A TECHNICIAN loads silver-zinc batteries into the forward compartment of the Electrovair II preparatory to a test on the chassis dynamometer at General Motors Technical Center, Warren, Mich.

GM Vice President E. N. Cole:

"ENERGY CONVERSION IS OUR BUSINESS"

General Motors Research Allows a Brief but Electrifying Peek Through the Test-Tube Curtain

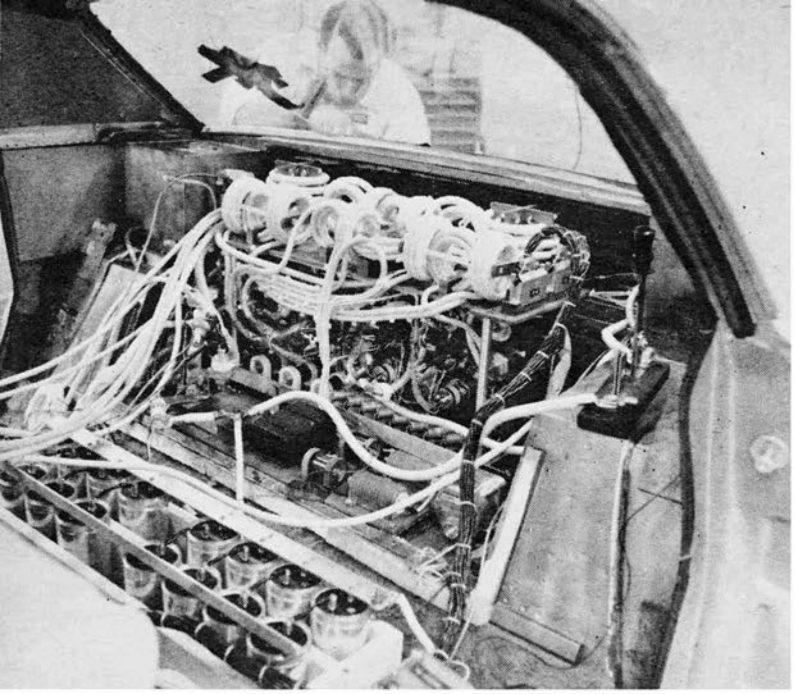
BY GENE BOOTH

THE LUSTROUS metallic blue Corvair sits beside the curb at General Motors Technical Center in Warren, Mich. It has a customized look about it, with artfully applied paint stripes and a neat script "Electrovair" identification on the front fenders. There is an air inlet cut in the front panel just above the bumper and an air scoop below. The driver of this subtly altered 1966 model introduces himself to three passengers taking seats inside.

"My name is Bill Bond, your driver this morning and one of the project engineers on this car. First, I'll explain the dash and how I operate the car." Then, moving his hand from left to right across the gauges that appear both thoroughly familiar yet somehow strange, he explains: "This is a production speedometer. Next is a tachometer, or motor rpm in thousands of rpm. This one has 14,000 rpm maximum—it doesn't quite get up there, but this is the secret to our small motor size, its high rpm."

The word "motor," one notes, is being used correctly here. This is GM's running test bed for electric-powered automobiles. It has no engine, in front or in the rear. In its place is a small, 100-bhp alternating current motor which is fitted to one side of the Corvair's transaxle. It drives, Bond says, through a 3.45:1 planetary gearset and the 3.27 rear axle for an 11.27:1 overall reduction. Rows of clear plastic battery cells in the engine compartment hide the drive-train from view, however. A similar deck of battery cells is installed under the forward hood in the luggage compartment. These batteries use silver and zinc as active elements.

"Next, we have the battery capacity, or 'fuel' gauge," continues the driver, "and this has been going down steadily while we've been driving. It goes down a little faster than a normal fuel gauge because of the shorter range of this car, as compared with the internal combustion engine car." Moving his finger to a lever jutting ▶



COILS, CAPACITORS and switches form the control system for Electrovair II—and completely fill rear seat area.

ELECTROVAIR II, left, and Electrovan make test runs on the 1-mile check road at GM's Warren Technical Center.

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from the dash, much like the Corvair's normal automatic transmission selector, Bond identifies it as the drive selector with reverse-neutral-drive positions. "The next gauge is our battery voltage in hundreds of volts," he says, and notes: "We're now reading 445 volts. And this last gauge is our motor current in hundreds of amperes," he says, pointing to the final dial, "which gives an indication of how much 'torque' we're producing. You'll see this go up or down as we drive along.

