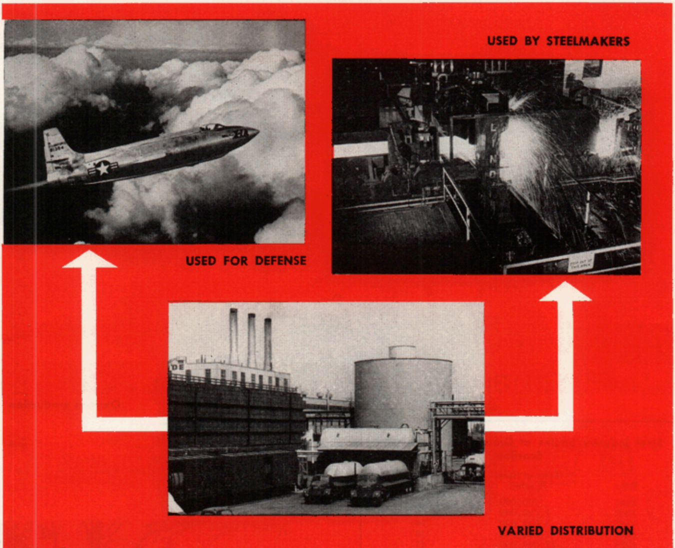
In less than a decade production of high purity oxygen has almost tripled, to a point where 29 billion standard cubic feet were produced in 1955. Selling for 30 cents and up per hundred cubic feet, this represents an almost $100 million annual business, and keeps on growing.

I&EC's editors think readers will be interested in solutions to problems of distribution and handling, as well as commercial applications of high purity oxygen. We have asked two men, intimately concerned with the field, to present this viewpoint.



Industrial Oxygen—Distribution and Applications

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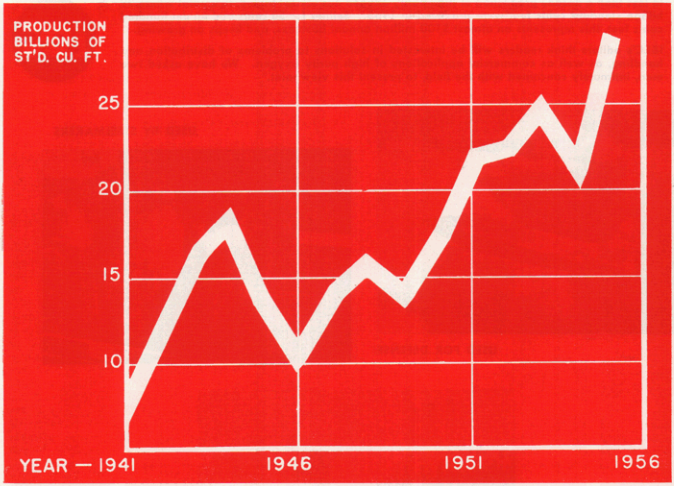
NEWS about rockets and rocket-powered aircraft is hot any time. Even the man on the street knows liquid oxygen is used with alcohol as a rocket fuel; it is less widely known that this is but one of many commercial uses of high-purity oxygen.

More than 30 billion cubic feet of high-purity oxygen will probably be produced this year. This does not include "tonnage oxygen" facilities, generally "captive" or integrated with the consuming process on the premises. Tonnage oxygen, with a purity of 95%, is used for enrichment of the air fed to blast furnaces, and is also used in open hearth furnaces, and production of water gas and petrochemicals.

High-purity oxygen is used in the steel and metal working industry for welding and cutting. A recent application is in steel billet scarfing to remove surface imperfections prior to final rolling. This operation was formerly performed on the cold billets using hand-guided pneumatic chipping hammers; now an oxygen cutting machine scarfs the hot billet as it leaves the blooming mill, resulting in substantial economies in steel rolling operations. About 75% of all high-purity oxygen is used for steel production and metal fabricating.

Selling prices for high-purity oxygen vary greatly with quantity. The 100,000 cubic feet per month user of bulk shipments pays about 71 cents per hundred (delivered within



Oxygen production

Steel Industry Smiles at Growth in Mechanized Scarfing

Year	Tons of Steel Scarfed	Machines in Operation
1936	300,000	1
1940	1,200,000	5
1945	5,013,000	18
1950	7,800,000	28
1955	17,000,000	43
1956 est.	23,600,000	52

Data are from a talk presented at the 56th International Acetylene Assoc. Meeting by Irwin H. Such.

25 miles) while the consumer who uses 1 million cubic feet monthly will pay only half that figure.

Generally there is no difference in selling price between bulk gaseous and liquid oxygen—the choice is that of the supplier. With extremely large quantities, greater transportation savings tend to lower the cost of delivered liquid oxygen.

