

single-minded focus on love as universal guide to human behavior.

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PHYSICS TODAY's celebration of the World Year of Physics, marking the centenary of Albert Einstein's 1905 papers, got off on the wrong foot with your publication of "God's Rays" by Bryce DeWitt in the January issue. The essay's only mention of Einstein is his "The Lord God is subtle but He is not malicious" quote, but for Einstein, "God" was a poetic metaphor for Nature. Einstein wrote, "I have repeatedly said that in my opinion the idea of a personal God is a childlike one," and "From the viewpoint of a Jesuit priest I am, of course, and have always been an atheist."¹

DeWitt claims that "it is common knowledge that theoretical physicists often start out as amateur theologians," but it is certainly not common knowledge, and is very likely untrue. His fellow religionists should express themselves in a journal other than PHYSICS TODAY.

Reference

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Thoughts on Starting the Hydrogen Economy

In their article "The Hydrogen Economy" (PHYSICS TODAY, December 2004, page 39), George Crabtree, Mildred Dresselhaus, and Michelle Buchanan say that "basic research must provide breakthroughs . . . to make a hydrogen-based energy system . . . vibrant and competitive." This statement overlooks the near-term feasibility of an ammonia-mediated hydrogen-based system.¹ A research breakthrough might reduce the cost of ammonia production, by emulating its biosynthesis,² for example. But we have known how to make NH_3 economically for almost a century. Nowadays, between 1% and 2% of the world's energy is devoted to synthesizing ammonia from air

and hydrocarbons, notably natural gas, via the Haber-Bosch process.³

Because ammonia forms hydrogen bonds, unlike H_2 or methane, it liquefies at about 8 atmospheres and room temperature, or ambient pressure and -33°C . Indeed, because of this favorably situated phase transition, anhydrous ammonia was used as a household refrigerant for much of the 20th century.

Pipelines are in place to distribute anhydrous ammonia. To fertilize their fields, farmers routinely pull tank trucks up to ammonia "filling stations." An ammonia-fueled automobile with an internal-combustion engine was reported in the 1970s.⁴ Commercial catalytic cells are available to break ammonia into nitrogen and hydrogen and thus produce feedstock for a hydrogen fuel cell. Solid-electrolyte ammonia fuel cells have been demonstrated.⁵

Because Bosch synthesis is performed in large industrial plants, the carbon dioxide byproduct can be captured and sequestered relatively easily—for example, by pumping it back into the wells that supplied the natural-gas feedstock. Any means of producing hydrogen based on a renewable energy source could

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substitute for the Haber–Bosch process, and thereby allow for “renewable” ammonia production.

Unlike CH_4 and CO_2 , ammonia is not a greenhouse gas. In the atmosphere, it quickly forms hydrogen bonds to water vapor and returns to the ground in alkaline rain. However, NH_3 is toxic, chills its surroundings rapidly on vaporizing, and releases heat on contact with water. Engineering a safe fuel tank for an ammonia-fueled vehicle would be a key priority.

Ammonia is an excellent material for hydrogen storage. As Crabtree and coauthors report in their figure 4, the volume density of hydrogen in liquid NH_3 is more than 40% greater than in liquid H_2 , and the comparison becomes much more favorable when one considers the weight of the required fuel tank and peripherals. Unlike H_2 gas, ammonia explodes in air only over a narrow range of concentrations. Shipping ammonia from production site to point-of-use does not require a great deal of cooling or high pressure. Thousands of miles of NH_3 pipeline in the US stand as evidence that reliable infrastructure for NH_3 transport and storage has been engineered. In sum, liquid NH_3 is not just

an excellent hydrogen-storage material but also an ideal medium for moving hydrogenic energy from place to place.

Given these advantages, it is hard to avoid the conclusion that relatively modest investments in the science and engineering of NH_3 synthesis and fuel cells, and in safer transport, storage, and delivery of NH_3 , are the best hope for making the hydrogen economy a reality in our lifetimes (and by the way, I am 62).

References

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George Crabtree, Mildred Dresselhaus, and Michelle Buchanan assert that the energy required to split the water molecule and release hydrogen is later recovered during oxidation to produce water. As any undergraduate student of thermodynamics knows, that statement is false; only some of the energy is recovered in any realizable manner. This fact points up the general fallacy in the public's mind about hydrogen being an energy source. Unless and until we are able to connect a hose to Jupiter, hydrogen should be viewed not as an energy source but as a storage medium.

Moreover, as the authors aptly point out, hydrogen does not store energy nearly as efficiently as does gasoline. As long as gasoline is abundantly available, hydrogen will not be cost competitive. Given the stress on the federal budget, large-scale government funding of R&D related to the hydrogen economy is not likely to happen. My guess is that, for the foreseeable future at least, hybrid gasoline technology is where the action will be in the energy sector.

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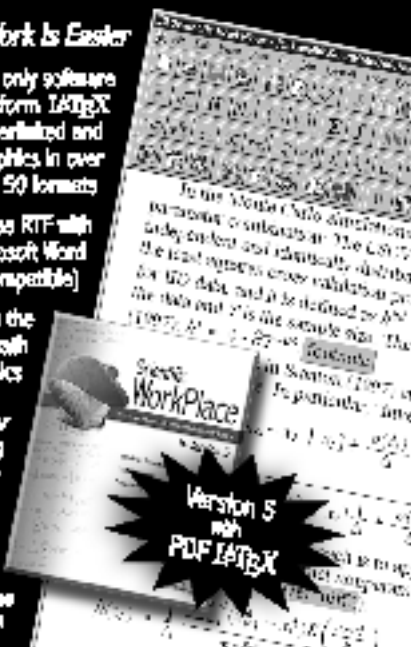
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