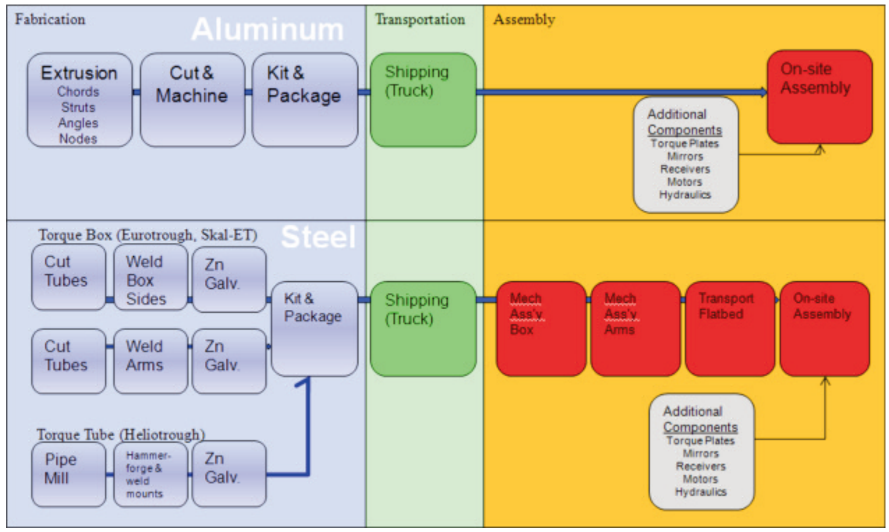
Standardized aluminum extrusion frame
A scaled-up version of the Acciona/FP&L eight meter design with a wider aperture

Collector length: 12 m
Aperture width: 5.77 m
Total aperture area: 69.2 m^2

	Number of Pieces	Mass lbs (kg)	Structure Steel Surface Area (sq ft)	
Eurotrough	390	2667.5 (1209.8)	1240.7	~ 18 kg/m^2 of aperture
Skal-ET 150	390	2684.9 (1217.6)	1025.2	~ 18 kg/m^2 of aperture
HelioTrough	678	5918.3 (2684.1)	2292.6	~ 21 kg/m^2 of aperture
SenerTrough	87	3604.0 (1634.5)	551.6	~ 21 kg/m^2 of aperture
Aluminum Extrusion	179	1628.9 (738.6)	24.6	~ 10.7 kg/m^2 of aperture

Comparative manufacturing and assembly process flows

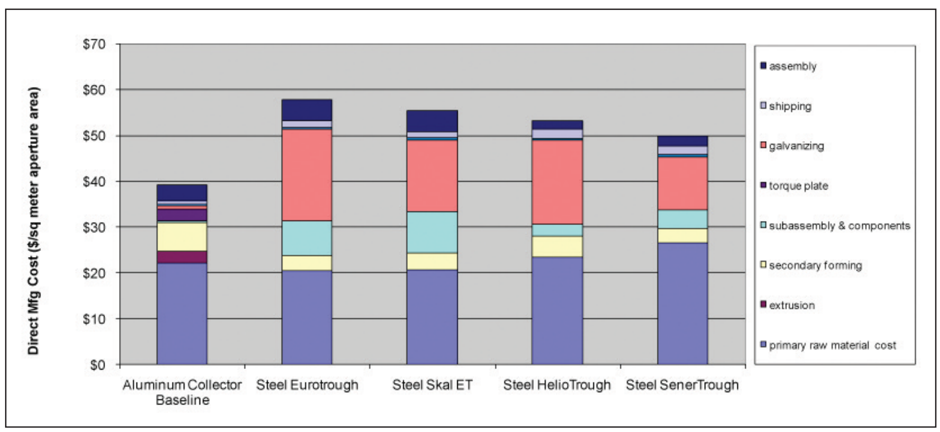
The aluminum extrusion-based design requires fewer manufacturing/finishing steps and a more straightforward, lower cost, assembly operation.



Scenario comparison / breakdown by category / cost per unit area

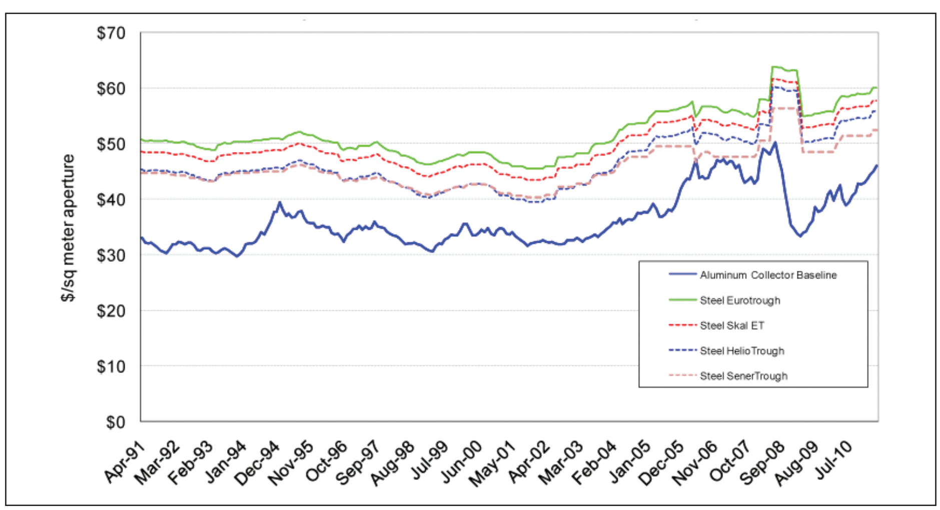
Cost modeling methodology

The following cost estimates are built from the bottom up and consider all variable and fixed elements of each of the operations required to fabricate, assemble, and install solar thermal parabolic collectors. These are direct manufacturing costs that would be incurred by a company that is completely integrated from raw material acquisition to final field installation. There are no SG&A costs nor profit added to these estimates.

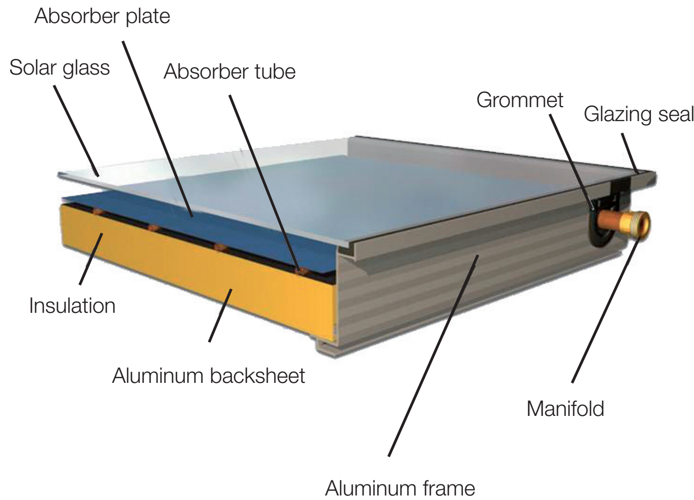


Projected collector cost over market history

Steel costs less than aluminum on a per pound basis, but comparable frame solutions using aluminum weigh approximately 1/3 that of steel. Using aluminum extrusions for the frame structure provides cost and performance benefits which far outstrip the pure material cost differences. Despite fluctuating material costs, at no time from 1991 through 2011 would the comparative prices of steel, zinc and aluminum extrusions have resulted in a case where the cost of the extruded aluminum frame would have been greater than the galvanized steel frames.



