light-emitting polymer known as poly-p-pridylene-vinylene (PPyV) to a film of a nonemitting polymer. Then, they trained a pair of lasers on the film to excite light emission from the scattered PPyV molecules, and zoomed in with a microscope to watch the action unfold.

"What we found really surprised us," says Barbara. The molecules neither immediately winked out nor dropped their emission slowly. Rather, individual polymer molecules blinked on and off thousands of times before going dark for good. Barbara theorizes that the incoming laser light triggers the blinking: By kicking an electron off the polymer, the light creates a defect in the chain that causes excess energy to be released as heat instead of light. If a free electron jumps back onto the polymer, the light switch is turned back on. Eventually, however, another unknown type of defect quashes the light emission. Whether such results will help chemists design longer lasting polymers is "still too early to say," says Barbara. In any case, he adds, "it will give them some new things to think about."

Polymer chemists won't be the only ones with new findings to ponder. Single-molecule experimenters are also exploring a host of other areas, including rapid DNA sequencing by detecting the subtle light-emission differences in the molecule's four bases, imaging proteins in cell membranes, and creating optical data-storage systems. These initial forays into the tiny world of single molecules show that life in the lab is not only catching up to the idealized view in chemistry textbooks; it is rewriting them.

–Robert F. Service

ECOLOGICAL ECONOMICS

Putting a Price Tag on Nature's Bounty

How much is the world worth? A group of conservation-minded ecologists and economists has attempted to answer that question —bringing intangibles such as a livable environment into the world of economic costs and benefits—by putting a price tag on the "ecosystem services" daily provided *pro bono* by Mother Nature. Their ambitious appraisal covers environmental resources such as fresh water and soil, as well as processes such as climate regulation, crop pollination, and biological pest control. And their best estimate is that replacing these goods and services would cost $33 trillion per year—nearly twice the combined gross domestic product (GDP) of Earth's 194 nations.

But it's not the exact sum that matters, argue the 13 co-authors of the report, which appears in this week's issue of *Nature*. Rather, they say, societies need to overhaul their environmental and economic policies, for example, by taxing the loss of wetlands, to avoid facing a bill of this magnitude. Says lead author Robert Costanza, an ecologist who directs the Institute for Ecological Economics at the University of Maryland, "The big conclusion from the study is that environmental 'externalities' "—economists' term for benefits from resources that belong to no one in particular and so are enjoyed for free—"are relatively huge. We should do something to account for them" in environmental regulations.

Some researchers welcome the report, calling it a corrective for what they consider a nearsighted assumption—that just because a resource is free, society can afford to use it inefficiently. "Having this number calls people's attention to the fact that ecosystem services are absolutely essential for human life, and that there's no price we could pay that would be enough" to replace them, says Stanford University economist Lawrence Goulder. Among the report's many critics, however, are those who say that extravagant valuations render the final estimate too high and others who consider the whole exercise pointless. "There is no debate about the need to protect resources," says Jerry Taylor, director of natural resources studies at the Cato Institute, a Washington, D.C., think tank that has taken conservative positions on issues such as taxation. "The debate today is regarding how best to do that, and this kind of study doesn't enlighten us in any particular manner."

The study took shape last year at a weeklong workshop held at the National Center for Ecological Analysis and Synthesis at the University of California, Santa Barbara, a National Science Foundation–sponsored institute dedicated to improving understanding of global ecosystems (*Science*, 17 January, p. 310). Costanza and a dozen colleagues from Brazil, the Netherlands, Sweden, and the United States first agreed on a list of 17 categories of goods and services provided by nature, including processes such as nitrogen fixation and resources such as crop varieties and plant-derived pharmaceuticals. They then partitioned Earth's surface into 16 specialized "biomes," or environmental types, such as oceans, estuaries, and tropical forests (see table), and judged which services each biome provides.

Finally, they sifted through scores of published studies for estimates of the value per hectare of each service in each biome. Most of the studies measured either market prices, people's willingness to pay for improvements in the service, or the cost of replacing the service. For example, a 1981 study estimated that for each hectare of U.S. wetlands destroyed by development, the lost ability to soak up floodwaters increased annual flood damages by $3300 to $11,000. The group then tallied the lowest and highest estimates for each item, and concluded that all of the items put together were worth $16 trillion to $54 trillion per year, for an average of $33 trillion. For comparison, the U.S. GDP in 1996 was about $6.9 trillion.

Pricing the biosphere is useful, Costanza says, because it dramatically illustrates that "there is a value [to natural systems], even if we aren't paying it in our normal transactions. ... There is no free lunch." But the prices Costanza's group assigned to many ecosystem services are too high, says David Pimentel, an ecologist at Cornell University in Ithaca, New York. In a similar study in press at the journal *BioScience*, Pimentel and co-authors use different categories of ecosystems and assign more conservative values to items such as seafood and estuaries. They pin the yearly benefits from the global ecosystem at just $3 trillion. Pimentel says both totals are "very large"—but adds that in his view, Costanza and colleagues "were giving some things much too high a value."

And the main policy recommendation Costanza sees emerging from the study—a new tax on the depletion of natural capital such as wetlands—has its own foes. Because each ecosystem is different, a general usage tax "will lead to overprotection in some areas and underprotection in others," argues the Cato Institute's Taylor.

Costanza admits his group's numbers are "back-of-the-envelope" estimates with large, built-in uncertainties, but says they are close enough to help set ecosystem usage taxes. Stanford's Goulder agrees. The new study itself, he says, is "an important service."

–Wade Roush

PUTTING A PRICE ON NATURE

Total $33.3 Trillion

Ecosystem*	Area (millions ha)	Value ($/ha/yr)	Global Value ($trillions/yr)
Open Ocean	33,200	252	8.4
Coastal	3102	4052	12.6
Tropical Forest	1900	2007	3.8
Other Forests	2955	302	0.9
Grasslands	3898	232	0.9
Wetlands	330	14,785	4.9
Lakes and Rivers	200	8498	1.7
Cropland	1400	92	0.1
Total Worth of the Biosphere:			**$33.3 Trillion**

*Desert, Tundra, Urban, and Ice/Rock ecosystems omitted

SOURCE: COSTANZA *ET AL./NATURE*