Candidate Fuels for Vehicle Fuel Cell Power Systems: Stakeholder Risk Analysis

Work in Progress

2003 Hydrogen and Fuel Cells Merit Review Meeting

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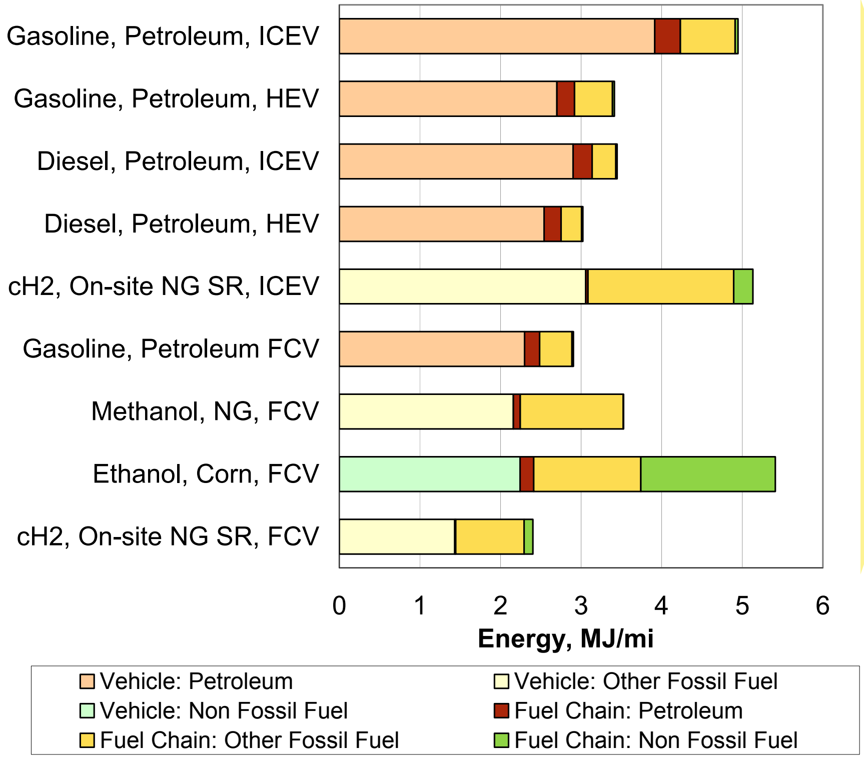
Fuel cell vehicles (FCV) could result in significant environmental and other benefits by way of improvements in fuel economy and energy diversity.

Well-to-Wheel Energy Use



Potential Benefits

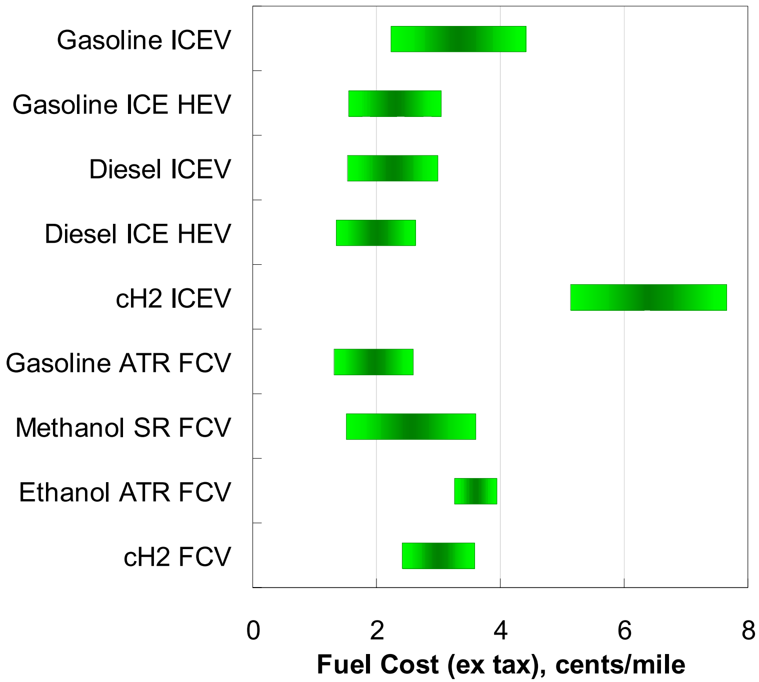
- Energy security
- Energy use reduction
- Greenhouse gas (GHG) and other emissions reductions
- Other health and environmental impacts

