McClure's Magazine
March, 1899

Liquid Air

A New Substance that Promises to Do the Work of Coal and Ice and Gunpowder, At Next to No Cost

CHARLES E. TRIPLER of New York City reduces the air of his laboratory to a clear, sparkling liquid that boils on ice, freezes pure alcohol, and burns steel like tissue paper. And yet Mr. Tripler dips up this astounding liquid in an old tin saucepan and pours it about like so much water. Although fluid, it is not wet to the touch, but it burns like a white-hot iron, and when exposed to the open air for a few minutes, it vanishes in a cold gray vapor, leaving only a bit of white frost.

All this is wonderful enough, but it is by no means the most wonderful of the inventor's achievements. I saw Mr. Tripler admit a quart or more of the liquid air into a small engine. A few seconds later the piston began to pump vigorously, driving the flywheel as if under a heavy head of steam. The liquid air had not been forced into the engine under pressure, and there was no perceptible heat under the boiler; indeed, the tube which passed for a boiler was soon shaggy with white frost. Yet the little engine stood there in the middle of the room running apparently without motive power, making no noise and giving out no heat or smoke, and producing no ashes. And that is something that can be seen nowhere else in the world—it is a new and almost inconceivable marvel.

"If I can make little engines run by this power, why not big ones?" asks Mr. Tripler. "And if I can produce liquid air practically without cost—and I will show you that I really can—why shouldn't we be able soon to do entirely away with coal and wood and all other fuel?"

"And run entirely with air?"

"Yes, with liquid air in place of the water now used in steam boilers, and the ordinary heat of the air instead of the coal under the boilers. Air is the cheapest material in the world, but we have only begun learning how to use it. We know a little about compressed air, but almost nothing about utilizing the heat of the air. For centuries men have been digging their source of heat out of the earth at enormous expense, and then wasting ninety percent of it in burning. Coal is only the sun's energy stored up. What I do is to use the sun's energy direct.

"It is really one of the simplest things in the world," Mr. Tripler continues, "when you understand it. In the case of a steam engine, you have water and coal. You must take heat enough out of the coal and put it into the water to change the water into a gas—that is, steam. The expansion of this gas produces power. And the water will not give off any steam until it has reached the boiling point of 212 degrees Fahrenheit.

"Now, steam bears the same relation to water that air bears to liquid air. Air is a liquid at 312 degrees below zero—a degree of cold that we can hardly imagine. If you raise it above 312 degrees below zero it boils, just as water boils above 212 degrees. Now then, we live at a temperature averaging, say, seventy degrees above zero—about the present temperature of this room. In other words, we are 382 degrees warmer than liquid air. Therefore, compared with the cold of liquid air, we are living in a burning fiery furnace. A race of people that could live at 312 degrees below zero would shrivel up as quickly in this room as we should if we were shut up in a baking oven. Now then, you have liquid air—a liquid at 312 degrees below zero. You expose it to the heat of this furnace in which we live, and it boils instantly, and throws off a vapor which expands and produces power. That's simple, isn't it?"

It did seem simple; and you remembered, not without awe, that Mr. Tripler was the first man who ever ran an engine with liquid air, as he was also the first to invent a machine for making liquid air in quantities, a machine which has, by the way, been passed upon as original by the patent office in Washington. But these two achievements, extraordinary as they are, form merely the basis for more surprising experiments.

Manner and Cost of Producing Liquid Air

It is easy enough, after obtaining a supply of liquid air, to run an engine with it; but where is there any practical advantage in using steam power to make liquid air and then using the liquid air for running engines? Why not use steam power direct, as at present?

Mr. Tripler always anticipates this question after explaining his engine—which is still running smoothly before our eyes.

"You have seen how I run this engine with liquid air," he says. "Now, if I can produce power by using liquid air in my engine, why not use that power for producing more liquid air? A liquid air engine, if powerful enough, will compress the air and produce the cold in my liquefying machine exactly as well as a steam engine. Isn't that plain?"

You look at the speaker hard and a bit suspiciously. "Then you propose making liquid air with liquid air?"

"I not only propose doing it, but this machine actually does it."

"You pour liquid air into your engine, and take more liquid air out of your liquefier?"

"Yes; it is merely an application of the power produced by my liquid air engine."