"Normally, I turn the key on (it's already on, though there is only a barely discernible hum from somewhere in the rear, a hum caused by the cooling fan drawing air through the oil radiator, it is later explained) and the green light will come on. This tells me I can go to Drive, because that's the direction I want to travel, but nothing happens until I touch the throttle."

Before touching the throttle, the driver explains the sound that will occur. It is a sound completely unlike any exhaust note yet appreciated by any enthusiast driver, and as later is noticed, is virtually unheard outside the vehicle. Bond calls it a buzz, but it begins like the crackle of shorting wires and rapidly turns into a whine or whistle climbing up a scale until its pitch reaches the lower limits of canine irritability.

"Now, when I do touch the throttle, what you hear is the inverter switching," Bond explains, "turning DC into AC. The buzzing sound is actually the current that we're switching, rushing through the wires. That sounds kind of way out, but that's actually what it is. Well, here's what it sounds like."

BUUUZZZZZZZYYYYHHHHIII-IIIIEEEEEEEEEEEEeeeeeeeeee. . . . The blue Corvair has moved briskly and smoothly away from the curb and out to the road beside the Center's huge reflecting pool. It accelerates with an uncanny propulsion that seems almost motionless. Bond lets the speedometer touch 60 mph, where the tachometer registers 9000 rpm, then removes his foot from the throttle. All sound stops except for the rush of wind past the windows and a far-off hum of tires rolling across macadam. He continues:

"The car weighs 3400 lb. at the curb and with all four of us in here, we must weigh in over 4000 lb., so it's a pretty heavy vehicle. This is typical of battery powered cars—small in size and heavier than normal in weight. Now, when I took my foot off the throttle, the system actually stopped. It's just resting now, waiting for the next command. We're free wheeling, we're not regenerating," he says. Speed is dropping and Bond brakes slightly to round a corner before moving his right foot back to the throttle.

HHHHHHHHHHIIIIIIIIIEEEEEEE EEEEEeeeeeeeee. . . "Take my foot off it, it stops. Step on it, we go. The acceleration control is fully variable; there are no steps. This particular system is a modulating inverter. That is to say, it inverts the DC into AC and it also modulates it, simultaneously. Now, electrically, we do have shift points in it, and if we don't have these tuned precisely, you will feel some shift points. But that's a matter of our tuning, not necessarily of the system itself.

"We've got a little linkage that goes to a linear potentiometer (variable resistance) which controls the voltage—a signal voltage that goes into our low level electronics and tells our SCRs (silicon controlled rectifiers) to turn on now, or if you want more power, it says wait a minute and turns on later. In other words, it is upping the duty cycle of the pulse width modulation. If you just turned the power on, it would come on and go out like this (gesturing in a broad straight line across the seat). Now, if you turn it on and shut it off, turn it on and shut it off, you've got holes in there (tracing a sequence of plateaus and valleys). Well, the motor averages this out and the more holes you've got, of course, the lower the average power. So, we're really filling in the holes by giving it this signal voltage, leaving the SCR on longer. That's the way we control it and that's why this thing is infinitely variable."

EEEEEEEEeeeeeeeeeeEEEEEEEEEEE IIIIIIIIIZZZZZZZPPPPP. Not a loud noise, but a persistent presence particularly rasping in the ears of the rear seat passengers. Whooshing, whining, whistling, the Electrovair rushes effortlessly back toward the curbside parking spot left only a moment ago and Bond finishes his explanation.