Legend: ICEV = internal combustion engine vehicle, HEV = hybrid (battery/ICE) electric vehicle, NG SR = natural gas steam reformer

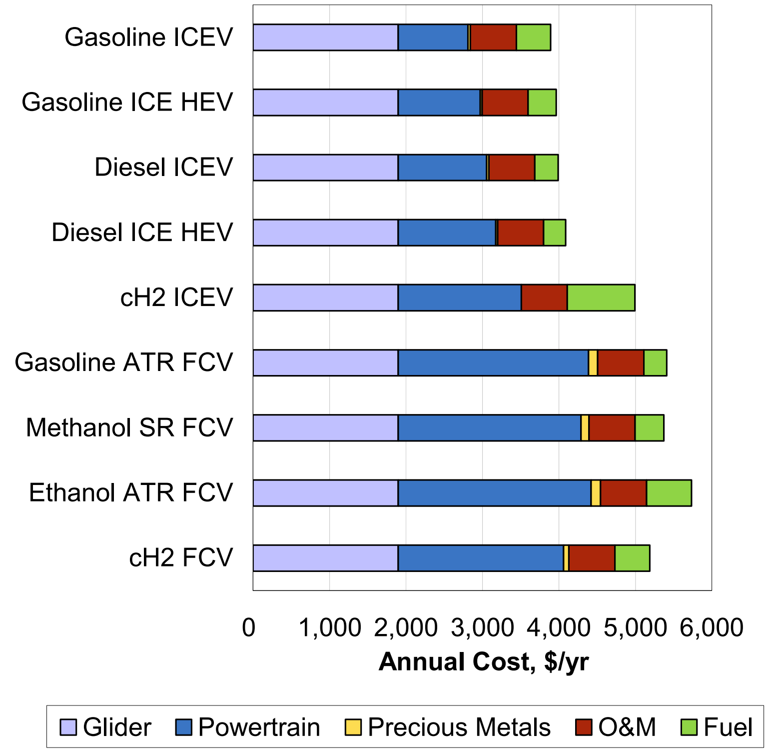
Compressed hydrogen (cH_2) could provide the largest energy use and GHG emissions benefits of all the FCV options.

An earlier study indicated that long-term operating costs for FCVs could be competitive with conventional vehicles...

Vehicle Fuel Cost



Vehicle Ownership Cost



Note: sensitivity is based on historical feedstock variability, not vehicle performance (i.e. fuel economy) uncertainties

Legend: ATR = autothermal reformer, SR = steam reformer, O&M = operation and maintenance

… but that ownership costs are much higher due to high vehicle purchase costs.

In addition, there are significant technical and market uncertainties that could result in transitional risks for the introduction of FCVs.

Technical Uncertainties	Market Uncertainties
• Fuel economy • FCV and fueling equipment life • Refueling time/convenience • Performance under extreme conditions	• Fuel infrastructure development (coverage) • Future fuel prices • FCV price premium • Subsidies/taxes • Supply chain (natural gas, materials)

- Technical and market uncertainties translate into investment risk to one or more stakeholders (e.g. car manufacturers, energy companies)
- Types and magnitude of risks vary amongst fuel options
- DOE needs to understand the risk trade-offs between different fuel options in order to properly guide and support appropriate research and development