This all but takes your breath away. "That is perpetual motion,"you object.

"No," says Mr. Tripler sharply, "no perpetual motion about it. The heat of the atmosphere is boiling the liquid air in my engine and producing power just exactly as the heat of coal boils water and drives off steam. I simply use another form of heat. I get my power from the heat of the sun; so does every other producer of power. Coal, as I said before, is only a form of the sun's energy stored up. The perpetual motion crank tries to utilize the, attraction of gravitation, not the heat of the sun."

Then Mr. Tripler continues more slowly: "But I go even further than that. If I could produce only two gallons of liquid air from my liquefying machine for every two gallons I put into my engine, I should gain nothing at all; I should only be performing a curious experiment that would have no practical value. But I actually find that I can produce, for every two gallons of liquid air that I pour into my engine, a larger quantity of liquid air from my liquefier. This seems absolutely unbelievable, and it is hard to explain; you will understand it better after I show you exactly my process of making liquid air. Briefly, the liquefaction of air is caused by intense cold, not by compression, although compression is a part of the process. After once having produced this cold, I do not need so much pressure on the air which I am forcing into the liquefying machine. Indeed, so great does the cold actually become that the external air, rushing in under ordinary atmospheric pressure to fill the vacuum caused by liquefaction, itself becomes liquefied. That is, my liquefying machine will keep on producing as much liquid air as ever, while it takes very much less liquid air to keep the compressor engine going. This difference I save. It is hard to understand just how this comes about, for you must remember that we are dealing with intensely low temperatures—an unfamiliar domain, the influences and effects of which are not yet well understood — and not with pressures.

“I have actually made about ten gallons of liquid air in my liquefier by the use of about three gallons in my engine. There is, therefore, a surplusage of seven gallons that has cost me nothing and which I can use elsewhere as power.”

“And there is no limit to this production; you can keep on producing this surplusage indefinitely?”

“I think so. I have not yet finished my experiments, you understand, and I don’t want to claim too much. I believe I have discovered a great principle in science, and I believe I can make practical machinery do what my experimental machine will do.”

What if Mr. Tripler can build a successful “surplusage machine”? It is bewildering to dream of the possibilities of a source of power that costs nothing. Think of the ocean greyhound unencumbered with coal bunkers, and sweltering boilers, and smokestacks, making her power as she sails, from the free sea air around her! Think of the boilerless locomotive running without a firebox or fireman, or without need of water tanks or coal chutes, gathering from the air as it passes the power which turns its driving wheels! With costless power, think how travel and freight rates must fall, bringing bread and meat more cheaply to our tables and cheaply manufactured clothing more cheaply to our backs. Think of the possibilities of aerial navigation with power which requires no heavy machinery, no storage batteries, no coal—but I will take up these possibilities later. If one would practice his imagination on high flights, let him ruminate on the question, “What will the world be when power costs nothing?”

It is not until you begin to speculate upon the changes that such a machine as Mr. Tripler’s, if successful, will work, that you begin to doubt and waver and feel the total improbability of it all. The announcement fairly shocks the hearer out of his humdrum, and turns his well-regulated world all topsy-turvy. And yet it is not difficult to remember what people said when Morse sent words by telegraph from Washington to Baltimore, and when Bell spoke miles over a copper wire.

“We have just begun discovering things about the world,” Says Mr. Tripler.

Then he begins at the beginning of liquid air, and builds up his wonders step by step until they have almost assumed the familiar garb of present-day realities.

Previous Attempts to Liquefy Air

Until twenty years ago, scientists thought that air was a permanent gas—that it never would be anything but a gas. They had tried compressing it under thousands of pounds of pressure to the square inch; they had tried heating it in reverberatory furnaces and cooling it to the greatest known depths of chemical cold; but it remained air—a gas. But one day in 1877, Raoul Pictet submitted oxygen gas to enormous pressure combined with intense cold. The result was a precious few drops of a clear bluish liquid that bubbled violently for a few seconds and then passed away in a cold white mist. M. Pictet had proved that oxygen was not really a permanent gas, but merely the vapor of a mineral, as steam is the vapor of ice. Fifteen years later Olzewski, a Pole, of Warsaw, succeeded in liquefying nitrogen, the other constituent of air. About the same time Professor James Dewar of England, exploring independently in the region of the North Pole of temperature, not only liquefied oxygen and nitrogen, but produced liquid air in some quantity, and then actually froze it into a mushy ice—air ice. The first ounce that he made cost more than $3,000. A little later he reduced the cost to $500 a pint, and the whole scientific world rang with the achievement. Yesterday, in Mr. Tripler's laboratory, I saw five gallons of liquid air poured out like so much water. It was made at the rate of fifty gallons a day, and it cost, perhaps, twenty cents a gallon.

