

2. COMMERCIALIZATION

Closely related to the issue of scalability and timing is commercialization, or the question of how far away a proposed alternative energy source stands from being fully commercialized. Often, newspaper reports of a scientific laboratory breakthrough are accompanied by suggestions that such a breakthrough represents a possible “solution” to our energy challenges. In reality, the average time frame between laboratory demonstration of feasibility and full large-scale commercialization is twenty to twenty-five years. Processes need to be perfected and optimized, patents developed, demonstration tests performed, pilot plants built and evaluated, environmental impacts assessed, and engineering, design, siting, financing, economic, and other studies undertaken. In other words, technologies that are proved feasible on the benchtop today will likely have little impact until the 2030s. This reality is reflected in the key message of the now-famous Hirsch Report, which noted that to properly mitigate the economic impacts of peak oil [2005], we would have needed to start fundamentally redesigning our national energy infrastructure *twenty years* in advance of the peak.⁵

3. SUBSTITUTABILITY

Ideally, an alternative energy form would integrate directly into the current energy system as a “drop-in” substitute for an existing form without requiring further infrastructure changes. This is rarely the case, and the lack of substitutability is particularly pronounced in the case of the electrification of transportation, such as with electric vehicles. Although it is possible to generate the electricity needed for electrified transportation from wind or solar power, the prerequisites to achieving this are extensive. Electric-car development would require extensive infrastructure changes, including:

Retooling of factories to produce the vehicles

- Development of a large-scale battery industry
- Development of recharging facilities
- Deployment of instruments for the maintenance and repair of such vehicles
- A spare-parts industry

- “Smart-grid” monitoring and control software and equipment
- Even more generation and transmission facilities to supply the additional electricity demand

The development of wind and solar-power electricity also requires additional infrastructure; wind and solar electricity must be generated where the best resources exist, which is often far from population centers. Thus, extensive investment in transmission infrastructure to bring it to consumption centers is required. Today, ethanol can be blended with gasoline and used directly, but its propensity to absorb water and its high oxygen content make it unsuitable for transport in existing pipeline systems,⁶ and an alternative pipeline system to enable its widespread use would be materially and financially intensive. While alternative energy forms may provide the same energy services as another form, they rarely substitute directly, and these additional material costs need to be considered.

4. MATERIAL INPUT REQUIREMENTS

Unlike what is generally assumed, the input to an alternative energy process is not money per se: It is resources and energy, and the type and volume of the resources and energy needed may in turn limit the scalability and affect the cost and feasibility of an alternative. This is particularly notable in processes that rely on advanced technologies manufactured with rare-earth elements. Fuel cells, for example, require platinum, palladium, and rare-earth elements. Solar-photovoltaic technology requires gallium, and in some forms, indium. Advanced batteries rely on lithium. Even technology designed to save energy, such as light-emitting diode (LED) or organic LED (OLED) lighting, requires rare earths, indium, and gallium. Expressing the costs of alternative energy only in monetary terms obscures potential limits arising from the requirements for resources and energy inputs.

Because alternative energy today constitutes only a small fraction of total energy production, the volume of resources and energy demanded for its production has so far been easily accommodated. This will not necessarily be the case with