Solar thermal design considerations



Solar collectors use the heat from the sun to produce hot water. Flat plate collectors are the dominating solar thermal technology. Typically, the sides and backs of these collectors are made of aluminum. Over the past few years, aluminum has displaced copper as the preferred material for absorber sheets. Recently, aluminum absorber tubes have entered the market.

While the thermal conductivity is higher for copper than aluminum, it is the heat transfer coefficient that is more relevant in thermal systems. The heat transfer coefficient explains how much heat that may be transferred per unit area and is measured in $W/(m^2K)$.

Warping is a known phenomenon in welded assemblies. Being consistent when choosing materials, such as aluminum sheets and tubes, significantly improves the quality of an absorber. When copper tubes are welded to an aluminum sheet, the absorber becomes warped as the absorber's temperature increases. This is due to the difference in the two materials' thermal expansion coefficients. Different materials expand at different rates as the absorber's temperature increases, thereby warping the absorber and subjecting the welding points to material stress.

Designing aluminum systems against corrosion requires matching alloys appropriately as well as taking precautionary measures to maximize the life expectancy of the system. Aluminum as a stand-alone material is resistant even to aggressive environments, including seawater conditions. When designing a solar thermal system, there are two main types of corrosion to consider.

Internal corrosion

To secure the system against internal corrosion, Hydro recommends an alloy which is corrosion resistant. Also, the system needs to be a closed system (hermetically sealed) that contains a heat transfer fluid containing an inhibitor. An open system, or a system with fresh water without an inhibitor, will corrode. Most commercially available heat transfer fluids contain inhibitors. We also only recommend the use of aluminum or stainless steel fittings in hot areas (i.e. at the absorber). We do not recommend brass fittings in these areas since brass contains zinc. This is because zinc introduces corrosion in a solar thermal system at high temperatures.

External corrosion

There are mainly two areas of risk for external corrosion, at joints to copper or brass fittings, or at joints between the absorber tubes and sheet. External galvanic corrosion may occur between aluminum and other metals if water is allowed to condense on the joint area.

To avoid corrosion where aluminum is directly joined to copper or brass fittings, it is good practice to protect the joint area with a suitable coating against outside moisture.

To avoid corrosion between the absorber tubes and sheet, it is important to select the right alloy combination for the aluminum absorber plate and tube. The tube has to be slightly more noble than the plate in order to guarantee that any potential material sacrifice is of the plate and not tube. The larger the difference in material nobility, the higher the risk that the less noble material will sacrifice electrons to the more noble material, introducing corrosion. Thanks to lower differences in potentials in an all-aluminum absorber, compared to an absorber with copper tubes and an aluminum sheet, the overall corrosion risk is reduced and a longer collector lifetime may be obtained.

Good welding is essential for the absorber to perform well under working conditions.

Laser welding

Tests of laser welding aluminum tubes to aluminum sheets have confirmed that less energy is needed compared to welding copper tubes to aluminum sheets. Process times have been reported to be reduced by as much as 20-30%.

Ultrasonic welding

Ultrasonically welding copper tubes to aluminum sheets is delicate and difficult, and so far only the very best ultrasonic welders have managed to weld the two materials together. This has kept many absorber manufacturers from switching to aluminum sheets and they continue to produce expensive all-copper absorbers. With the introduction of aluminum tubes, absorber manufacturers with ultrasonic welding equipment may also switch to aluminum sheets without having to change welding equipment.

Continuous Step Welding (CSW)

CSW is a new welding technology that uses very low amounts of energy and also deforms the tubes to introduce turbulence.

For more information on specialized alloys, go to:
www.hydro.com/en/Subsites/Hydro-Aluminium-Precision-Tubing/Solar-aluminium-products-solution/Competences-solar/solar-tests

Aluminum is often called the green metal because of its inherent characteristics and the ease with which it can be recycled, using only a fraction of the energy required to make primary aluminum.

A mere 5% of the original energy used in primary aluminum production is needed to remelt aluminum products. Recycling aluminum saves nearly 95% of the greenhouse gas emissions associated with primary aluminum production. Today, aluminum recycling now saves close to 170 million metric tons of greenhouse gas emissions per year.

And, aluminum can be recycled time and time again. In contrast to many other materials, aluminum's properties never change. Of an estimated total of around one billion metric tons of aluminum produced in the world since commercial manufacture began in the 1880s, about three quarters is still in productive use. Recycling the metal currently in use would equal up to16 years' primary aluminum output. The global inventory of aluminum in use has grown from 90 million metric tons in 1970 to about 600 million metric tons today and is forecast to reach more than 1 billion metric tons in 2020. This is creating a vast material and energy storage bank for future recycling use.

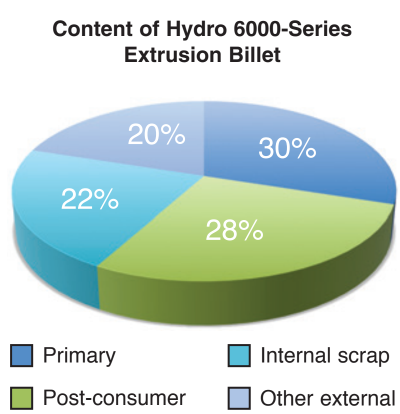
Aluminum's light weight and overall excellent in-use performance ensures that the life-cycle of many products are enhanced. The low density of aluminum benefits the transportation, aviation, and aerospace industries because lighter structural systems result in lower fuel consumption. For example, every kilogram of aluminum that is used in substitute for heavier materials in a car or light truck, has the potential to avoid the release of 20kg of CO_2 over the lifetime of the vehicle.

As society's demand for "green" products increases, recycled aluminum will become an even more important material source. Today, aluminum is the most commonly recycled post-consumer metal in the world. Recycling aluminum makes environmental sense and it also makes good economic sense. Products built with aluminum extrusions can have a lower life-cycle cost and provide full end-of-life recyclability.

Using proprietary remelt technology, Hydro is the leading supplier of aluminum billet in North America and produces primary-grade metal which contains more than 70% recycled content. Our extrusions, produced using Hydro remelt billet, are ideal for "green" applications, like solar.

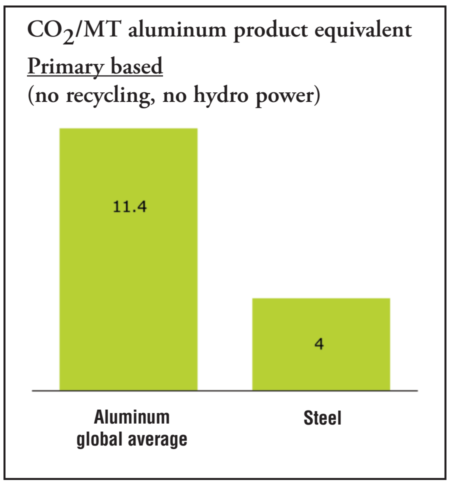
Sources of aluminum — Recycling is the path to reduced carbon footprint

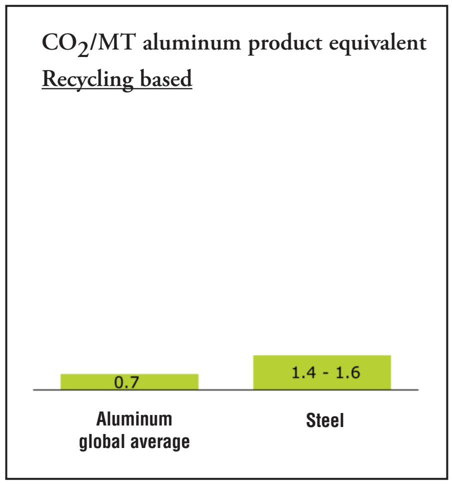
- Hydro recycled about 275 million pounds of aluminum in 2011 in North America
- Our 6000 series alloy has > 70% recycled content
- Recycling is the path to reduced carbon footprint
- Recycled aluminum is excellent for LEED related building products or for any product with a "green" aspect



Carbon footprint - Emissions per metric ton (MT) of product

Using aluminum with high recycled content has a smaller impact on the carbon footprint of producing the material.