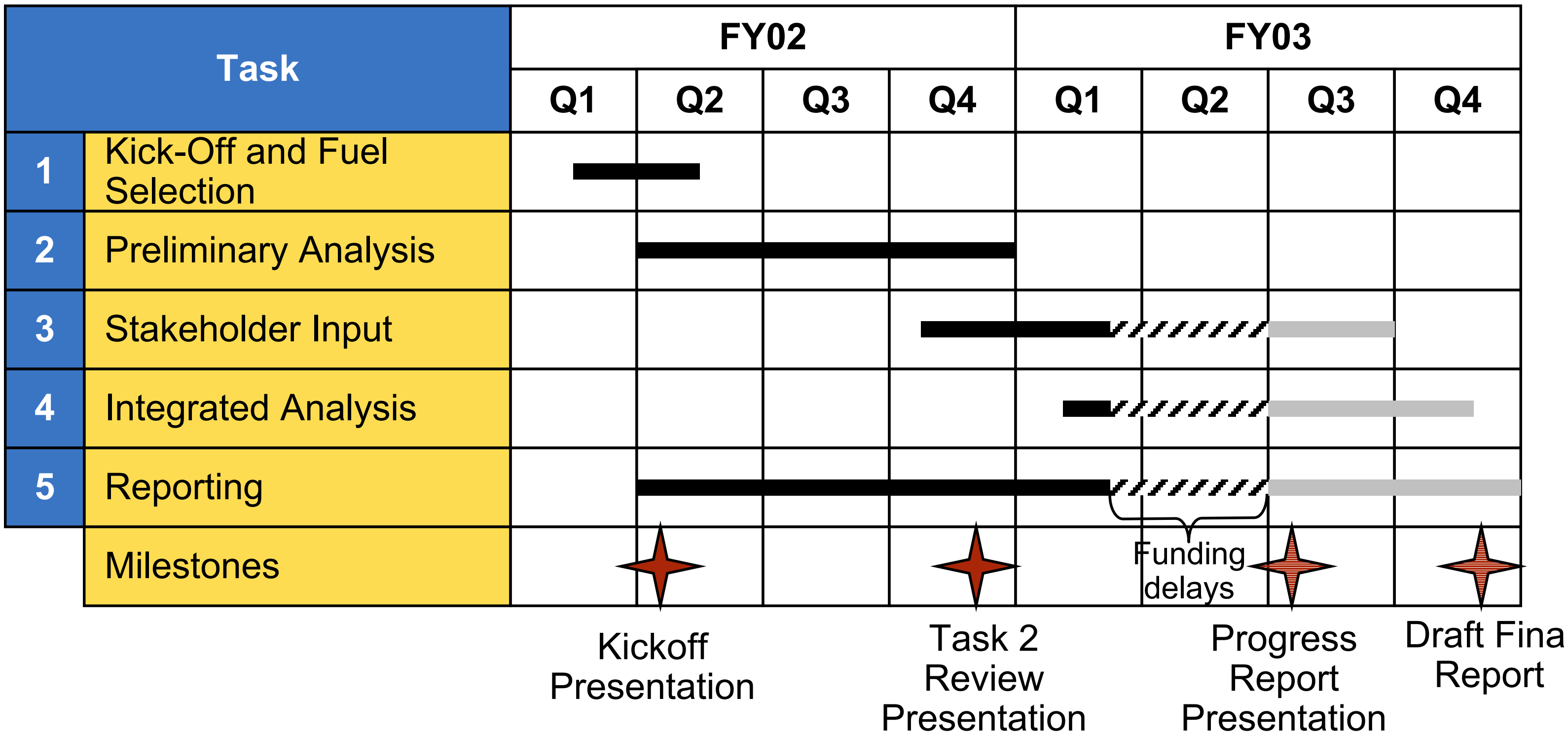
The topic of this report, and of most interest currently, is the uncertainty and risks associated with transitioning to a hydrogen infrastructure.

- Owners of alternative fueled FCVs will expect to pay about the same (or less) as fueling with gasoline today
  - Especially if they pay a premium for the vehicle
- Hydrogen will not likely be cheaper than gasoline in the early years
  - Initial costs per production plant and fueling station will be high
    - Low production volumes can't take advantage of economies of scale
  - Utilization of fueling stations (capacity factors) will be low early on - owners of hydrogen fueled vehicles will demand coverage
- FCV developers face large financial risks if they invest in fuel cell technology and the fuel infrastructure is not acceptable to FCV owners
  - Coverage must be above a minimum level - is it 10%, 50%?
- Similarly, energy companies and fuel distributors face large financial risks if they build a hydrogen fuel infrastructure and FCVs do not take off
  - Or another fuel dominates the market
  - They depend on the FCV developers to make the technology attractive (e.g. dependable, fuel efficient, competitively priced)

The motivation of this study is to facilitate the commercialization of fuel cell vehicles by understanding the risk surrounding fuel choices.

