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Challenges in Analyzing a Transition to Hydrogen

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“Examining Hydrogen Transitions” Study for DOE

1. **Literature Review of future scenarios of hydrogen use in transport (primary focus: light-duty vehicles)**
2. **Identify analytic issues – evaluating a hydrogen transition**
3. **Identify requirements for a hydrogen transition model**
4. **Characterize 3 DOE models in development**
5. **Compare 3 and 4, and identify opportunities for model improvements**

Underlying issue: Modeling of long-term energy transitions is in its infancy, and there are difficult tradeoffs among competing requirements – so there is no readily-identifiable “best” approach.

Most of the reviewed scenario analyses appeared to have little rigor

- **Many ignored the transition phase, focused only on steady-state conditions**
- **None examined surprises, whether oil disruptions or climate change discontinuities**
- **Most simply *assumed* high levels of hydrogen use**
- **Most did not test for realism (or did not describe such tests) – and those that did used only the simplest tests**
- **Most used a Reference Case where a hydrogen transition would have made little sense**

Note: the literature review was completed 4/2005; more sophisticated scenario analyses have been published in the interim.

Choose a Reference Case that describes a world in which a hydrogen transition may be an important option…or a range of futures that includes such a world as a strong possibility

- **Benefits and costs are the *differences* between cases with and without hydrogen…..so the choice of an appropriate Reference Case is critical.**
- **Annual Energy Outlook Reference Case or other "business as usual" cases were the usual choices for Reference Cases**
  - **These are cases without disruption, with ample oil resources – i.e., *without any need for a hydrogen transition***
  - **Implications: hydrogen vehicles will be compared to vehicles not much better than today's; oil savings are worth less in a future with moderate oil prices**
- **If the Hydrogen Fuel Initiative is designed to be an insurance policy against a risky future, a hydrogen transition must be compared to other options appropriate to such a future – even if they might occur without government intervention**

Hydrogen scenarios can be improved by reality testing….even without formal models. Examples:

- **What are the required investments, and do they satisfy investment hurdles? How long will it take to achieve positive cash flow?**
- **Are the schedules for infrastructure development realistic? How many workers are required/will they be available?**
- **Does the "rest of the world" make sense in a future where a hydrogen transition is occurring? Example: If ultra-efficient fuel cell vehicles are being made and successfully sold, how likely is it that the vehicles they're competing with would be little different from today's?**
- **What feedstocks are being used to fuel the transition….and do their prices make sense if hydrogen's incremental demand is added to competing demands for them?**

Modeling investor behavior is crucial….and extremely challenging

- **Investors face unusual uncertainties, including "chicken or egg" issue (which comes first, vehicles or supply infrastructure?), untested consumer preferences, radically new vehicle technology, unstable oil prices**
- **Most models assume perfect foresight or simple myopia – can this capture likely investor behavior?**
- **Appropriate level of disaggregation, with multiple actors?**
- **Role of international actors?**

And even if we had limitless computer power and programming resources, how much do we understand about investor behavior?

The role of "learning" and scale is crucial to making hydrogen technology competitive – can models adequately capture this?

- **Current technology costs, especially for fuel cell systems, are orders of magnitude too high to compete with ICE systems.**
- **A successful hydrogen transition depends on *both* R&D breakthroughs and large cost reductions through scale economies and learning**
- **Current U.S. models "count" total U.S. FCV sales – but what is the true basis for learning?:**
  - **Worldwide or country-wide only?**
  - **Across the industry, or at the individual company (supplier) level, or something in-between?**
  - **At the "component" scale, or fuel cell system scale?**
- **Do we know enough about learning for this to make a difference?**

Modelers need to identify “swing” assumptions and handle them carefully (or parametrically)

- **A transition to hydrogen involves a huge change in the energy system, with reverberating effects that can accelerate or slow the transition**
- **Example: Petroleum refinery throughput will stop growing and then drop as the transition occurs. The refining system’s response will have drastic effects on future gasoline prices (the less response, the greater likelihood that gasoline prices will drop as gasoline is overproduced) – affecting the key competitor to hydrogen.**
- **Appropriate analytic response: parametric analysis of changing the refinery module in the energy model**

Developing a "wish list" for a transition model

- **Given tradeoffs with desirable characteristics (e.g., greater disaggregation comes with greater complexity and slower model runs) and infancy of some modeling issues, there is no "ideal" model…..but here's my list anyway:**
  - **Strong documentation, including evaluation of output sensitivity to starting assumptions**
  - **Easy parametric analysis capability**
  - **Ability to do risk analysis (perhaps Monte Carlo capability)**
  - **Spatial disaggregation**
  - **Incorporation of existing hydrogen sources**
  - **Robust vehicle choice model**
  - **Multiple reality checks for scenarios – tracking key variables (cash flow, labor requirements, etc), embedded limits on construction rates, etc.**

Developing a "wish list" for a transition model (cont'd)

- **Wide analytic boundaries, considering how non-transport factors affect and are affected by transport hydrogen use, etc.**
- **Modular structure**
- **Appropriate investment model, including investment rules and disaggregation of types of investors – with clients understanding precisely what question the model is answering!**

DOE has sponsored development of three hydrogen transition models:

- **NEMS-H2, an offshoot of EIA's National Energy Modeling System run by OnLocation**
- **HyTrans, developed by ORNL**
- **MARKAL, version run by BNL**

each with its own unique characteristics.

Each of the modelers filled out a questionnaire designed to profile the model's characteristics associated with the "wish list," e.g. level of spatial disaggregation, type of investment model, treatment of investor foresight, etc.

Results of comparing individual model characteristics to our "wish list":

- **Parametric analysis is cumbersome for all three models; there may be a modeling framework that can ease this process**
- **Ability to model uncertainty/risk – thus far, only MARKAL has incorporated Monte Carlo capability**
- **Learning effects are not yet modeled in NEMS-H2; HyTrans and MARKAL both track learning according to drivetrains sold in U.S. (HyTrans will soon track components). Further research is needed.**
- **Limited or no capability to incorporate potential contribution of existing H_2 sources**
- **No capability to incorporate non-transport hydrogen use in modeling transport hydrogen transition**

Results of comparing individual model characteristics to our "wish list" (continued):

- **Competition for hydrogen feedstocks – HyTrans cannot track non-transport uses, important for biomass and natural gas**
- **Level of disaggregation of investors varies substantially – NEMS-H2 treats each market sector (e.g., all fuel producers) as a single entity, MARKAL optimizes over the entire energy sector, HyTrans treats individual (but generic plants) as actors. *This is an area demanding significant attention.***
- **Analysis of electricity production for electrolytic H_2 – *if* electrolytic hydrogen becomes important, analysis of generation sources is crucial – HyTrans uses GREET, has no generation model**
- **Modeling investment decisionmaking under uncertainty – this is an area that deserves much more attention from the modeling community, not just the three model developers.**

All three models serve a critical purpose:

- **The scenario analyses we examined have few or no controls to insure compatibility of assumptions, do not allow reviewers to track underlying assumptions and how they affect outcomes**
- **Each of the models provides a robust framework to track underlying assumptions and assure that a uniform methodology is provided to transform assumptions into outcomes.**

However, each of the models will seem like a "black box" to much of the audience for its results. It is the modelers' responsibility to help avoid misuse of their model (e.g., avoid its use in addressing issues that the model cannot handle well) and misunderstanding of its results