2012 Recycled Content Declaration

Hydro's Extrusion North America unit sources billets for our extrusion facilities and external customers from our own network of three remelt casthouses. These casthouses, located in St. Augustine, FL, Monett, MO, and Phoenix, AZ, utilize state-of-the-art and proprietary technology to produce primary-quality extrusion billet with high recycled content.

In 2011, these facilities used in their production close to 275 million pounds of recycled aluminum — 20 percent more than in 2010 and 32 percent more than in 2009. Nearly 20 percent of last year's amount was post-consumer material, with the remainder coming from pre-consumer scrap from our casthouses and extrusion plants, our customers, and other extruders. The scrap content of 6000-series alloy billet we produced in 2011 was around 70 percent.

Through technology and practical improvements, Hydro's Extrusion North America unit is committed to increasing its share of the goal that Hydro has set for its global operation: To recycle 1 million metric tons of contaminated and post-consumer scrap annually by the year 2020.

The properties of aluminum

Aluminum has a unique and unbeatable combination of properties that make it versatile, effective, and attractive for a vast array of applications

Weight - Aluminum is light with a density one third that of steel (0.097 lbs/in^3).

Strength - Aluminum is strong with a tensile strength of 10 to 100 KSI, depending on the alloy and manufacturing process. Extrusions of the right alloy and design are as strong as structural steel.

Elasticity - The Young's modulus for aluminum is a third that of steel (10,008 KSI). This means that the moment of inertia has to be three times as great for an aluminum extrusion to achieve the same deflection as a steel profile.

Formability - Aluminum has good formability, a characteristic that is used to the fullest extent in extruding, facilitating shaping and bending of extruded parts. Aluminum can also be cast, drawn, and milled.

Machining - Aluminum is very easy to machine. Ordinary machining equipment such as saws and drills can be used along with more sophisticated CNC equipment.

Joining - Aluminum can be joined using normal methods such as welding, soldering, adhesive bonding, and riveting. Additionally, Friction Stir Welding (FSW) is an alternative in certain applications.

Corrosion resistance - A thin layer of oxide is formed in contact with air, which provides very good protection against corrosion even in extremely corrosive environments. This layer can be further strengthened by surface treatments such as anodizing or powder coating. And corrosion resistance can be enhanced through alloy selection.

Reflectivity - Aluminum is a good reflector of light and heat.

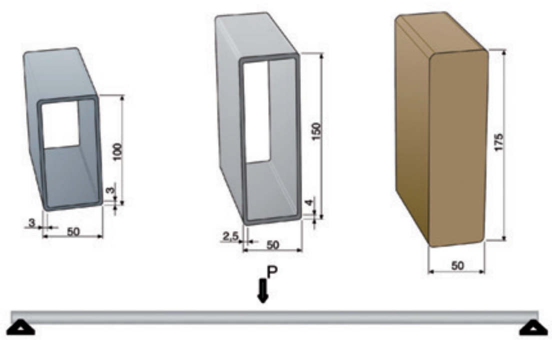
Thermal conductivity - Thermal conductivity is very good even when compared with copper. Furthermore, an aluminum conductor has only half the weight of an equivalent copper conductor.

Electrical conductivity - When compared to copper, aluminum has good electrical conductivity.

Linear expansion - Aluminum has a relatively high coefficient of linear expansion compared to other metals. Differences in expansion can be accommodated at the design stage, or in manufacturing.

	Steel	Aluminum	Wood
Modulus of Elasticity	30500 ksi	10,000 ksi	1,600 ksi
Moment of Inertia	2.4 in^4	7.9 in^4	5.3 in^4
Weight	4.5 lb/ft	2.0 lb/ft	2.35 lb/ft

Different material beam solutions giving the same deflection under load



Deflection $f=P*L^3/(48*E*I)$

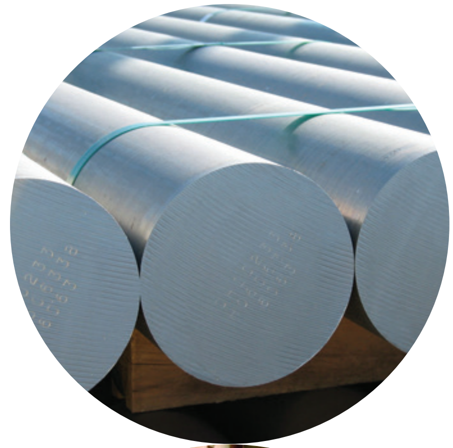
Properties of materials

	Aluminum*	Copper	Steel 371	Plastic
Strength (ksi)	36	36	58	7
Density (lbs/in^3)	0.097	0.32	0.28	0.05
Melting point °F	1110-1210	1980	2730	180
Electrical conductivity (% IACS)	50	95	12	-
Heat conductivity (Btu-in/ft^2hr°F)	1390	2780	527	1.04
Non-magnetic	Yes	Yes	No	Yes
Weldable	Yes	Yes	Yes	Yes

*6000 series

Aluminum alloys

The choice of material is a critical decision in all product development. Aluminum can give a product suitable physical and mechanical properties and, at the same time, help achieve an aesthetically attractive appearance.



Pure aluminum is only used in a limited way commercially. The majority of extrusions are made from aluminum alloyed with other elements. The most common elements used are magnesium (Mg), silicon (Si), manganese (Mn), zinc (Zn) and copper (Cu). Most aluminum extrusions are made from the alloy series listed below:

1000 series Al
3000 series Al + Mn
5000 series Al + Mg
6000 series Al + Mg + Si
7000 series Al + Zn + Mg

The 1000 series is non-heat-treatable. These alloys are often selected for products where high thermal and electrical conductivity are desired. They have low strength.

The 3000 and 5000 series are non-heat-treatable. 3000 series is often used in drawn tubing for highly ductile applications and printer components. The 5000 series is mostly used in extremely corrosive environments such as marine.

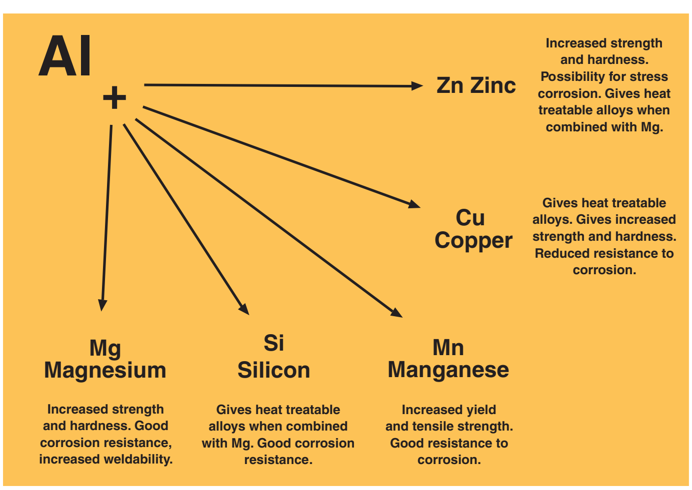
The 6000 and 7000 series are heat-treatable. They are the most commonly used extrusion alloys and have a wide range of applications.