- Assess potential benefits and risks of various FCV and fuel choices, specifically compressed hydrogen
  - Compare the financial risks of direct hydrogen with onboard reforming
  - Characterization of the transition period
- Assess impact on various stakeholder and how risks could be shared and minimized
  - Identify key barriers and possible development paths
- Determine what range of factors might trigger the introduction of FCVs (e.g. oil price increase, carbon taxes, FCV cost reduction)

Prior to finalizing our analysis, we intend to obtain input from a range of potential stakeholders in both conventional and hydrogen fuel chains.



- The work to date has been slowed due to funding delays, but we are on schedule to finish by the end of this fiscal year
- We are about 60% through the total budget

We will evaluate the economic and other risks of alternative fuel introductions, particularly hydrogen.

- We will focus on financial risks due to the introduction of:
  - Hydrogen infrastructure
    - Central and local hydrogen production from natural gas (near-term)
  - The financial risks for other alternative fuel chains and the fuel cell vehicles themselves will be considered at a high level
- Perform analysis in the context of:
  - Discounted cash flows (i.e. "time value of money")
  - Improvement of cash flow over time based on FCV introduction scenarios
- Analysis will include:
  - Characterization of financial, safety, environmental, and technical risks
  - Impact on current fuel production and distribution infrastructure
  - Feedback from stakeholders (car makers, technology developers, energy companies, fuel distributors, government)
  - Identify how risks might be shared and minimized

Likely hydrogen and FCV introduction scenarios are inputs to net present worth calculations that will be used in support of an issues analysis.

- A hydrogen infrastructure introduction analysis will be used to determine hydrogen fueling station buildup
  - Using DOE FCV introduction scenarios for hydrogen demand - not a market model
  - Regional buildup analysis to estimate station capacity factors over time
- Net Present Worth (NPW) will be used to compare financial investments for various options with business as usual (gasoline ICEVs)
  - Both FCV and fuel infrastructure investments
  - Equipment cost reduction with higher production volumes using progress ratios
  - Hydrogen revenue increase with fueling station utilization (capacity factors)
- Overall financial risk will be sum of NPW from all stakeholder groups representing net cost to the nation
  - Risks depend on volume, timing, performance assumptions, etc.
- The NPW results will be inputs to an issues analysis that we will use to obtain feedback from key stakeholder groups
  - What could go wrong by stakeholder and stage of introduction
  - Key barriers/risks

To date, we have built a time-resolved model that allows us to assess the impact of new fuel / vehicle combinations under various scenarios.

- Built time-resolved model that allows assessment of ....:
  - Economic impact of new fuel / vehicle combinations compared with conventional gasoline / ICEVs
  - Time-resolved, cumulative investment and NPW assessment
  - Triggers for implementation of alternative fuel scenarios

  … and can take into account:
  - Scenarios for the vehicle (introduction rate, performance, transitional costs)
  - Scenarios for fuel chain (pathways, introduction rate, performance, transitional cost)
  - Developments in baseline vehicle & fuel technologies
- We have evaluated a “strawman” case for the introduction of a hydrogen infrastructure using the model
  - Vehicle introduction matches DOE’s FCV introduction scenarios
  - Cost and performance assumptions are consistent with previous analysis results
- We are now seeking inputs from stakeholders to identify the most relevant alternative scenarios for analysis

A net present worth model has been developed to track vehicle and infrastructure investments on an annual basis.