"This noise problem is somewhat analogous to early conventional auto-

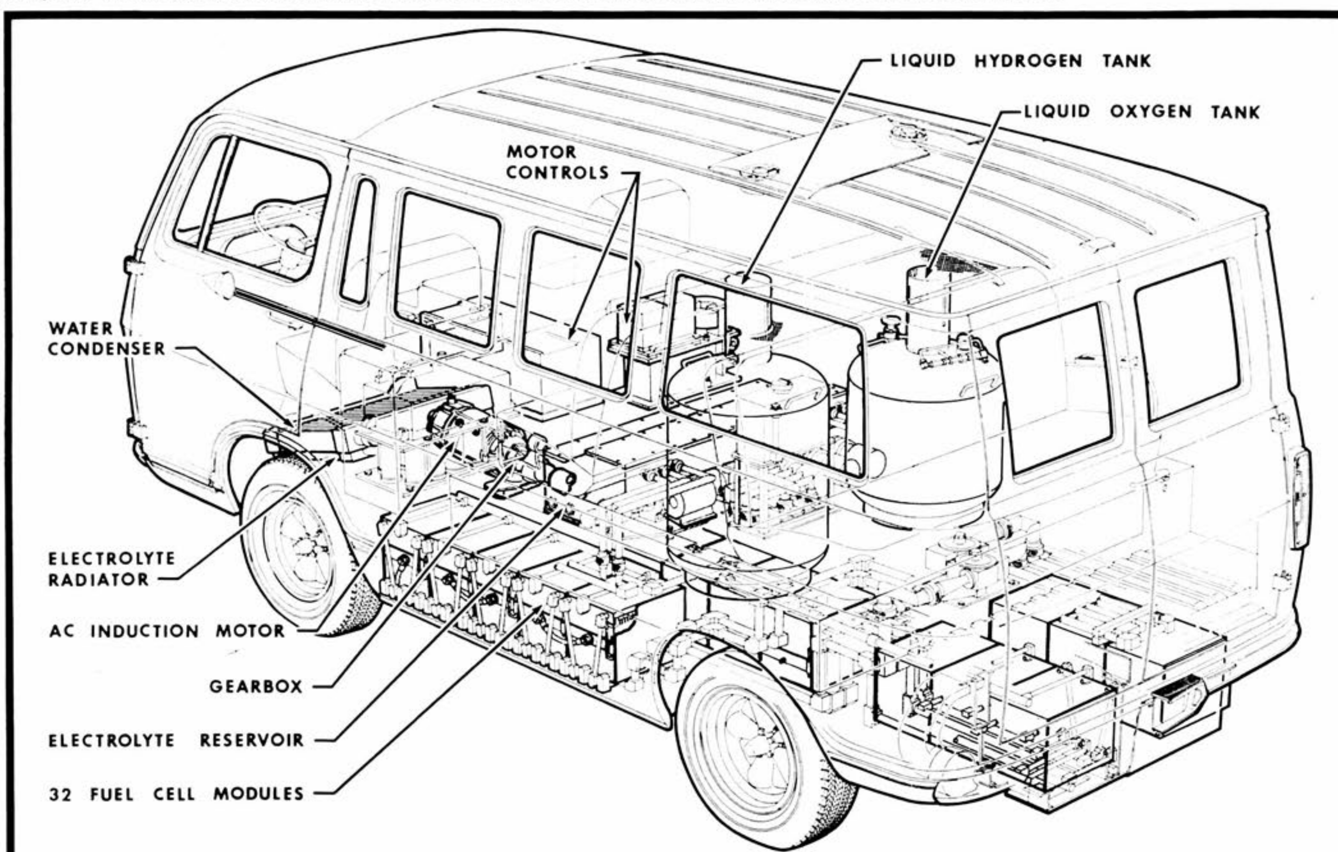
mobiles. They were noisy and nowhere near the quiet, smooth automobiles which we have today. The noise is tied into the superstructure of the automobile, into the paneling. We found that we were gaining practically nothing by continuing to put more and more sound insulating material behind the rear seat, which indicated that we weren't working on the right path. The key, of course, is isolating the generator so that all it does is dissipate air, and then put it in a sound insulating cavity and you've got it."