6000 series

The 6000 series is the primary alloy used for solar applications. It has good extrudability and can be solution heat-treated during hot working at the extrusion temperature. Solution heat treatment enables some of the alloying elements, such as Mg and Si, to go into solid solution and be maintained in a supersaturated state on quenching. This homogenous material is subsequently age hardened to obtain the required mechanical properties.

The 6000 series alloys are termed “soft alloys”. They are easy to weld and offer good resistance to corrosion. The bulk of extruded materials are for load bearing applications.

Among the 6000 series, the 6060 alloy offers low to medium strength and is easy to extrude even for complicated cross-sections. It has good formability during bending in the T4 condition. This material is highly suitable for



Properties that can be achieved when alloying with other metals anodizing, both for decorative and protective reasons.

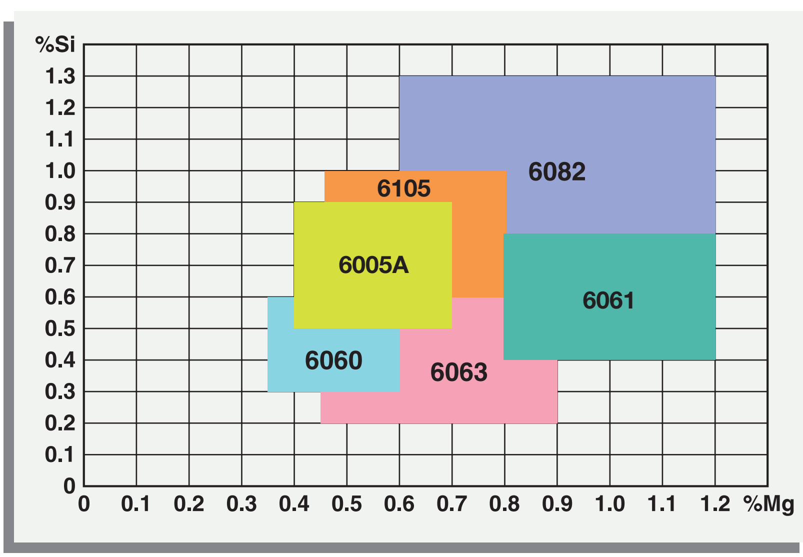
The 6005A alloy has higher strength than 6063 but is slightly harder to extrude. 6005A is relatively less ductile than 6060/6063 alloys in the heat-treated condition. It is suitable for anodizing for protective purposes but the quality of the surface makes decorative finishing more difficult. 6105 is an alloy of similar chemical composition to 6005A but is considered less robust for demanding medium-strength applications.

6061 and 6082 alloys provide high strength and are suitable for extrusion of cross-sections that are not too complicated. With its superior material performance characteristics, 6082 can often replace 6061. The material is suitable for anodizing for protective purposes.

Temperature – mechanical properties
Care should be taken when using aluminum at high temperatures. Mechanical properties can be significantly reduced at temperatures above 250°F, especially if the material has been thermally hardened or cold worked. Fortunately, extended exposure above 250°F is rare in general extrusion applications. When such exposure is anticipated, ensure that the component is not structural or load bearing. For such applications, specialty alloys in the 3000 or 7000 series should be considered.

In general, the 6060, 6063, 6005, 6061 and 6082 alloys should not be used in structural applications which experience temperatures above 250°F. The tensile strength decreases as the temperature increases while elongation before fracture usually increases.

Low temperature properties
In contrast to steel, aluminum alloys do not become brittle at low temperatures. In fact aluminum alloys increase in strength and ductility while impact strength remains unchanged. As the temperature decreases below 32°F, the yield strength and tensile strength of aluminum alloys increase.



As seen above, some alloy groups overlap. Although different in name, chemical composition and properties can be the same or similar. 6060 and 6063 are lower strength alloys of comparable performance. 6105 and 6005 are similar, medium-strength alloys. 6061 and 6082 are high-strength structural alloys.

Corrosion resistance

One of the principal reasons for choosing aluminum for structural applications is its high corrosion resistance.

Although aluminum is a chemically-active metal, its behavior is stabilized by the formation of a protective oxide film on the surface. Generally, this film is stable in aqueous solutions with pH 4.5-8.5. Further considerations need to be made if the pH exceeds these limits or if the environment contains chloride. Although generally very stable, aluminum alloys can experience certain types of corrosion as summarized below:

Uniform attack

Corrosion proceeds homogeneously over the whole surface of the metal. With aluminum alloys this type of corrosion is mainly seen in very alkaline or acid environments where the solubility of the natural oxide film is high.

Pitting corrosion

Pitting corrosion is the most common type of corrosive phenomena with aluminum alloys and is characterized by local discontinuities in the oxide film (i.e. locally reduced film thickness, rupture, localized concentrations of impurities/alloying elements, etc.) Aluminum is sensitive to pitting when chloride ions are present (e.g. sea water). Pits develop at weak spots in the surface films and at places where the oxide film is mechanically damaged.

Pitting can penetrate several millimeters during a short period of time if the conditions are extremely poor. The pits can be of different shapes, wide or narrow. Narrow pits are undesirable since the pits could be deep and difficult to detect.

Choosing the right alloy and proper surface treatment (e.g. anodizing, powder coating or electrostatic painting) are two ways to limit or prevent pitting corrosion. Frequent cleaning, as well as ventilation of tight assemblies and a profile design which reduces the accumulation of stagnant water, are also recommended.

InterGranular Corrosion (IGC)

IGC is selective corrosion around the grains and in the adjacent zones without any appreciable attack on the grain itself. The reason for IGC is a difference in corrosion potential between grain boundaries and the bulk of the immediately adjacent grains. The difference in potential may be caused by the difference in chemical composition between the two zones. This situation may, for example, develop as a result of slow cooling after extrusion. In this case, the grains will be larger and the inter-metallic particles will precipitate on the grain boundaries, thus increasing the difference in corrosion potential between the grain boundaries and the interior of the grain.

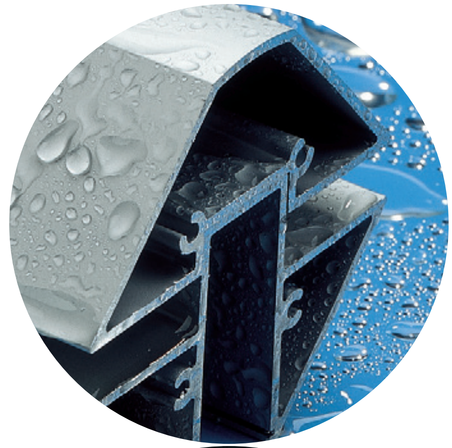
Due to low metal consumption, inter-crystalline corrosion is difficult to detect visually and even more difficult by measuring weight loss. However, if the corrosion is permitted to propagate into the metal, the mechanical properties of the material will severely deteriorate.

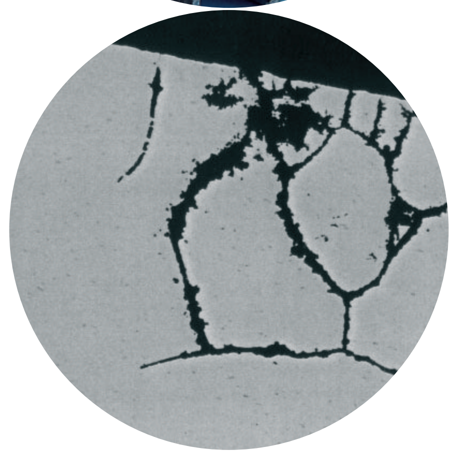
Alloys in the 6000-series are normally resistant against IGC, although this is dependent on the chemical composition. Recrystallized structures which already have a high content of Si or Cu, may allow corrosion of this type. Addition of Mn or Cr will prevent or minimize recrystallization.