Time Dependent Inputs

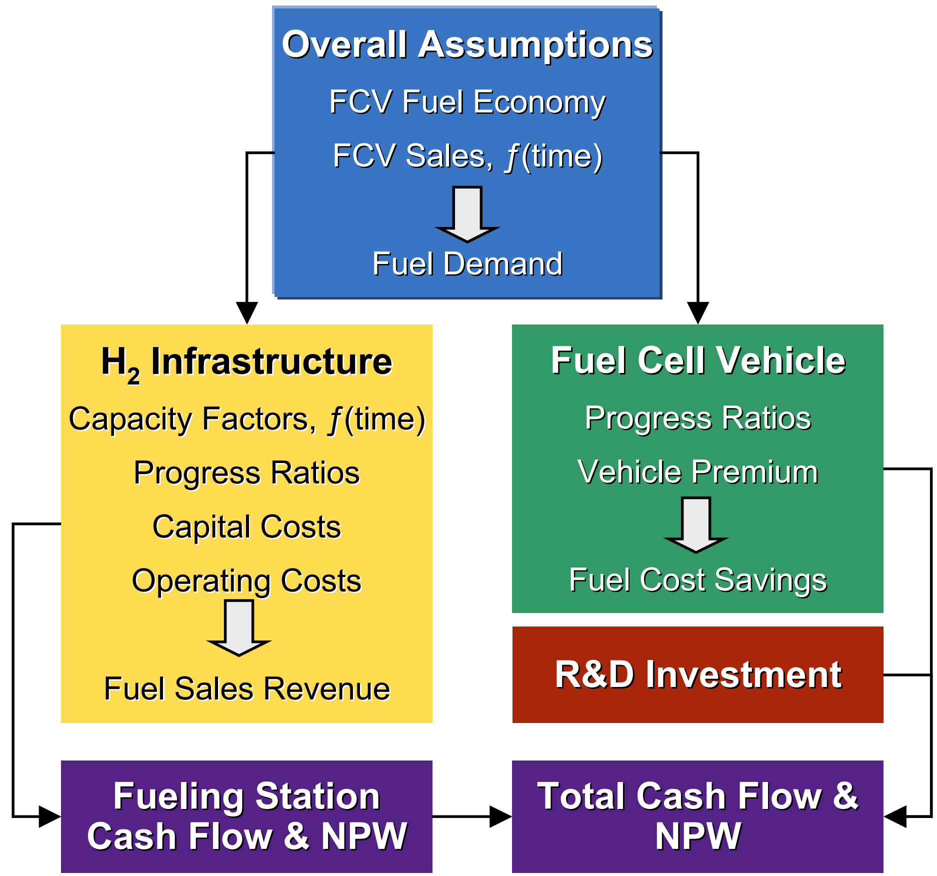
- DOE FCV introduction (sales) scenarios
- Infrastructure capacity factors
- Infrastructure pathways (central and local production, large and small stations)
- Equipment costs - based on progress ratios (infrastructure and FCV)

Time Independent Inputs

- FCV performance assumptions
- Fuel prices (e.g. gasoline, hydrogen)
- Other infrastructure costs (e.g. O&M)

Outputs

- Hydrogen revenues
- Fuel savings
- Cash flow and NPW for each stakeholder group

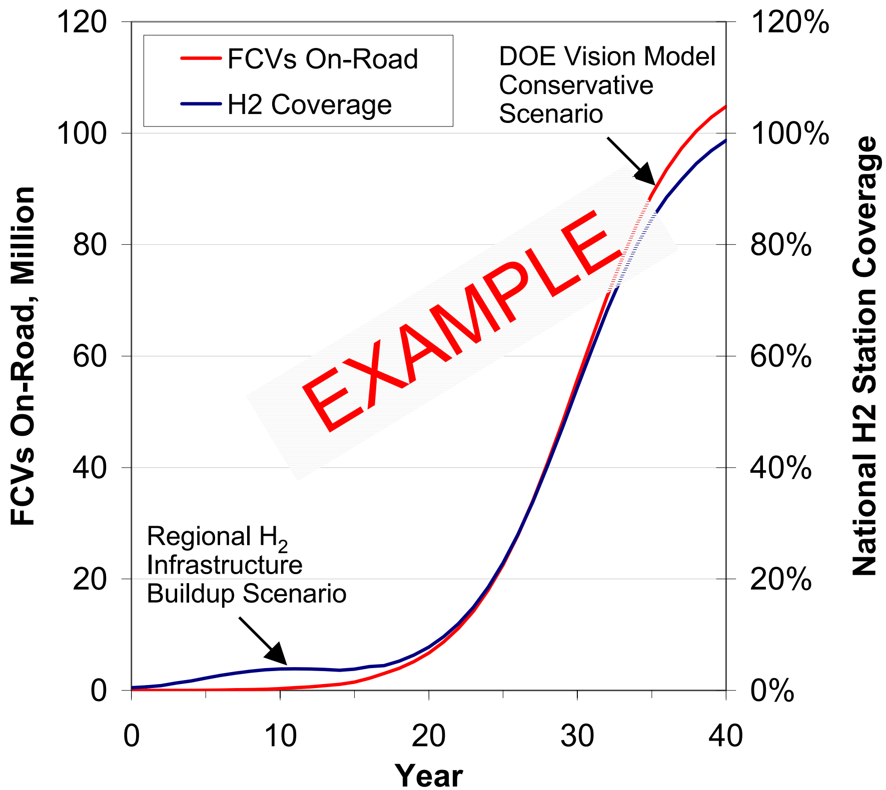


The model can also be used to track energy and environmental impacts over time.