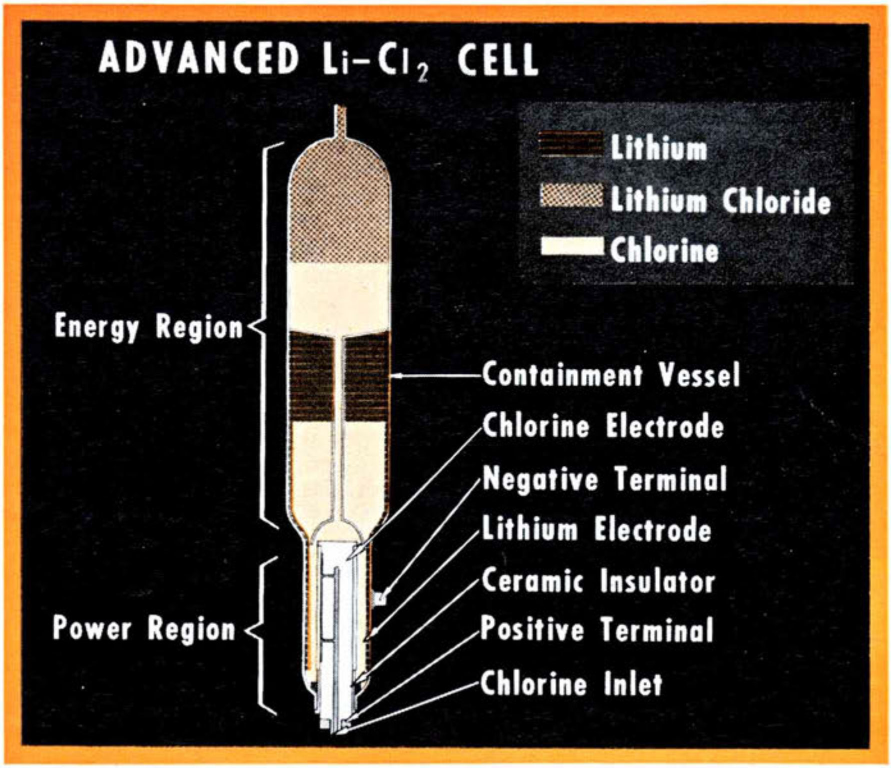
(A passenger said he expected to see more gadgets up in front there.) "We've tried to keep this car as close to production as we possibly could," Bond explains. With 600 lb. of batteries storing up something approaching 500 V., it's a curious note to see a very normal Delco 12-V. battery nestled in its customary place. It operates the car's normal electrical equipment, such as lights and horn, it is explained, avoiding wasted development time and work that is better concentrated on power delivery problems.

(Another passenger interjects that on maximum acceleration he noticed 300 on a dial and wonders if the reading is 300 amperes.) "That is 300 amps, that's correct," Bond concludes as his passengers disembark. "Naturally, this is only a state-of-the-art demonstration. The key to all this is furnishing the power to the system. Of course, the Achilles heel is the battery. As we go into discharge, the battery's performance does fall off somewhat. The battery only likes so much of this tour of duty. We can only get 40 to 80 miles between charges. The battery, then, has limitations."

A NEARBY ENGINEER picks up the explanation on that point. The buzz, he explains, emanates from induction coils atop the inverter box located directly below the rear package shelf. The coils are looped cables which, he says, "are just alive. Magnetically, they're trying to get out of each other's way as the current comes through them. We need this much inductance from the system, you see, but then that's not the best way to make inductances. Nor are those capacitors the best way to do it, but ▶

ELECTROVAN IS considered by GM engineers to be "the most advanced electric automotive vehicle ever built." Liquid gases fuel power cells which generate electricity to be fed to drive motors. Processes involve extreme cold and extreme heat.





AN ALLISON Division lithium-chlorine cell, shown in schematic form, is only in the design stage at present, requires additional engineering.

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we're using shelf items. When we design for it," our guide explains, "like we do for the rest of the automobile, those things go out the window."

What, it is asked, can be done about the short range of the electric car? The answer is offered by a tall man in a dark blue suit, Dr. Craig Marks, assistant engineer in charge of power development department. He agrees that the same question is pondered by his people. "Our survey of technology quickly focused on fuel cells," he replies, pointing to a Chevy II van—also obviously stylized and wearing similar metallic blue colors, whisking soundlessly around the same road the passengers had just traveled. "And that is our rolling test bed for fuel cell power, Electrovan."

Dr. Marks briefly outlines fuel cell technology. "These appear to be battery-like devices which produce electricity indefinitely if supplied with a fuel and an oxidant. Hydrogen-oxygen fuel cells were by far the most highly developed in 1964, so we took a closer look. Our first experience was with the baked carbon fuel cell system that had been under development at Union Carbide for several years. By the time we assembled a complete fuel cell system with the same output as our silver-zinc battery pack, we began to have sobering second thoughts. This system filled a whole room and certainly would never fit into a Corvair."