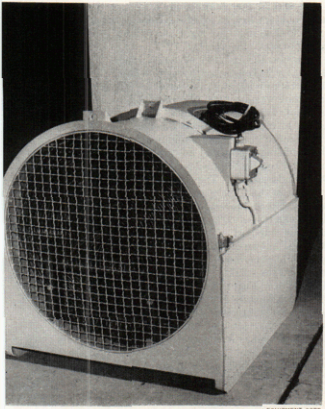
Gaseous oxygen, supplied in 244-cubic-foot cylinders, costs far more. The price range goes from $2.50 to less than $1.00 per hundred cubic feet, depending on shipment size. If the customer picks up the cylinders at the plant, he saves 20 cents per hundred cubic feet.

Gaseous Oxygen Distribution

Industrial oxygen is generally supplied as a gas and most liquid air fractionation plants are designed to produce a

COURTESY INDEPENDENT ENGINEERING CO.

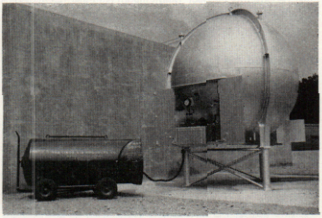
Figure 1. This trailer transports oxygen as compressed gas at 2400 lb./sq. inch; capacity: 45,000 std. cu. ft.



COURTESY ARC EQUIPMENT CORP.

Figure 2. Liquid storage and converting units of the type shown below find wide application as aircraft flight line refilling equipment for respiratory oxygen

gaseous oxygen product which is then compressed and distributed at 2000 to 2700 p.s.i.g. The compressed gas is handled either in individual containers holding 120 to 300 standard cubic feet, or in tube trailers (Figure 1) which can transport up to 60,000 cubic feet to meet large users' requirements. The tube trailer unit is usually parked, connected to the consumer's plant by a piping distribution system, and when empty, coupled to a tractor and hauled to the supplier for recharging. Distributed in this manner, or in the common 244-cubic-foot cylinder, only 10% of the gross load is oxygen—a very low pay load, making for high distribution costs per unit. When large users are located near the producing plant, oxygen gas may be piped to the user. This scheme is used successfully by Houston Oxygen Co. to supply its major consumers (C&EN, May 26, 1952, p. 2220).



COURTESY LINDE AIR PRODUCTS CO.

Typical liquid oxygen storage unit has a capacity of 100,000 std. cu. ft.

Large steel mills consume 30,000 to 40,000 cubic feet of oxygen per hour—the contents of one tube trailer or 150 standard cylinders. The handling of this amount of oxygen as a compressed gas becomes an unreasonable problem. At the high extreme one large user consumed 2.4 million cubic feet in an 8-hour day with no special operations in process.

Distributing Liquid Oxygen

Pay loads can be increased to as much as 50% of the gross load by handling and transporting the oxygen as a liquid. Other advantages of liquid oxygen distribution include less required customer storage space, lower moisture contamination, and far lower handling costs. Naturally, there has been a trend to liquid distribution to serve large consumers.

Handling of oxygen in this form is generally done near atmospheric pressure where the boiling point of oxygen is −297° F. Heat leakage into the container results in a boil-off loss of oxygen; to reduce this loss, low heat-leak vessels have been designed both to store and transport liquid oxygen.

One of the most widely used of these vessels is a double-walled container employing a powdered insulation and a vacuum of 500 to 1000 microns in the annular insulation space. Under these conditions the thermal conductivity of the insulation is approximately one tenth that of fiberglass. Low heat-gain supports for the inner vessel usually are stainless steel rods or some stable plastic material.

Railway tank cars holding the liquid equivalent of 750,000 cubic feet are coming into wide use. Heat leakage into the vessel results in a boil-off loss equal to 1% per day. Since the cars may take a number of days enroute to the consumer, there is a significant loss of oxygen which must be recognized as a distribution cost. The equipment continues to gain heat from its surroundings during the return of the empty car, and while it awaits refilling. When the car is refilled some additional oxygen is vaporized in cooling the car again to equilibrium temperature, but it is possible to recover this gas if proper measures are taken at the filling station. Total round trip evaporation losses for this operation may go as high as 10 to 15% of the tank car capacity.

For highway transport, semitrailer truck units have been built, holding the liquid equivalent of 325,000 cubic feet. Again, insulation and supports are carefully designed to minimize heat leaks. Pressures in transit are normally held under 25 p.s.i.g., as above this pressure, ICC regulations for compressed gases apply.

More recently, liquid distribution units equivalent to 2500 to 3000 cubic feet have been introduced on a limited basis, and are receiving wide acclaim. Operating at pressures up to 300 p.s.i.g., these units have self-contained vaporizing equipment, and can be handled by one man with much greater facility than the equivalent 10 to 12 high pressure cylinders.