We constructed a H_2 introduction scenario which proceeds from region to region so that regional coverage can be achieved cost effectively.

- DOE Vision Model results for the number of FCVs on-road
- Regional buildup to 10% coverage[1] in a short time (not from day 1)
  - Maximizes H_2 station capacity factors (CF)
  - CF are assumed to increase over time to 90% maximum (aggressive)
  - Region = 10 million vehicles
- National coverage takes longer and would not be uniform
  - 10% national coverage requires 12,000 new H_2 stations
- Other introduction scenarios will be constructed

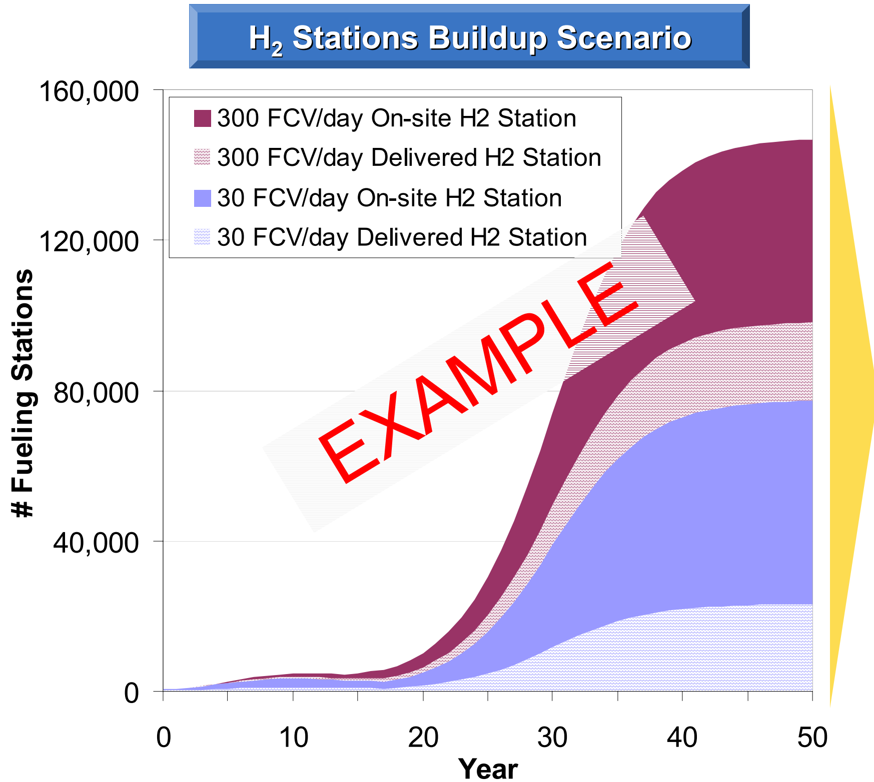
National FCV and H_2 Station Introduction