One way to prevent IGC is to choose the right alloy. Other preventative actions are mentioned under "Pitting corrosion."

Crevice corrosion

Crevice corrosion may occur in narrow crevices filled with liquids like water. Use of a sealant prior to joining may prevent moisture penetration. A good extrusion profile design will minimize the risk of crevice corrosion.





Water staining

Water staining is a type of crevice corrosion and is caused by water or moisture trapped between, for example, dense stacked profiles. Water staining is a very common corrosion type. Appearance varies from iridescent in mild cases, to white, grey or black in more severe instances. Water staining is normally removed by grinding or painting.

Because of the risk of condensation, profiles without any surface treatment should never be stored outdoors, even though plastic wrapping is used. Store extrusions in places with a relative humidity of 45% maximum, and a maximum temperature variation of +/-40°F. During transportation from a cold to a warm area, the temperature should be increased gradually to avoid condensation.

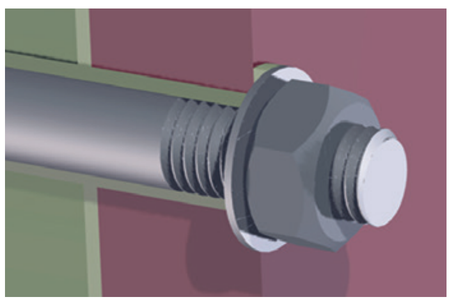
Galvanic corrosion

Galvanic corrosion occurs when two metallic materials are in contact in the presence of an electrolyte forming a galvanic cell. The least noble material (the anode) preferentially corrodes while the more noble material (cathode) is protected. Since aluminum is more anodic than most commonly used construction materials, with the exception of zinc, magnesium and cadmium, this can be a serious form of corrosion with aluminum.

Coupling aluminum with a more noble material can seriously deteriorate the protective effect from the oxide layer. This is especially dangerous in atmospheres or water with high concentrations of chlorides or other aggressive corrosives.

Most types of aluminum corrosion are the result of some kind of galvanic coupling with a dissimilar material.

Galvanic corrosion can be avoided or minimized by taking the following actions: Avoid using materials with large galvanic potential differences in a particular environment (stainless steel not included). If that is not practical, different materials have to be properly electrically insulated. It is very important to use insulation material of proper electrical resistance and to avoid metallic contact in the entire construction. This can be checked with resistance measurement instruments such as a multimeter.



Aluminum may also be protected by means of sacrificial anodes.

The most cathodic material can be surface treated with a metallic coating (Al/Zn), organic coating (lacquer, paint, plastic, rubber) or a special coating for screws and bolts. Surface treatment has to be carried out correctly and not done only on the anodic material. As a consequence, a defect in the surface coating may generate a very unfavorable cathode/anode ratio (a big cathode area in relation to a small anode area gives considerable corrosion).

Galvanic corrosion in combination with crevice corrosion may be especially damaging. Avoid entrapment of liquids in crevices between materials of various galvanic potentials.

Also avoid the transfer of ions of galvanic materials on aluminum surfaces. For instance, droplets from a copper tube on an aluminum surface will generate precipitation of copper metal. The result is corrosion of aluminum (deposition corrosion). The next step will be microgalvanic corrosion between aluminum and the copper particles in the aluminum surface. Severe pitting may occur within a few weeks.

Corrosion resistance in different environments

The atmosphere

Corrosion is insignificant in fresh, unpolluted air. Aluminum does not corrode where there are high levels of sulphur dioxide but can become dark or matte in appearance.

Water

Pitting can occur in stagnant water. The composition of the water is the important factor as the presence of copper, calcium, chloride and bicarbonate ions increase the risk significantly.

Seawater

Alloys containing silicon, magnesium and manganese show good resistance to corrosion in seawater. Copper alloys, on the other hand, should be avoided.

Soil

The resistance to corrosion is, to a great degree, dependent on the moisture in the soil and its pH level. Aluminum surfaces which may come into contact with soil are best treated with a thick layer of bitumen or a powder coating.

Acids

The majority of inorganic acids have a very corrosive effect on aluminum, except nitric acid. High temperature, high acid concentrations and high levels of impurities in the aluminum increase the rate of corrosion significantly.

Alkalis

Strong alkalis are very corrosive. Sodium hydroxide reacts violently with aluminum. The rate of corrosion can be reduced in environments where the pH is between 9 and 11 by using silicates. Wet cement has a high pH and therefore corrodes aluminum alloys.

Organic compounds

Aluminum is highly resistant to the majority of organic compounds. Corrosion can occur, however, with certain anhydrous liquids.

Other materials

In practice, the corrosion problem caused by contact with other materials is, for the most part, small. The natural oxide layer usually provides sufficient protection.

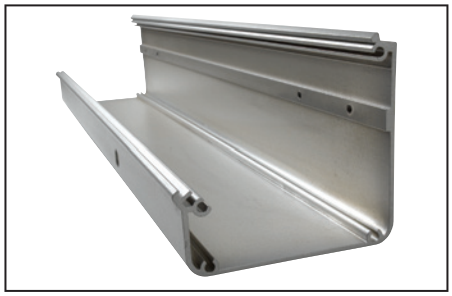
Types of extrusions

Hollow extrusions

A shape is described as a hollow if a completely enclosed void exists anywhere in its cross-section.

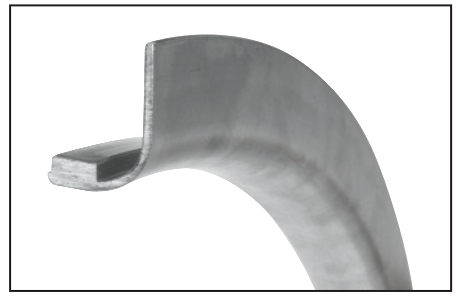
Semi-hollow extrusions

A shape is described as a semi-hollow if a partially enclosed void exists anywhere in its cross-section.



Solid extrusions

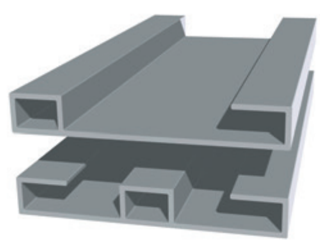
The shape is described as a solid if it does not have voids and is neither a hollow nor semi-hollow.



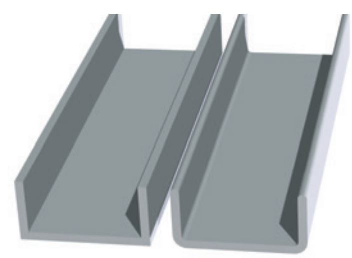
Extrusion design

To achieve a successful product design, an understanding of some basic extrusion design concepts could be very useful.

Uniform wall thickness
Uniform wall thickness within a section reduces the load on the die and minimizes the risk of damage to the die. Major differences in wall thicknesses within a section should also be avoided in order to minimize differences in surface appearance after anodizing.