Not long ago Mr. Tripler performed some of his experiments before a meeting of distinguished scientists at the University of the City of New York. It so happened that among those present was M. Pictet, the same who first liquefied oxygen. When he saw the prodigal way in which Mr. Tripler poured out the precious liquid, he rose solemnly, extended his arm across the table, and shook Mr. Tripler's hand. "It is a grand exhibition," he exclaimed in French; "the grandest exhibition I ever have seen."

The principle involved in air liquefaction is exceedingly simple, although its application has sorely puzzled more than one wise man. When a gas is compressed, it gives out its heat. Any one who has inflated a compressed air bicycle tire has felt the pump grow warm under his hand. When the pressure is removed and the gas expands, it must take back from somewhere the heat which it gave out. That is, it must produce cold.

Professor Dewar applied this simple principle in all his experiments. He compressed nitrous oxide gas and ethylene gas, and by expanding them suddenly in a specially constructed apparatus, he produced a degree of cold which liquefied air almost instantly. But nitrous oxide and ethylene are exceedingly expensive and dangerous, and the product that Professor Dewar drew off was worth more than its weight in gold; indeed, he could hardly afford enough of it for his experiments.

At the earliest announcement of the liquefaction of air Mr. Tripler had seen with the quick imagination of the inventor its tremendous possibilities as a power-generator, and he began his experiments immediately. That was eight years ago. After futile attempts to utilize various gases for the production of the necessary cold, it suddenly occurred to him that air also was a gas. Why not produce cold with it?

"The idea was so foolishly simple that I could hardly bring myself to try it," he said; "but I finally fitted up an apparatus, turned on my air, and drew it out a liquid."

And thus Mr. Tripler makes liquid air with compressed air.

A Near View of the Actual Making

Mr. Tripler's workroom has more the appearance of a machine shop than a laboratory. It is large and airy, and is filled with the litter of the busy inventor. The huge steam boiler and compressor engine in one end of the room strikes one at first as oddly disproportionate in size to the other machinery. Apparently there is nothing for all this power — it is a fifty-horsepower plant—to work upon; it is hard to realize that the engine is drawing its raw material from the very room in which we are walking and breathing. Indeed, the apparatus by which the air is actually liquefied is nothing but a felt-and-canvas-covered tube about as large around as a small barrel and perhaps fifteen feet high. The lower end is set the height of a man's shoulders above the floor, and there is a little spout below, from which, upon opening a frosty valve, the liquid air may be seen bursting out through a cloud of icy mist. I asked the old engineer who has been with Mr. Tripler for years what was inside of this mysterious swathed tube.

"It's full of pipes," he said.

I asked Mr. Tripler the same question. “Pipes,” was his answer; “pipes and coils with especially constructed valves for the air to go in, and pipes and coils for it to go out —that’s all there is to it.”

So I investigated the pipes. Two sets led back to the compressor engine, and Mr. Tripler explained that they both carried air under a pressure of about 2,500 pounds to the square inch. The heat caused by the compression had been removed by passing the pipes through coolers filled with running water, so that the air entered the liquefier at a temperature of about fifty degrees Fahrenheit.

“The first of these pipes contains the air to be liquefied,” explained Mr. Tripler; “the other carries the air which is to do the liquefying. By turning this valve at the bottom of the apparatus, I allow the air to escape through a small hole in the second pipe. It rushes out over the first pipe, expanding rapidly and taking up heat. You see the liquefier is so tall that it acts as a chimney, and the icy cold air is drawn up to the top, following the first pipe all the way and greedily extracting its heat. This process continues until such a degree of cold prevails in the first pipe that the air is liquefied and drips down into a receptacle at the bottom. Then all I have to do is turn a valce, and the liquid air pours out, ready for use.”