Users' Facilities Are Varied

High pressure gas cylinder storage and handling are adequate for many consumers, but for those with greater needs, storage of the oxygen as a liquid, with gasification as needed, provides far greater reserve and flexibility. Although some liquid-utilizers have storage units at 300 p.s.i.g., larger users such as steel mills and metal fabricators find it more econom-

One Company's Oxygen Goes to:

Steel production and metal fabricating	62%
Chemical	23%
Others, including hospitals, railroads, shipbuilding, small users	15%

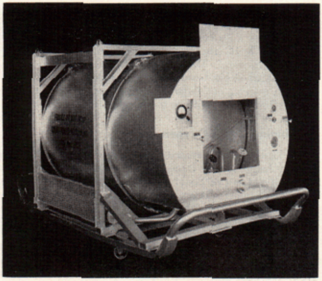


Figure 3. USAF Type B-1 liquid oxygen storage and transport container holds 17,000 std. cu. ft.

ical to have a main storage vessel at atmospheric pressure with an equivalent capacity of 1.5 million cubic feet. To vaporize and build up delivery pressure the liquid is pumped to a smaller intermediate vessel maintained at 200 to 300 p.s.i.g. by controlled addition of heat. The pressurized vessel permits direct feeding of vaporizer and immediate response to wide variations on customer demand.

Some vaporizers employ normal outside air as a heat source (Figure 2). Having operating pressures up to 3000 p.s.i.g., these are often used for high pressure cylinder filling service. However, formation of frost from moisture in the air may be a problem during continuous or other severe duty. Generally this is solved by using steam or electricity as a heat source, with an intermediate fluid such as an ethylene glycol-water mixture.

Oxygen for Defense

One of the great users of liquid oxygen today is the U. S. Air Force, employing vast quantities of it for high altitude

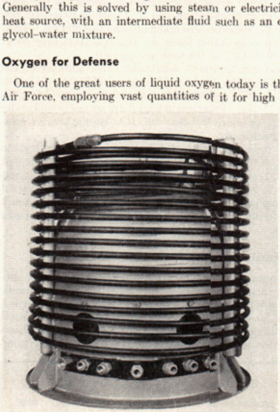


Figure 4. Liquid storage and converting unit for breathing oxygen

breathing and special fuel burning applications. Included in the modern military oxygen logistic system are storage and transport vessels (Figure 3) and flight line refilling equipment for respiratory oxygen (Figure 4).

Storage units are the vacuum insulated type. They are carefully tested for leakage so as to ensure holding a vacuum as low as 50 microns for lengthy time periods. The illustrated unit, having a tare weight of 890 pounds with both inner and outer vessels fabricated of aluminum, uses an air-heating vaporizing coil to rapidly pressurize the tank. Pressure of 50 p.s.i.g. is achieved in less than 5 minutes.

Flight line refilling equipment of the type shown holds 20 liters of liquid oxygen, equivalent to 600 cubic feet, and weighs 100 pounds loaded. The unit is equipped with a vaporizer converter, and the gaseous oxygen is supplied at constant temperature and pressure. As this liquid equipment allows weight reduction of 60% and space savings of 80%, it has become rather standard.

One of the best known alcohol-liquid oxygen fueled rocket craft is the 1650 miles per hour Bell X-1A. Its liquid oxygen supply is held near its $-297°$ F. boiling point, and is pumped to the rocket engine. Flight endurance of these planes under full power is approximately 4 minutes; sufficient, as they are designed as flying laboratories rather than tactical airplanes.

Numerous other aircraft and missile propulsion projects utilize liquid oxygen since it is one of the principal oxidants available for liquid fuel rockets. An up-to-date discussion of rocket propellants is published in I&EC, April 1956.

Safety Consciousness—A Necessity

Combustion proceeds far more rapidly in an oxygen-rich atmosphere than in air, so special precautions must be taken to isolate the liquid oxygen from combustibles. Its low temperature, and great volume increase when vaporizing must also be kept in mind from a safety point of view.

Ordinary carbon steels are usually too brittle for safe use at liquid oxygen temperature. The series Type 300 stainless steels and some nonferrous metals including brass, copper, Monel, and aluminum are satisfactory. For insulation, *packings, gaskets, and seals, an inorganic material is generally* employed. Asbestos is widely used, often in combination with metals for gasket applications. Some halogenated hydrocarbons—e.g., Teflon, Kel-F—have been successfully tried, as have graphitized carbon and stable organics like polyethylene.

Powdered insulations for use with vacuum insulated vessels are generally a diatomaceous silica or a synthetic aerated silica. Molded insulations are usually rock wool, magnesia, *or fiberglass.*

Piping and other equipment in contact with liquid oxygen must be carefully cleaned, removing all combustible materials including oil and grease.

Other Liquid Air Fractions

Liquid air fractionation products distributed in similar *fashion include nitrogen (boiling point $-320°$ F.) and argon* (boiling point $-302°$ F.).

Argon production today is four times the 1950 rate. Part of this increase results from new fields of application; part from substitution for less readily available helium. Major argon markets include inert gas shielded electric arc welding of stainless steel, aluminum, and magnesium; production and fabrication of titanium; production of light bulbs and electronic tubes.

Liquid nitrogen is increasingly being used as an inert gas source. It may also have a great future for prechilling perishable shipments to a point where in-transit refrigeration is not required.