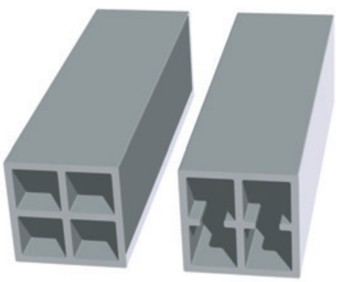


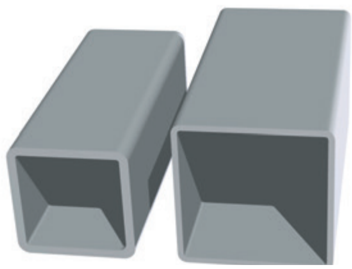
Symmetry
With symmetrical extrusion designs, a balanced flow of material through the die is achieved. At the same time, the load on the die is evenly distributed. The extrusion shape is, therefore, more accurate while the risk of damaged dies is significantly reduced.

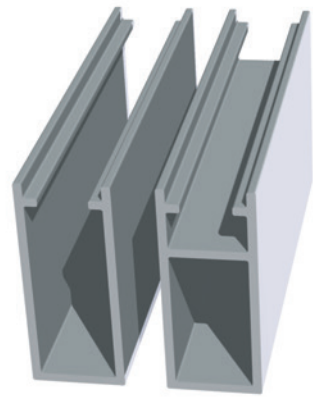


Rounded shapes
As a rule, all corners should be rounded. Normal radii are .016" to .040". If the design requires sharper edges and corners, a radius of .008" is the smallest that can be effectively produced.

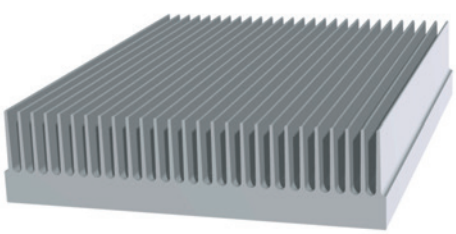
Simplify and facilitate
Here are some design changes that have no impact on extrusion function, but which simplify and facilitate production, lowering production costs and improving cost efficiencies.


Fewer cavities cut costs

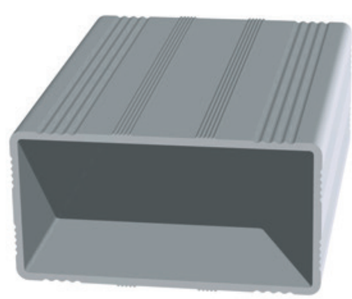

Increased size can cut weight and increase rigidity


For certain applications, converting to a hollow extrusion can increase strength and provide better dimensional control

Heatsinks
Incorporating flanges in the design increases the surface area of the extrusion and improves thermal conductivity.



Decorative lines
Decorative lines in an extrusion can conceal irregularities as well as protect against damage during handling and fabrication.

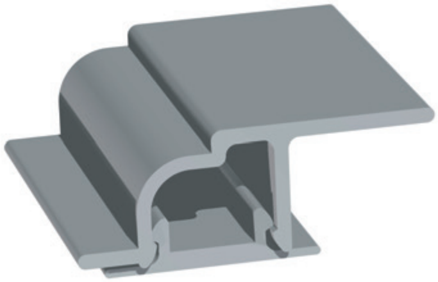


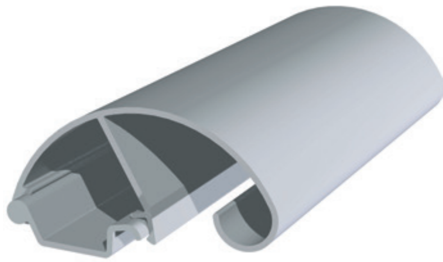
Joining options

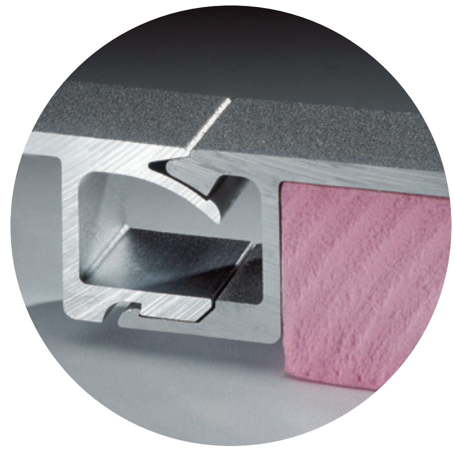
Snap joints
The elasticity of aluminum makes it ideal for snapped joints. Snap joints are highly effective at joining two or more extrusions, allowing for easy separation to give access to internal components.

Designed properly, this joining technique is ideal for many applications. For example, many extrusions can be snapped together to create a whole panel. Large extrusions that cannot be produced as a single unit can be made as two parts and then snapped together.

When designing snap connections, be sure to consider the risk of permanent shape change when the material loses its elasticity. This applies especially to connections that are frequently joined, separated and rejoined. In such cases, plastic clips, steel springs or similar connections should be used.

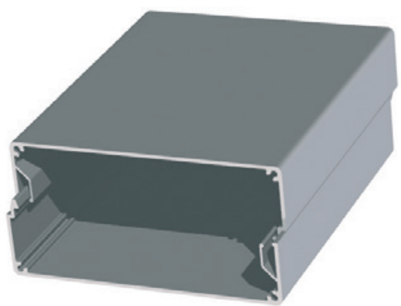


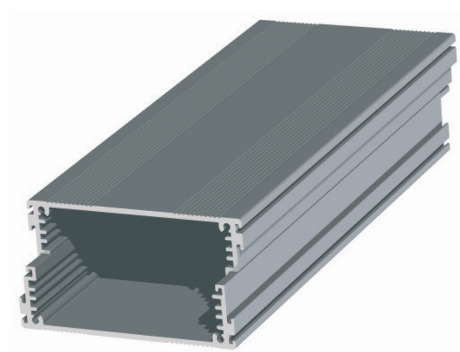




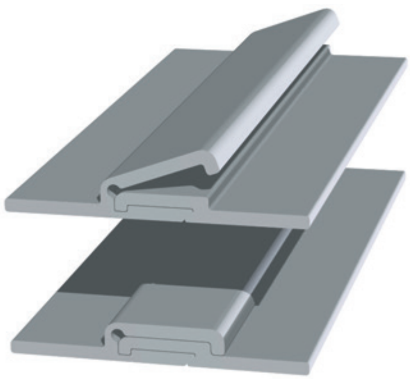
Creating enclosures
When joining one extrusion to another, they can either be slid together longitudinally in specially designed tracks or snapped together. Locking options include specially designed deformations, screws, or cylindrical plugs.

Cabinets and other enclosures are often built by sawing an extrusion and then joining the two halves together. They are locked together by fitting a cover. This technique makes for easier assembly of electronic components. It also reduces die costs since solid aluminum extrusions can be used, which are easier to produce than hollow extrusions.

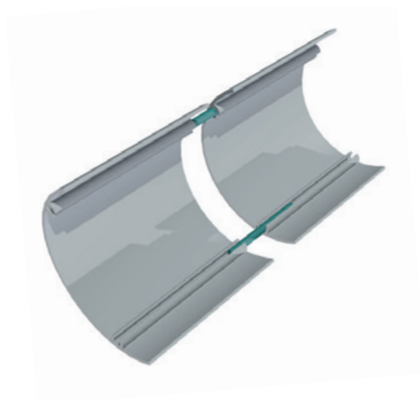




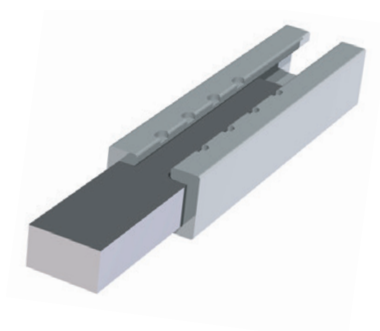
Formed joint
A formed joint can be a good solution if a permanent joint between two extrusions or an extrusion and another material is required. Long sections that are too wide to be extruded can be produced by rolling two extrusions together to the required dimension. Aluminum is excellent for this application as it can be easily manipulated without detriment to form or function.