Mr. Tripler says that it takes only ten or fifteen minutes to get liquid air after the compressor engine begins to run. Professor Dewar always lost ninety per cent, in drawing off his product; Mr. Tripler’s loss is inappreciable. Sometimes the cold in the liquefier becomes so intense that the liquid air actually freezes hard, stopping the pipes. Mr. Tripler has never tried, but he says he believes he could get a degree of cold in his liquefier sufficient to reduce hydrogen gas to liquid form.

This very simple process has given rise to some curious questions on which future scientists may work at their pleasure.

“I’ve been puzzling myself a good deal,” said Mr. Tripler, “over the question as to what becomes of all the heat that I take out of the air in the process of liquefaction. The air goes in at a temperature of this room, say seventy degrees Fahrenheit. At liquefaction it is 312 degrees below zero. It has lost 382 degrees of heat in fifteen minutes, and you would expect that the air which rises from the top of my apparatus would be red hot; but it isn’t, it’s cold. Now, where did all that heat go? A little of it, I know, becomes electricity, because the liquid air is always more or less charged when it comes out, but that only accounts for a small part of the whole.”

And then Mr. Tripler, who has the true speculative imagination of the scientist, which so often thrills the layman with its sudden reaches into the deep things of nature, asked suddenly: “Where does heat go to anyway? Did you ever think of that? Every transfer of energy tends to lower temperature. Every time that heat, for instance, is transferred into electricity, every time that electricity is transferred into heat, there is a loss—a leakage. Scientists used to think that there could be no real loss of energy—that it was all conserved, although changed in form. They have given up that theory, at least so far as this earth is concerned. We are gradually cooling off, and some time the cold will be so great that the air will all fall in liquid drops like rain and freeze into a quartzlike mineral. Then the hydrogen gas will liquefy and freeze; then helium gas; and the world will be nothing but a dead, inert block of mineral, without a vestige of the vibrations which cause heat. Now where does all this heat go?

“And when you come to think of it,” Mr. Tripler continued, “we’re a good deal nearer the cold end of the thermometer than we are to the hot end. I suppose that once we had a temperature equal to that of the sun, say 10,000 degrees Fahrenheit, We have fallen to an average of about sixty degrees in this latitude; that is, we have lost 9,940 degrees. We don’t yet know just how cold the absolute cold really is—the final cold, the cold of interstellar space—but Professor Dewar thinks it is about 461 degrees below zero, Fahrenheit. If it is, we have only a matter of 521 degrees yet to lose, which is small compared with 19,940. Still I don't think we have any cause to worry; it may take a few billion years for the world to reach absolute cold."

Mr. Tripler handles his liquid air with a freedom that is awe-inspiring. He uses a battered saucepan in which to draw it out of the liquefier, and he keeps it in a double iron can, not unlike an ice-cream freezer, covering the top with a wad of coarse felting to keep out as much heat as possible. "You can handle liquid air with perfect safety," he said; "you can do almost anything with it that you can with water, except to shut it up tight."

This is not at all surprising when one remembers that a single cubic foot of liquid air contains 800cubic feet of air at ordinary pressure—a whole hall bedroom full reduced to the space of a large pail. Its desire to expand, therefore, is something quite irrepressible. But so long as it is left open, it simmers contentedly for hours, finally disappearing whence it came.

Mr. Tripler showed me a Dewar bulb—an odd glass apparatus invented by Professor Dewar, in which liquid air in small quantities can be kept safely for some time. It consists of two vessels of glass, on within the other, having a high vacuum between the walls and joined in a common neck at the top. The vacuum prevents the passage of heat, so that the evaporation of the liquid air in the inner tube is reduced to a minimum. The neck of the bulb is, of course, left open to the air, although the cold, heavy mist of evaporation acts somewhat as a stopper. Mr. Tripler has sent liquid air in open cans to Boston, Washington, and Philadelphia. "But it is my belief," says he," that there will be little need of transporting it; it can be made quickly and cheaply anywhere on earth."