The researchers' learning experience with those early fuel cells encompassed such things as contamination; effects of temperature variations and electrolyte concentrations; the continuous operation, once started, until wear out occurred; and myriad other strange items of behavior. Beside that, Dr. Marks adds, "hydrogen and oxygen are not very practical fuels for a car. They are expensive and are difficult to carry around because they require a very heavy pressure tank. Of course, they can be stored as liquids in a lighter container built like a Thermos bottle, but liquid oxygen boils at −297° F and liquid hydrogen at −423° F, so they continually boil away. Still, the technology appears to be moving toward other more practical fuels—even gasoline-type hydrocarbons. Now a hydrocarbon-air fuel cell would eliminate the fuel supply problem," he suggests.

"We were certainly ready for the major improvement represented by Union Carbide's next design, the thin electrode fuel cell module," Dr. Marks continues. About one fourth the size, they had better electrical performance and lifetime. "Actually, we knew these thin electrode modules were under development, and the better power-to-weight ratio that they promised was why we thought it possible to consider fuel cells.

"The fuel-cell-powered van forced us to face many vehicle problems. We had to supply hydrogen and oxygen, which meant tankage and gas regulation during both steady state and transient operation. We wanted to obtain reasonable driving range—the goal of our fuel cell work—and this means we had to learn about cryogenics (extreme cold) and how to handle liquid hydrogen and oxygen. We had to consider a whole new set of safety questions; not safety in the highway accident sense, but simply minimizing the personnel hazards associated with hydrogen, oxygen and concentrated potassium hydroxide. I won't describe the many detours and heartbreaks along the road. I think the van you see today speaks for itself. It's a major technical achievement—the most advanced electric automotive vehicle ever built," he says with pride.

There are 32 modules fitted together to form a subfloor for Electrovan, almost a foot in depth and covering the entire floor area. To supply the fuels, two large tanks of about 55-gal. drum size—actually the specially designed cryogenic cylinders to keep fuels liquid—are installed inside the van. Converters to change that to gaseous elements, designed by GM researchers, still allow the van only a moderate range of 150 miles.

A TALL LANKY engineer, William K. Steinhagen, in charge of the power development department, continues the discussion. "The motor and controls are almost identical between the Electrovair and the Electrovan," he says. "There are some slight power differences, but essentially the basic principle is exactly the same. We built the Corvair to use as a test bed for motors and controls. We knew its silver-zinc batteries aren't practical. We didn't intend for them to be. But to develop the motor and controls, we had to have a test vehicle divorced from fuel cells. The battery car is something you can operate pretty readily to develop your motor controls.

"This is by far the lightest motor for its power rating that probably has ever been developed. When you start talking about these types of powers in electric machinery, they get very large. Look at a 100-horsepower electric motor sometime; it'd be taller than you are, probably. So this was a large development problem—to get the motor and controls down to what we have achieved here. This is only about 1.3 lb. per hp—but it still isn't good enough," he muses.

Warming to this subject, Steinhagen continues: "Whether you use fuel cells or whether you use a lithium-chlorine system (another type of power source, it soon is realized), you're getting DC power. So the motor and control development is the same whether you get your power from silver-zinc batteries, lead-acid batteries, fuel cells, lithium-chlorine cells. The motor and controls are one problem, the power source is a separate problem. They're interrelated, of course, in that you have to have the power source compatible with the type of motor and controls you use."

As a state of the art demonstration, it's evident that GM has advanced as far as a third running vehicle that it is willing to publicly display. The first Electrovair, built in a 1964 Corvair, posed more questions than it answered and gave way rapidly to the present Electrovair (designated II). And the Electrovan, without a doubt the world's heaviest van at 7100 lb. curb weight, illustrates the major problem yet to be dealt with as electric power sources are trimmed to size. For the fuel cell van, 45 gal. of potassium hydroxide are needed for electrolyte to fill modules, piping (some 550 ft.) and reservoir—a weight penalty of 550 lb. alone. Compared to the normal van's engine-transmission power train, the Electrovan's fuel cell electrics tipped the scales at 3650 lb.

Another means of generating electric current, as yet even less refined, shows some promise. This is the lithium-chlorine cell that GM demonstrates with a playroom-sized laboratory display. Somewhat more remote even than the fuel cells, the system has been a subject of extensive studies since 1964 as a part of Allison Division's work with molten salt electrochemical systems dating from 1958. To produce power, lithium is moved from its storage compartment to the reaction area of the cell, transported by capillary action through a metal fiber wick. Chlorine from external sources is fed to a graphite center electrode. The chemical reaction electrolyzes the lithium chloride. Chlorine is removed from the cell for reprocessing and storage. Lithium rises into the storage portion of the cell. The reaction requires 1100° F, slightly above the melting point of lithium chloride.

