to four steps, and each step translates into an entire plant once commercial manufacturing begins—reactor, feed systems, distillation columns, decanters, driers, storage tanks, compressors, pumps, and all the other paraphernalia of a chemical plant.

Manzer's job and that of his counterparts at other companies is to determine the most promising process for making a given compound. Once that decision is made, the company must build a pilot plant to learn those things about the process that were not apparent in the laboratory, such as catalyst lifetimes, the effects of recycling intermediate compounds, how the system handles the small impurities present, and what the best materials are to stand up to the various hazardous materials that are being put under high temperature and pressure. Du Pont has started construction on pilot plants to produce HFC-134a, HCFC-123, and HCFC-141b and has announced plans to build commercial-scale plants for HFC-134a and HCFC-141b/142b. The company says it will spend $1 billion over the next 10 years on plants to make CFC replacements.

It seems certain that whichever substitutes are chosen, they likely will cost more and do the job less effectively than CFCs. For instance, the leading candidate to replace the blowing agent CFC-11 is flammable and could cost three times as much to manufacture. The most attractive substitute to replace CFC-12 as a refrigerant will not work in the refrigeration and air-conditioning systems now in use. They would have to be refitted or replaced.

HCFC-22, which is already being sold for use in air-conditioning systems and in making foam containers, causes less than 5% of the ozone layer damage that CFCs do. However, HCFC-22 has poor insulating qualities, which makes it a poor candidate for insulation sheeting, and it has a low boiling point that makes it incompatible with existing automobile air conditioners. An automobile that used HCFC-22 would need a higher pressure cooling system with stronger hoses, a larger compressor, and a heavy-duty battery for extra power. General Motors has estimated it would cost $600 million to modify its manufacturing process to accommodate HCFC-22.

The Alliance for Responsible CFC Use estimates it will cost more than $10 billion to wean the world from CFCs, including the costs of building new chemical plants and retooling industry to make products that will work with the substitute materials. Nonetheless, it is a small price to pay when one considers the alternative—the loss of the global ozone layer and the resulting havoc wreaked upon much of the life on Earth.

■ ROBERT POOL

# Subtleties of Mating Competition

Male and female primates have a similar "aim" in life, which is to be reproductively successful, but their strategies for achieving that aim are different. For females, the principal constraint on reproductive success is access to sufficient food resources. While it is also true that males must eat to survive, it is also true that what limits their reproductive success is access to mature, mating females. As a result, males usually find themselves in various kinds of competition with each other for the chance to inseminate estrous females, a fact that leaves its biological mark. For instance, males often have to fight each other for the right to control a group of mature females, and as a result natural selection may have endowed the male of the species with weapons of conflict, such as large body size relative to the female, or long, dagger-sharp canine teeth. But there are more subtle forms of competition too: sperm competition.

Some years ago Roger Short of the Medical Research Council's Reproductive Biology Unit in Edinburgh showed that among great apes, gorillas and orangutans have small testes for their body size, whereas chimpanzees have relatively large—not to say enormous—testes. Short explained the difference as the outcome of different breeding systems. Gorilla and orangutan males, for instance, compete with other males for control of a group of females: the winners then have relatively unchallenged access to the females, a mating system known as unimale polygyny. Male gorillas and orangs are much larger than females, as is often seen in polygynous species.

In chimpanzee social organization, by contrast, several adult males have roughly equal access to all the females in the group, a promiscuous arrangement known as multimale polygyny. Physical competition among males is relatively constrained, as reflected in their modest body size. Where they do compete with each other, however, is in the female's fallopian tube: they copulate frequently, and (via the exigencies of natural selection) try to outdo their competitors by leaving more sperm, hence the large testes. This pattern of multimale polygyny being associated with relatively large testes holds up not just among apes but, as Short later demonstrated in collaboration with Alexander Harcourt, Paul Harvey, and S.G. Larson, in many primates.

This equation has now been extended by Anders Pape Moller of Uppsala University, Sweden. Reasoning that quality as well as quantity might be the target of natural selection, he examined not only the volume of ejaculate across 25 primates species, but also the total sperm number, degree of sperm motility, and number of motile sperm. Taking into account effects of absolute body size, Moller found that those species that had relatively large testes also excelled in quality of ejaculate: more sperm, highly motile sperm, and a high percentage of motile sperm. Competition, honed by natural selection, clearly reaches the subtlest of levels. ■ ROGER LEWIN

ADDITIONAL READING

A. P. Moller, "Ejaculate quality, testes size and sperm competition in primates," *J. Hum. Evol.* **17**, 479 (1988).