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Review of Solutions to Global Warming, Air Pollution, and Energy Security

Briefing to Senator Jeff Bingaman
Chairman, Senate Energy and Natural Resources Committee

Yang and Yamazaki Environment and Energy Building
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Thank you, Senator Bingaman, for meeting with us today. I would like to discuss a review of proposed solutions to global warming, air pollution mortality, and energy security that is the culmination of several years of work. I have handed out a draft copy of the review, which contains the calculations referred to here in an appendix, and some slides. The review considers the proposed solutions with respect not only to climate, pollution, and energy security, but also to water supply, land use, wildlife, resource availability, thermal pollution, water pollution, nuclear proliferation, and reliability.

Nine electric power sources and two liquid fuel options were considered. The electricity sources included solar-photovoltaics (PVs), concentrated solar power (CSP), wind, geothermal, hydroelectric, wave, tidal, nuclear, and coal with carbon capture and storage (CCS) technology. The liquid fuel options included corn-E85 and cellulosic E85. To place the electric and liquid fuel sources on an equal footing, I examined their comparative abilities to address the problems mentioned above by powering new-technology vehicles, including battery-electric vehicles (BEVs), hydrogen fuel cell vehicles (HFCVs), and flex-fuel vehicles run on E85.

Twelve combinations of energy sources and vehicle type were considered. Upon ranking and weighting each combination with respect to each of 11 impact categories, four clear divisions of ranking, or tiers, emerged. Tier 1 (highest-ranked) included wind-BEVs and wind-HFCVs. Tier 2 included CSP-BEVs, Geothermal-BEVs, PV-BEVs, tidal-BEVs, and wave-BEVs. Tier 3 included hydro-BEVs, nuclear-BEVs, and CCS-BEVs. Tier 4 included corn- and cellulosic-E85.

Wind-BEVs ranked first (best) in seven out of 11 categories, including mortality, climate damage reduction, footprint on the ground, water consumption, effects on wildlife, thermal pollution, and water chemical pollution. In fact, the U.S. in 2007 could theoretically replace all onroad vehicles with BEVs powered by electricity from 73,000-144,000 5-MW wind turbines operating in 7-8.5 m/s mean wind speeds. This number of turbines is less than the 300,000 airplanes the U.S. produced during World War II. Such wind-BEVs could reduce U.S. CO_2 by 32.5-32.7% and nearly eliminate 15,000 onroad gasoline vehicle-related air pollution deaths per year in the U.S. projected in 2020 (a reduction from about 20,000/yr today). The footprint area of wind-BEVs is 500,000-1 million times less than that of producing ethanol for E85 regardless of whether ethanol is from corn or prairie grass, 10,000 times less than those of CSP-BEVs or PV-BEVs, 1000 times less than those of nuclear- or coal-BEVs, and 100-500 times less than those of geothermal, tidal, or wave BEVs. Because of their low footprint and pollution, wind-BEVs cause the least wildlife loss as well, accounting for bird fatalities.

Although HFCVs are less efficient than BEVs, wind-HFCVs provide a greater benefit than any other vehicle technology aside from wind-BEVs. Wind-HFCVs are also the most reliable combination due to the low downtime of wind turbines, the distributed nature of turbines, and the ability of wind's energy to be stored in hydrogen over time.

The Tier 2 combinations (CSP-, Geothermal-, PV-, tidal-, and wave-BEVs) all provide outstanding benefits with respect to climate and mortality and are also recommended. Among Tier 2 combinations, CSP-BEVs result in the lowest carbon emissions and mortality. Geothermal-BEVs requires the lowest array spacing among all options examined. Although PV-BEVs result in slightly less climate benefit than CSP-BEVs, the resource available for PVs is the largest among all technologies considered. Further, many PVs can be implemented unobtrusively on rooftops. Underwater tidal-BEVs are the least likely to be disrupted by terrorism or severe weather.

Tier 3 options (hydro-, nuclear-, and coal-CCS-BEVs) are less desirable. However, hydroelectricity, which was ranked ahead of coal-CCS and nuclear with respect to climate- and health-relevant emissions, is an excellent load balancer, thus recommended. Nuclear and coal-CCS are not recommended since they emit significantly more carbon and air pollutants than the Tier 1 and Tier 2 options or hydroelectricity, and the large-scale spread of nuclear energy poses a nuclear weapons security threat to all nations, as illustrated shortly.

