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What Happens Next

The absolute limit to the performance of a chemical rocket, even in space, appears to be somewhere below 600 seconds. This is a frustrating situation, and various far-out methods of cracking this barrier have been suggested. One is to use free radicals or unstable species as propellants, and to use the energy of their reversion to the stable state for propulsion. For instance, when two atoms of hydrogen combine to form one molecule of H_2, some 100 kilocalories of energy are released per two-gram mole. This means that a 50–50 (by weight) mixture of monatomic hydrogen and ordinary hydrogen would have a performance of some 1000–1100 seconds. That is, it would if (A) you could make that much monatomic hydrogen and could mix it with ordinary hydrogen and (B) if you could keep it from reverting immediately to $H_2 \rightarrow$ in a catastrophic manner. So far, nobody has the foggiest idea of how to do either one. Free radicals such as CH_3 and OOF *can* be made, and can be trapped in a matrix of, say, frozen argon, whose mass is so great compared to that of the captured radicals that the whole idea is a farce as far as propulsion is concerned. Texaco for one has been investigating such trapping phenomena and the electronic states in the trapped molecular fragment for several years, but the whole program, interesting as it is academically, must be classified as a waste of the taxpayers' money if it is claimed to be oriented toward propulsion. To quote a mordant remark heard at one meeting, "The only people who have had any luck at trapping free radicals are the FBI."

So it appears that the only practical way to increase the specific impulse in large-thrust applications is to shift to the nuclear rocket, which, fortunately, works and is well on the way toward operational status. (Ionic and other electrical thrusters are useful only in low-thrust applications, and are outside the scope of this book—and of my competence to describe them.) So the chemical rocket is likely to be with us for some time.

And here are my guesses as to which liquid propellants are going to be used during the next few years, and possibly for the rest of the century, although here I'm sticking my neck out a long way.

For short-range tactical missiles, with a range up to 500 km or so, it will be RFNA-UDMH, gradually shifting over to something like ClF_5 and a hydrazine-type fuel. Monopropellants are unlikely to be used for main propulsion, and the problems with gels and slurries are so great that it is unlikely that the benefits to be derived from them can outweigh the difficulty of developing them to operational status.

For long-range strategic missiles, the Titan II combination, N_2O_4 and a hydrazine mixture will continue in use. The combination is a howling success, and if somebody wants to put a bigger warhead on the brute—I can't see why—it would be a lot simpler just to build a bigger Titan than to develop a new propellant system.

For the big first-stage space boosters we will continue to use liquid oxygen and RP-1 or the equivalent. They work and they're cheap—and Saturn V uses a lot of propellant! Later, we *may* shift to hydrogen as a first-stage fuel, but it appears unlikely. The development of a reusable booster won't change the picture, but if a ram-rocket booster is developed all bets are off.

For the upper stages, the hydrogen-oxygen combination of the J-2 is very satisfactory, and will probably be used for a long time. Later, as more energy is needed, there may be a shift, for the final stage, to hydrogen-fluorine or hydrogen-lithium-fluorine. The nuclear rocket will take over there.

For lunar landers, service modules, and the like, N_2O_4 and a hydrazine fuel seem likely to remain useful for a long time. I can't think of any combination likely to displace them in the foreseeable future.

Deep space probes, working at low temperatures, will probably use methane, ethane, and diborane for fuels, although propane is a possibility. The oxidizers will be OF_2, and possibly ONF_3 and NO_2F, while perchloryl fluoride, ClO_3F, would be useful as far out as Jupiter.

I see no place for beryllium in propulsion, nor any role for N_2F_4 or NF_3. Perchloryl fluoride may, as I've mentioned, have some use in space, and as an oxygen-bearing additive for ClF_5, which will probably displace ClF_3 entirely. Pentaborane and decaborane and their derivatives will, as far as liquid propulsion is concerned, revert to their former decent obscurity. Hydrogen peroxide will continue to be used, as a monopropellant, for attitude control and in other low-thrust applications. It will probably not be used as an oxidizer for main propulsion.

This is the picture, as I see it in my somewhat clouded crystal ball. It may be wrong in detail, but I believe that, on the whole, it won't appear too far out of drawing twenty years from now. There appears to be little left to do in liquid propellant chemistry, and very few important developments to be anticipated. In short, we propellant chemists have worked ourselves out of a job. The heroic age is over.

But it was great fun while it lasted.