Butt joint
Butt joints can be made by using guide pins or screws along the length of the extrusions.

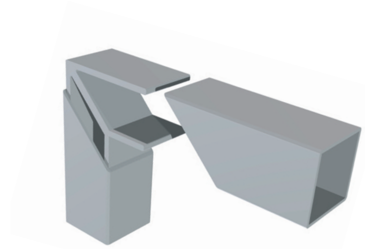


Sleeve joint
A sleeve joint gives a more durable and permanent joint.

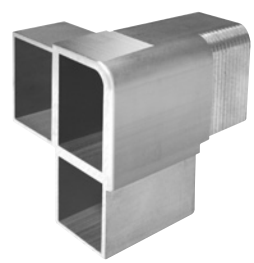


Corner joints

Simple joining of two extrusions that are screwed, riveted or bonded



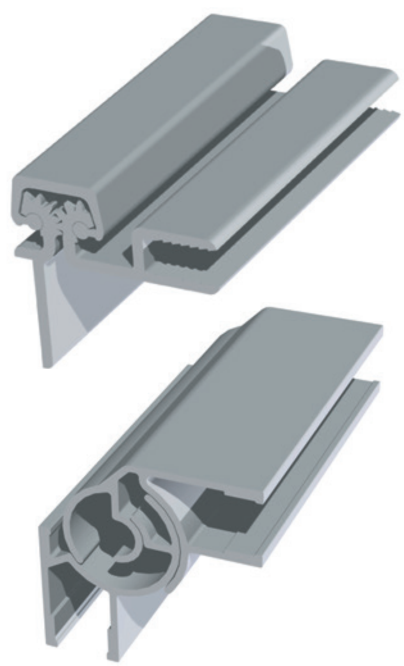
Extruded corner cleat

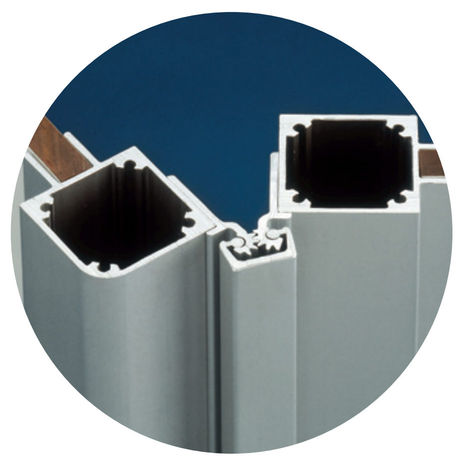


Extruded 3-D corner cleat

Hinges
Aluminum extrusions provide many opportunities for designing integrated joints and hinges. Correct design can give a movement of 90° without any need for machining. Screw grooves can also be designed into the extrusion for later assembly and connection of other parts.

One very practical solution is a geared hinge assembly where two curved gearlike extrusions interweave within a protective third extruded housing to form a unique hinge.





Anodizing

Anodizing is an electrochemical process that creates a significantly thicker layer of oxide than occurs naturally. This provides protection against mechanical wear and corrosion at the same time as electrically insulating the surface.

The process involves placing the extrusion in an electrolyte bath with a DC current where the extrusion acts as the anode (hence the name). When the current is applied, a thick oxide layer is formed, which becomes an integral part of the material. The thickness of the layer is determined by a combination of the temperature and composition of the bath, applied current, and anodizing time.

The oxide layer created consists of a number of open pores that enable dying or coloring. The anodic oxide layer can be colored in a wide range of shades. The process is completed by sealing with boiling water which closes the pores.

Properties

The anodic oxide layer formed by anodizing provides very good resistance to corrosion. The surface is not normally affected by contact with solutions and substances with 4 to 8.5 pH. The surface can be stained and damaged by strongly alkaline substances. This is something to remember for aluminum building components, which should be protected during construction from concrete, cement, etc.

Aluminum's natural oxide layer has a thickness of about 0.02µm. By anodizing, the thickness of the oxide layer can be increased to 25µm.

The hardness of the anodized layer exceeds that of steel, nickel and chromium and is the same as corundum. At the same time, the melting point of the surface increases to around 3600°F.

The oxide layer formed by anodizing has good insulation properties and a breakdown voltage of 500V - 600V at a thickness of 12µm - 15µm. The wear and corrosion resistance of the surface can be improved by increasing the thickness of the anodized layer. The table below gives recommended thicknesses for various applications.

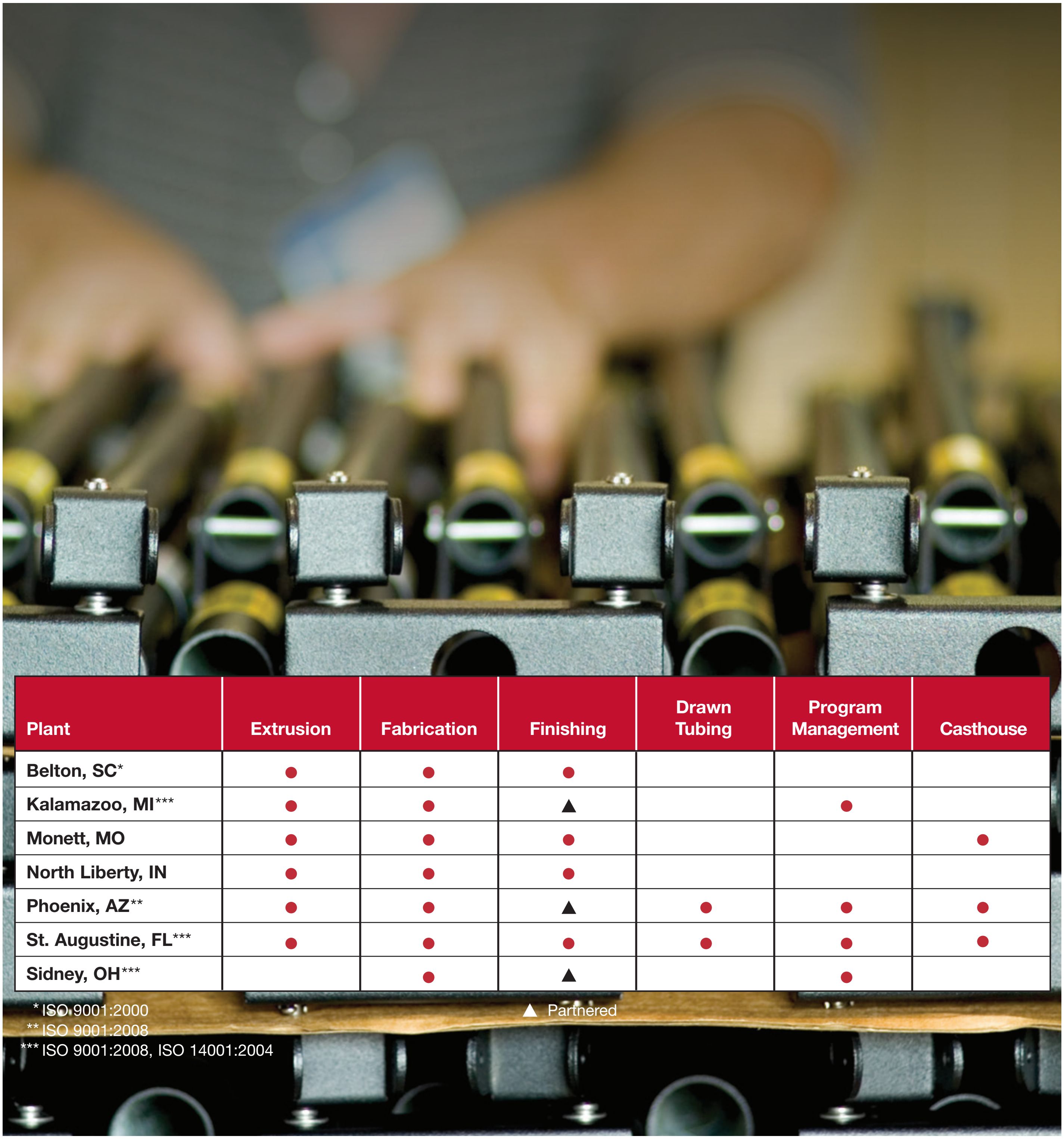
Anodized extrusions are suitable for a range of architectural and decorative applications that require a beautiful and durable surface. Anodized aluminum extrusions minimize the need for maintenance. They should, however, for aesthetic reasons, be cleaned regularly with water and a neutral or mild soap and put through a clean water rinse. Strong acids and alkalis should not be used.