Curious Properties of Liquid Air

Liquid air has many curious properties. It is nearly as heavy as water and quite as clear and limpid, although, when seen in the open, air, it is always muffled in the dense white mist of evaporation that wells up over the edge of the receptacle in which it stands and rolls out along the floor in beautiful billowy clouds. No other substance in the world, unless it be liquid hydrogen, is as cold as liquid air, and yet Mr. Tripler dips his hand into it fearlessly, taking care, however, to remove it instantly. A few drops retained on a man's hand will sear the flesh like a white-hot iron; and yet it does not burn; it merely kills. For this reason it is admirably adapted to surgical uses where cauterization is necessary; it will eat out diseased flesh much more quickly and safely than caustic potash, or nitric acid, and it can be controlled absolutely. Indeed, Mr. Tripler has actually furnished a well-known New York physician with enough to sear out a cancer and entirely cure a difficult case. And it is cheaper than any cauterizing chemical in use.

It is difficult to conceive of the cold of liquid air. Mr. Tripler performs a number of striking experiments to illustrate its low temperature. He partially fills a tin teapot with it and sets it on a cake of ice, where the air at once begins to boil violently, throwing off a fierce white vapor. The temperature of the ice is about thirty-two degrees Fahrenheit, while the temperature of the liquid air is 312 degrees below zero. In other words, ice is 344 degrees warmer than liquid air; consequently it makes the air boil.

Mr. Tripler set the teakettle over a hot gas-flame, but it boiled only a shade more vigorously than it did on the ice, and a thick sheet of frost actually formed on the bottom of the kettle where the flame played most fiercely.

Alcohol freezes at so low a temperature —202 degrees below zero—that it is used in thermometers to register all degrees of cold. But it will not measure the fearful cold of liquid air. I saw a cup of liquid air poured into a tumbler partly filled with alcohol. Mr. Tripler stirred it up with a glass rod. It boiled violently for a few minutes, and then it thickened up suddenly until it looked like sugar syrup; then it froze solid, and Mr. Tripler held it up in a long steaming icicle. Mercury is frozen until it is as hard as granite. Mr. Tripler made a little pasteboard box the shape of a hammerhead, filled it with mercury, suspended a rod in it for a handle, and then placed it in a pan of liquid air. In a few minutes it was frozen so solid that it could be used for driving nails into a hardwood block. What would the scientists of twenty-five years ago have said if anyone had predicted the use of a mercury hammer for driving nails?

Liquid air freezes other metals just as thoroughly as it freezes mercury. Iron and steel become as brittle as glass. A tin cup which has been filled with liquid air for a few minutes will, if dropped, shatter into a hundred little fragments like thin glass. Copper, gold, and all precious metals, on the other hand, are made more pliable, so that even a thick piece can be bent readily between the fingers.

I saw an egg boiled—or frozen —in liquid air. It came out so hard that a sharp blow of a hammer was required to crack it, and the inside of it had the peculiar crystalline appearance of quartz—a kind of mineral egg.

“The time is certainly coming,” says Mr. Tripler, “when every great packinghouse, every market, every hospital, every hotel, and many private houses will have plants for making liquid air. The machinery is not expensive, it can be set up in a tenth part of the space occupied by an ammonia ice machine, and its product can be easily handled and placed where it is most needed. Ten years from now hotel guests will call for cool rooms in summer with as much certainty of getting them as they now call for warm rooms in winter.

“And think of what unspeakable value the liquid air will be in hospitals. In the first place, it is absolutely pure air; in the second place the proportion of oxygen is very large, so that it is vitalizing air. Why, it will not be necessary for the tired out man of the future to make his usual summer trip to the mountains. He can have his ozone and his cool heights served to him in his room. Cold is always a disinfectant; some disease germs, like yellow fever, it kills outright. Think of the value of a ‘cold ward’ in a hospital, where the air could be kept absolutely fresh, and where nurses and friends could visit the patient without fear of infection.”

Suppose, also, as Mr. Tripler does, that every warship could have a liquid-air plant. It would not only operate the ship’s propellers, but it would be absoutely invaluable in cooling off the guns after firing, in saving the lives of the sailors in the sweltering sick bay, and, indeed, in firing the cannon.

Air is composed of twenty-two parts of oxygen and seventy-eight of nitrogen. Oxygen liquefies at 300 degrees below zero, and nitrogen at 320 degrees. Consequently, when in the form of liquid air, nitrogen evaporates the more rapidly. This difference is shown by Mr. Tripler by pouring a quantity of the liquid air into a large glass vessel, partly filled with water. For a moment it floats, boiling with great violence, liquid air being slightly lighter than water. When, however, the nitrogen has all boiled away, the liquid oxygen, being heavier than water, sinks in beautiful, silvery bubbles which boil violently until they disappear. A few drops of liquid air thrown into water will instantly freeze for themselves little boats of ice which sail around merrily until the liquid air boils away.