Such is the extent of GM's admitted quest for a practical electric passenger car with the minimal performance level of a stock Corvair. There are, of course, other electrochemical reactions which generate power in carefully controlled experiments—"laboratory curiosities," in the words of Dr. Lawrence R. Hafstad. GM's vice president in charge of research laboratories says, however, the lithium-chlorine combination is "representative of one of the best of this family of couples. High temperature, high energy, molten metal systems are very attractive from the standpoint of high energy and high power output. However, all such systems have disadvantages for automobiles. They present start-up and shut-down problems, or else must be kept at very high operating temperatures when not in use. Potential hazards of high temperature molten materials in millions of passenger cars must be considered. Molten lithium and sodium both react violently in water and would have to be completely contained to eliminate this hazard."

Dr. Hafstad is cautious about the electrical vehicle under the present state of the art, regardless of power source. Initial cost of normal lead-acid batteries is "several times that of an internal combustion engine, with other batteries and fuel cells even higher. Equally important, they have high replacement costs that may run to several times the operating cost per mile. All batteries have a high wear-out rate.

"A conceivable solution to the performance and range problem," he suggests, "may be to combine a relatively small fuel cell, running continuously to provide average power, with some sort of high-performance battery to provide peak power when required. And, obviously, a Stirling cycle heat engine could serve in the same way to provide average power with a minimum of air pollution."

The Stirling engine is another, somewhat different area in which GM has been conducting extensive research. It is a thermal engine, a closed cycle external combustion engine that could be compared to a refrigerator in operation. A working gas such as hydrogen or helium is confined within the working areas. Heat is added to or subtracted from the working gas through the metal walls of heat exchangers, respectively called the heater and cooler. Any heat source of sufficient temperature can operate the engine—including nuclear reaction or solar energy. GM has developed a military power unit using Diesel fuel to develop the heat, with hydrogen as the working gas within the sealed circuit under 1000 psi pressure. Two interesting characteristics about a Stirling engine: A fantastically low level of pollutant emission and silence.

Corporate researchers are also anxious to show off their development in gas turbines. Starting with a huge, jet airplane size turbine first shown in 1953 as part of the Firebird program, this power source has been trimmed in size to the most recent model 409, used experimentally in highway tractor trailers (such as Turbo-Titan II) and a transcontinental bus called Turbo Cruiser. But even more graphic is the latest production offspring, an Allison T-63-250-C18 turboshaft engine for military helicopters. This is an extremely small engine weighing 136 lb. and developing 270 bhp at 6000 shaft rpm. Compare that with the most modern GM passenger car engine, the Buick 430-4, developing 360 bhp at 5000 rpm, but weighing 610 lb. and occupying about twice the cubic volume as the Allison.

Harry Barr, GM's engineering vice president, moves into the group and warns, "We aren't fearless forecasters. Electric vehicle propulsion is technically feasible. But that doesn't say when it would become economically feasible or commercially acceptable, particularly from a performance standpoint. Anyway, we think we've got a little more here than simply a test tube for you to look at."

"Energy conversion is our business," adds executive vice president Edward N. Cole. "It's our job to be alert and attuned to both our own and other technologies. We have been actively researching and experimentally developing these various power sources for more than ten years. As far back as 1956 Research was involved in a comprehensive study of storage battery requirements for an electric automobile. But in the past few months, you've heard and read much about the possibilities of electric vehicles and fuel cells," he adds.

Cole concludes that a timetable for development is impossible to guess at the present state of the art, that to build and market a salable automobile able to hold its own in modern expressway traffic still will require several years. Even turbines, as well developed as they are, have problems yet that will limit them to long distance, heavy payload applications for a few years. Air pollution, which some of these future power sources are specifically expected to reduce, is being successfully attacked by progressive development work on that old standby, the internal combustion engine. And that, for the immediate future, seems likely to keep more exotic power sources at a disadvantage as alternatives. One thing common to all these power producers: All discharge some sort of by-product that is capable of causing its own air pollution problems. ■