Recommended layer thickness after anodizing

Coating thickness (µm)	Industry STO designation	Application
18.0	215 R1 Class I Arch.	Strong or normal exposure outdoors (e.g. building materials, vehicles and boats)
18.0	215 R1 Class I Arch.	Strong exposure indoors to chemicals, in damp air (e.g. the food industry)
10.3	204 R1 Class II Arch.	Relatively hard wear indoors (e.g. handrails or decorative features outdoors)
7.7	204 R1	Normal exposure indoors or outdoors in dry, clean air. For reflectors, fittings, decorative strips on vehicles, sports equipment
5.1	201 R1	Normal indoor exposure

The Aluminum Anodizers Council (AAC) website provides layer thickness specifications for various applications and other useful information.
www.anodizing.org/Reference/reference_guide.html

Hydro plant capabilities



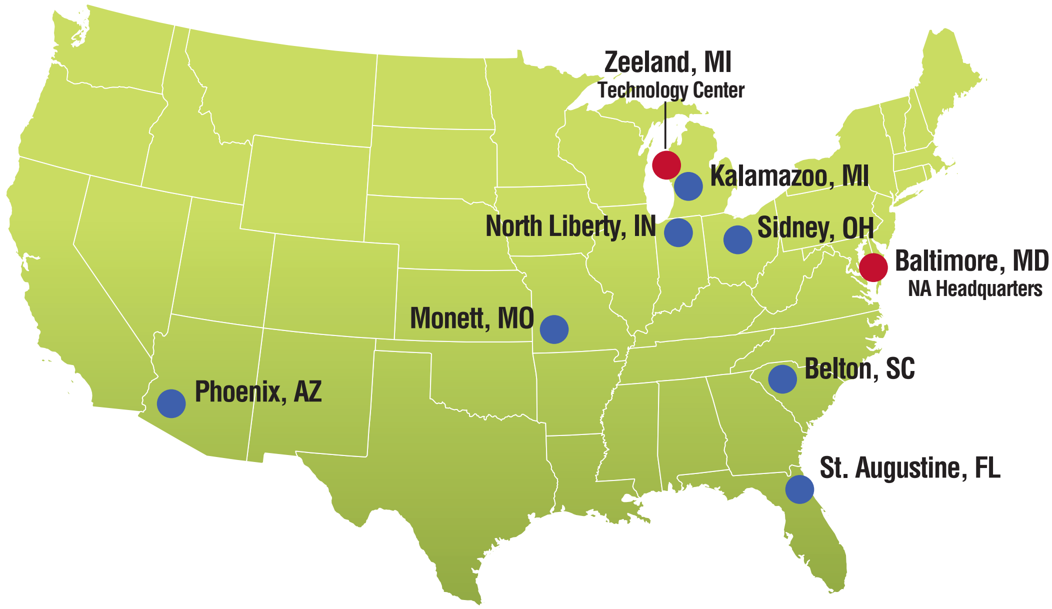
Plant	Extrusion	Fabrication	Finishing	Drawn Tubing	Program Management	Casthouse
Belton, SC*	●	●	●			
Kalamazoo, MI***	●	●	▲		●	
Monett, MO	●	●	●			●
North Liberty, IN	●	●	●			
Phoenix, AZ**	●	●	▲	●	●	●
St. Augustine, FL***	●	●	●	●	●	●
Sidney, OH***		●	▲		●	

* ISO 9001:2000
** ISO 9001:2008
*** ISO 9001:2008, ISO 14001:2004

▲ Partnered

www.hydro.com/en/Subsites/NorthAmerica/Facilities

North American resources



When you choose Hydro, you partner with the nation's premier extrusion components supplier backed by the resources of a global aluminum authority. We are committed to finding new and better ways to improve our processes through research, knowledge exchange, innovation and investment to help customers transform designs and ideas into elegant, cost-effective products.

Our Extruded Products network consists of 7 extrusion/fabrication facilities with nearly 2,000 employees and roots that go back more than 50 years. Three plants have adjacent casthouses with capacity to, annually, produce more than 150,000 metric tons of primary-grade metal with high recycled content.

All facilities are supported by Hydro's global network of Competency Centers, including the Zeeland, MI Technology Center, a critical resource for research, analysis, development of new technology, and knowledge sharing.

We are firmly committed to sustainability and mutual benefit and believe that our work should contribute to our communities and protect our environment as it benefits our employees and customers.

We are a unit of Hydro Aluminum, a global extrusion technology leader and one of the world's largest aluminum companies with 23,000 employees in more than 40 countries.

Belton, SC
Toll-Free Phone: (888) 935-5754

Monett, MO
Toll-Free Phone: (888) 935-5755

Kalamazoo, MI
Toll-Free Phone: (888) 935-5758

North Liberty, IN
Toll-Free Phone: (888) 935-5757

Phoenix, AZ
Toll-Free Phone: (800) 459-3030

St. Augustine, FL
Toll-Free Phone: (800) 835-6502

Sidney, OH
Toll-Free Phone: (888) 935-5759

Hydro Solar Solutions
Phone: (602) 427-1434

To learn more about Hydro in North America, visit us at:
www.hydro.com/en/Subsites/NorthAmerica/Facilities

A complete listing of Hydro global extrusion facilities can be found at:
www.hydro.com/en/About-Hydro/Hydro-worldwide

Accreditation and memberships

Aluminum Association
www.aluminum.org

Aluminum Extruders Council (AEC)
www.aec.org

American Architectural Manufacturer's Association (AAMA)
www.aamanet.org

Solar Electric Power Association (SEPA)
www.solarelectricpower.org

Aluminum Anodizers Council (AAC)
www.anodizing.org

On top of the Dow Jones Sustainability Indexes

Hydro is one of only two aluminum companies included in the Dow Jones Sustainability World Indexes (DJSI World), which includes the 10 percent best performers in each industry. Hydro has been included in the DJSI every year since the indexes were launched in 1999.

Hydro is listed on the following social responsibility indices:

Hydro is a global supplier of aluminum with activities throughout the value chain, from bauxite extraction to the production of rolled and extruded aluminum products and building systems. Based in Norway, the company employs 23,000 people in more than 40 countries. Rooted in a century of experience in renewable energy production, technology development and progressive partnerships, Hydro is committed to strengthening the viability of the customers and communities we serve.

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HYDRO