In this way liquid air left exposed becomes stronger in its proportion of oxygen, and oxygen in such a concentrated form is a very wonderful substance. For instance, ordinary woolen felt can hardly be persuaded to burn even in a hot fire, but if it is dipped in this concentrated oxygen, or even in liquid air, and lighted, it will explode and burn with all the terrible violence of guncotton. Indeed, liquid air will burn steel itself. Mr. Tripler demonstrates this most strikingly by making a tumbler of ice, and filling it half full of liquid oxygen. Then he fastens a burning match to a bit of steel spring and dips it into the liquid air, where the steel burns exactly like a greasy bit of pork rind—sputtering, and giving out a glare of dazzling brilliancy.

The property of liquid oxygen to promote rapid combustion will make it invaluable, Mr. Tripler thinks, for use as an explosive. A bit of oily waste, soaked in liquid air, was placed inside of a small iron tube, open at both ends. This was laid inside of a larger and stronger pipe, also open at both ends. When the waste was ignited by a fuse, the explosion was so terrific that it not only blew the smaller tube to pieces, but it burst a great hole in the outer tube. Mr. Tripler thinks that by the proper mixture of liquid air with cotton, wool, glycerine, or any other hydrocarbon, an explosive of enormous power could be made. And unlike dynamite or nitroglycerine, it could be handled like so much sand, there being not the slightest danger of explosion from concussion, although, of course, it must be kept away from fire. It will take many careful experiments to ascertain the best method for making this new explosive, but think of the reward for its successful application! The expense of heavy ammunition and its difficult transportation and storage would be entirely done away with. No more would warships be loaded down with cumbersome explosives, and no more could there be terrible powder explosions on shipboard, because the ammunition could be made for the guns as it was needed, a liquid-air plant on shipboard furnishing all the necessary materials.

But all other uses of liquid air fade into insignificance when compared with its utilization as power for running machinery, of which I have already spoken.

“My greatest object is the production of a power-giving substance,” says Mr. Tripler; “if you can get cheap power, all other problems are solved.”

And that is why Mr. Tripler has spent so much time on the little engine in his laboratory, which runs by liquid air. The reasons for the supremacy of this strange liquid over steam are exceedingly simple. In the first place, liquid air has about 100 times the expansive power of steam. In the second place, it begins to produce power the instant it is exposed to the atmosphere. In making steam, water has first to be raised to a temperature of 212 degrees Fahrenheit. That is, if the water as it enters the boiler has a temperature of fifty degrees, 162 degrees of heat must be put into it before it will yield a single pound of pressure. After that, every additional degree of heat produces one pound of pressure, whereas every degree of heat applied to liquid air gives twenty pounds of pressure.

“Liquid air can be applied to any engine,” says Mr. Tripler, “and used as easily and as safely as steam. You need no large boiler, no water, no coal, and you have no waste. The heat of the atmosphere, as I have said before, does all the work of expansion.”

The advantages of compactness and the ease with which liquid air can be made to produce power at once suggested its use in all kinds of motor vehicles, and a firm in Philadelphia is now making extensive experiments looking to its use. A satisfactory application will do away with the present huge, misshapen, machinery-laden automobiles, and make possible small, light, and inexpensive motors.

Mr. Tripler believes firmly that liquid air makes aerial navigation a distinct probability. The great problem in the past has been the immense weight of the steam or electrical machinery necessary to operate the air screws. With liquid air no heat of any kind save that of the sun would be required; the boiler could be made of light tubing, and much of the other machinery of aluminum, so that the weight would be scarcely noticeable.

Much has yet to be done before liquid air becomes the revolutionizing power which Mr. Tripler prophesies. This much is certain: A machine has been built which will make liquid air in large quantities at small expense, and an engine has been successfully run by liquid air. Beyond these two actual achievements Mr. Tripler has yet to perfect his machinery for producing liquid air without expense. When this is accomplished, liquid air must certainly take its place as the foremost source of the world's power supply.