Specifically, coal, with CCS (and its 85-90% reduction in coal-plant exhaust emissions), puts out about 77-110 times more lifecycle carbon and other pollutants per kWh than wind energy. Coal-CCS emissions are primarily from the mining and transport of coal, exhaust that escapes the CCS equipment, the greater time-lag between the planning and implementation of a coal-CCS plant that from a wind, solar, or geothermal plant, and potential leakage from underground storage reservoirs. Further, the addition of CCS equipment to a coal power plant requires an additional 14-25% energy for coal-based integrated gasification combined cycle (IGCC) systems and 24-40% for supercritical pulverized coal plants according to the Intergovernmental Panel on Climate Change. Such equipment also does not capture health-damaging pollutants, such as NO_x, NH_3, and SO_x.

Nuclear power puts out about 24 times more lifecycle carbon and other pollutants per kWh than wind energy. For nuclear, carbon emissions include those due to the mining and transport of uranium, the opportunity-cost emissions due to the time-lag between planning and operation of a nuclear power plant (10-19 years), and the risk (between 0 and 1) of carbon emissions due to the burning of cities associated with nuclear war or terrorism that is linked to the future increase of nuclear fuel production in nuclear power plants worldwide. For example, the explosion of 1.5 MT of nuclear weapons material, or 0.1% of the yields proposed for a full-scale nuclear war, during a limited nuclear exchange or a terrorist attack in a megacity would burn 63-313 Tg of fuel in city infrastructure, adding CO_2 and 1-5 Tg of soot to the atmosphere, much of it to the stratosphere, and killing 3-17 million people based on a recent paper (Toon et al.).

As stated in a Los Alamos Report in August 1981, "There is no technical demarcation between the military and civilian reactor and there never was one." Currently, 42 countries have fissionable material to produce weapons; 22 of these countries have facilities in nuclear energy plants to produce enriched uranium or to separate plutonium; 13 of these countries are active in producing enriched uranium or separating plutonium; 9 of these countries have nuclear stockpiles. Having a nuclear reactor facilitates the basis for obtaining uranium that can then be used either for energy production and either secretly or openly for weapons production. The U.S. would need to add 200-275 850 MW nuclear power plants to power all U.S. electric vehicles, and once the U.S. started to do this, most countries of the world would try to follow, increasing the risk of nuclear weapons proliferation. Any solution to global warming, air pollution, and energy security on a large scale must involve technology that can be disseminated worldwide. As such, this technology cannot be nuclear. If the U.S. uses alone nuclear, this will undercut international efforts to slow global warming and air pollution mortality.

The Tier-4 combinations, cellulosic- and corn-E85, were ranked lowest overall and with respect to climate, air pollution, land use, wildlife damage, and chemical waste. Cellulosic-E85 ranked lower than corn-E85 overall, primarily due to its potentially larger land footprint based on new data and its higher upstream air pollution emissions than corn-E85. Whereas cellulosic-E85 may cause the greatest average human mortality, nuclear-BEVs may cause the greatest upper-limit mortality risk as discussed above. The largest consumer of water is corn-E85. The smallest are wind-, tidal-, and wave-BEVs.

An important issue to address with respect to wind, solar, and wave power is intermittency. Intermittency can be reduced in several ways, including (1) interconnecting geographically-disperse intermittent sources through the transmission system, (2) combining different intermittent sources (wind, solar, hydro, geothermal, tidal, and wave) to smooth out loads, using hydro to provide peaking and load balancing, (3) using smart meters to provide electric power to electric vehicles at optimal times, (4) storing wind energy in hydrogen, batteries, pumped hydroelectric power, compressed air, or a thermal storage medium, and (5) forecasting weather to improve grid planning. Currently, the greatest limitation to the large-scale implementation of new, clean electric power plants is limited transmission line availability.

In sum, the use of wind, concentrated solar, geothermal, tidal, photovoltaics, wave, and hydroelectric to provide electricity for BEVs and HFCVs will result in the most benefit and least impact among the options considered. Coal-CCS, nuclear, corn-E85, and cellulosic-E85 put out much more carbon and health-damaging pollutants than the other options examined. Thus, the investment in corn- or cellulosic ethanol, coal-CCS, or nuclear at the expense of the others will cause certain climate and health damage, thus economic damage. Because sufficient clean natural resources (wind, sunlight, hot water, ocean energy, gravitational energy) exists to power all energy for the world, our failure to focus on these resources by diverting our attention to less efficient or non-efficient options will guarantee that the significant environmental and energy problems we face today will not be solved any time soon. The philosophy, that we should try a little bit of everything is wrong. We need to focus on the technologies that provide the best benefit. We know which technologies these are.

Finally, the relative ranking of each electricity option for powering BEVs also applies to the electricity source when used to provide electricity for general purposes. The implementation of the recommended electricity options for providing vehicle and general electricity requires organization. Ideally, good locations of energy resources would be sited in advance and developed simultaneously with an interconnected transmission system. This requires cooperation at multiple levels of government.