Futures 58 (2014) 34–52

Contents lists available at ScienceDirect

Futures

journal homepage: www.elsevier.com/locate/futures

Analyzing the transition to electric drive vehicles in the U.S.

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ARTICLE INFO

Article history:
Available online 19 October 2013

ABSTRACT

Scenarios of the transition to electric drive passenger cars and light trucks are created using the same model, technology and market behavior assumptions used in the recent National Research Council study, *Transitions to Alternative Vehicles and Fuels*. The transition is assumed to begin in California and the other U.S. states that have adopted California's Zero Emission Vehicle (ZEV) requirements. Five years after the ZEV standards take effect in 2015, the rest of the U.S. adopts polices strongly supporting the transition. After roughly a decade of net costs, market adoption of electric drive vehicles becomes self-sustaining. In the long run, the model implies that social benefits exceed excess costs by approximately an order of magnitude. Analysis of major energy transitions is characterized by deep uncertainty due to the long time constants for energy system change, the unpredictability of technological change and government policies, inadequate understanding of market processes, and the many important positive feedback mechanisms that create tipping points.

1. Introduction a new challenge for public policy

> "Without question a radical transformation of the present energy system will be required over the coming decades."
>
> "An effective transformation requires immediate action."
>
> "In all (sustainable, ed.) pathways conventional oil is essentially phased out shortly after 2050. Every scenario that achieves the sustainability goals essentially eliminates petroleum use."
>
> [1]

Achieving sustainability, assuring that the world we leave to future generations allows a quality of life at least as good as our own, may be humanity's greatest task in the 21st century [2]. Transitioning to sustainable energy systems is perhaps the essential element of a physically and economically sustainable global society [3,4]. As the world's vehicle population grows toward 2 billion, motorized transportation is challenged to contribute to protecting of the global climate system, enhancing energy security and reducing the adverse health effects of local air pollution [5]. There is no single solution to these problems [6–9]. However, it is becoming increasingly clear that achieving sustainable transportation implies a transition from petroleum-based, internal combustion engines to nearly zero emission electric drive.

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0016-3287/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.futures.2013.07.003

How such a transition can be accomplished is a new conundrum for public policy. The time constants for such transitions are measured in decades [10]. The future progress of technology is inherently uncertain. Knowledge of how the market will respond to advanced vehicle technologies and fuels is meager. A genuinely sustainable energy system for transportation requires a sustainable energy supply chain from energy source to vehicle. How can society manage such a transition efficiently and effectively?

Bringing about a large scale energy transition for the public good requires a new paradigm for environmental policy. It is not just a matter of internalizing externalities and letting markets do the rest. Externalities are an important part of the problem but not all of the relevant social costs are externalities, e.g., monopoly power in the world oil market [11]. Major energy transitions take decades. On this time scale the difference between social and private discount rates becomes critical. The transition requires technological progress beyond the current state of the art, and that is inherently uncertain. Equally importantly, the transition creates network external benefits which are difficult for private agents to capture. Among these are, (1) the value of fuel availability to car buyers, (2) learning-by-doing spillover effects, (3) reduction of the majority of consumers' aversion to the risk of new products, (4) the value of choice diversity (which conflicts with the need for scale economies during the early stages of a transition) and (5) "deep uncertainty" about outcomes in the mid- to long-range future and the difference between social and private perceptions of and tolerance for risk.

An economic paradigm for large scale energy transitions can be constructed from the concepts of net present social value, network external benefits, and adaptation to an uncertain future (e.g., [12]). Net social benefits are the key metric because a broadly based cost/benefit framework is necessary to compare very different future states of the world; marginal analysis is inadequate. Novel technologies must overcome higher initial costs that temporarily prevent them from displacing the incumbent "locked in" technology [10]. Network external benefits are key concepts for understanding technology transition because the process of breaking down the natural economic barriers to transition is comprised of actions that provide future benefits to others with costs incurred in the present (e.g., [13]). Uncertainty is an inescapable dimension because future technologies and markets will undoubtedly surprise us.

2. Modeling the transition to electric drive

The transition to electric drive vehicles requires replacing an entrenched technology and its physical and human infrastructure with new technologies that deliver superior public goods. At present the new technologies are not superior in the eyes of most potential buyers. However, with continued technological progress they have the potential to become superior from a private perspective as well. Electric drive technologies thus face six major economic barriers that lock in petroleum powered internal combustion engine vehicles and lock them out.

(1) Current technological limitations of electric drive power-trains and fuels.
(2) High costs that can be reduced through experience (i.e., learning by doing).
(3) High costs that can be reduced by volume production (i.e., scale economies).
(4) Consumers' aversion to the risk of novel products.
(5) Lack of diversity of choice in the early market for electric drive vehicles.
(6) Lack of an energy supply infrastructure for hydrogen and a limited infrastructure for plug-in electric vehicles.

Each of these barriers is difficult to quantify and uncertain in the future. Yet much can be learned about the transition process by quantifying each of them using available information with the expectation that as knowledge improves and conditions change, assessments can be revised and policies adapted. By quantifying the transition barriers, the costs of overcoming them can be measured.

Each of the six barriers above can be viewed as a *transition cost*. On the other hand, early adopters willing to purchase electric drive vehicles and entrepreneurs willing to manufacture them or to supply the new fuels they require reduce the barriers and generate positive feedback effects that benefit existing and future e-drive vehicle owners. Modern economics calls these positive feedback effects "network externalities", positive external benefits that one user of a commodity can produce for another [14]. Network external benefits have been extensively studied in the development of personal computer operating systems and cell phones. Similarly, when an innovator purchases one of the first hydrogen fuel cell vehicles, it reduces the risk for all other buyers who may now consider buying a slightly less novel technology, and it lowers prices via scale economies and learning by doing.[3] When a city installs a public recharging station it increases the value to the owners of every electric vehicle. Likewise, adding a hydrogen refueling station makes fuel cell vehicles more attractive, while the sale of another fuel cell vehicle improves the economics of the first few hydrogen refueling stations.

Network external benefits are essential to the transition to electric drive vehicles because they create important positive feedbacks that can eventually lead to a self-sustaining transition. The Light-duty Alternative Vehicle and Energy Transitions (LAVE-Trans) model developed for the International Council on Clean Transportation was designed to measure these external benefits, albeit imperfectly. Recognizing and measuring the value of early deployment of vehicles and infrastructure

[3] The latter two benefits are referred to as pecuniary network external benefits because they are reflected in the prices of the vehicles.