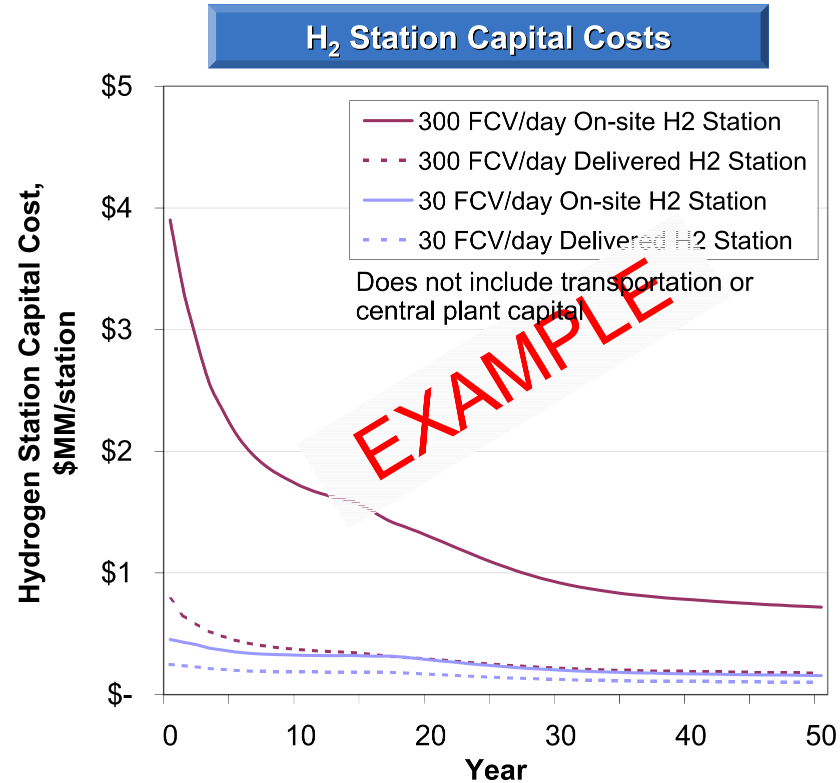


[1] Assumes 0.48 gasoline stations per 1000 vehicles based on 1997 data for convenience stores/refueling stations and truck stops which have gasoline sales of at least 50% of total established sales according to US DOE Transportation Energy Data Book (TEDB) Edition 20, 2000. Note: diesel fuel coverage is about 10%.

We assume the capital cost for H_2 fueling station equipment is reduced over time with higher production volumes (i.e. economies of scale).

- Economies of scale: intensively using expensive machinery, buying supplies in bulk for a discount, developing new and better products, etc.



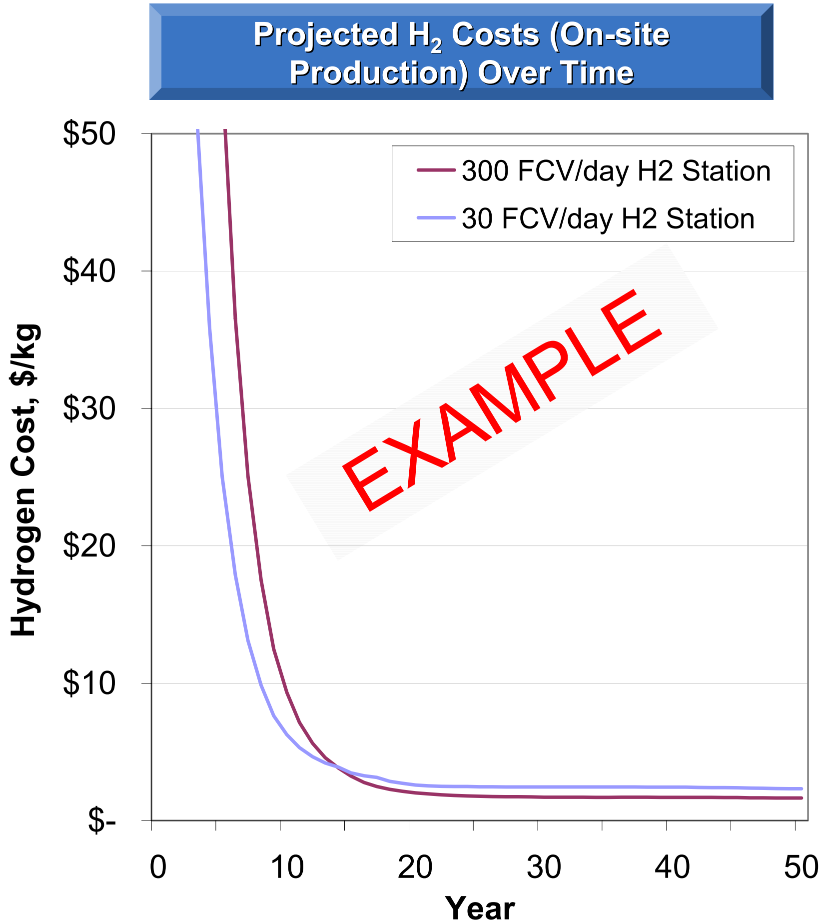


Note: On-site hydrogen production via natural gas steam reforming (SR). Delivered liquid hydrogen via tanker trucks from central SR plant. 300 FCV/day = 690 kg hydrogen per day.

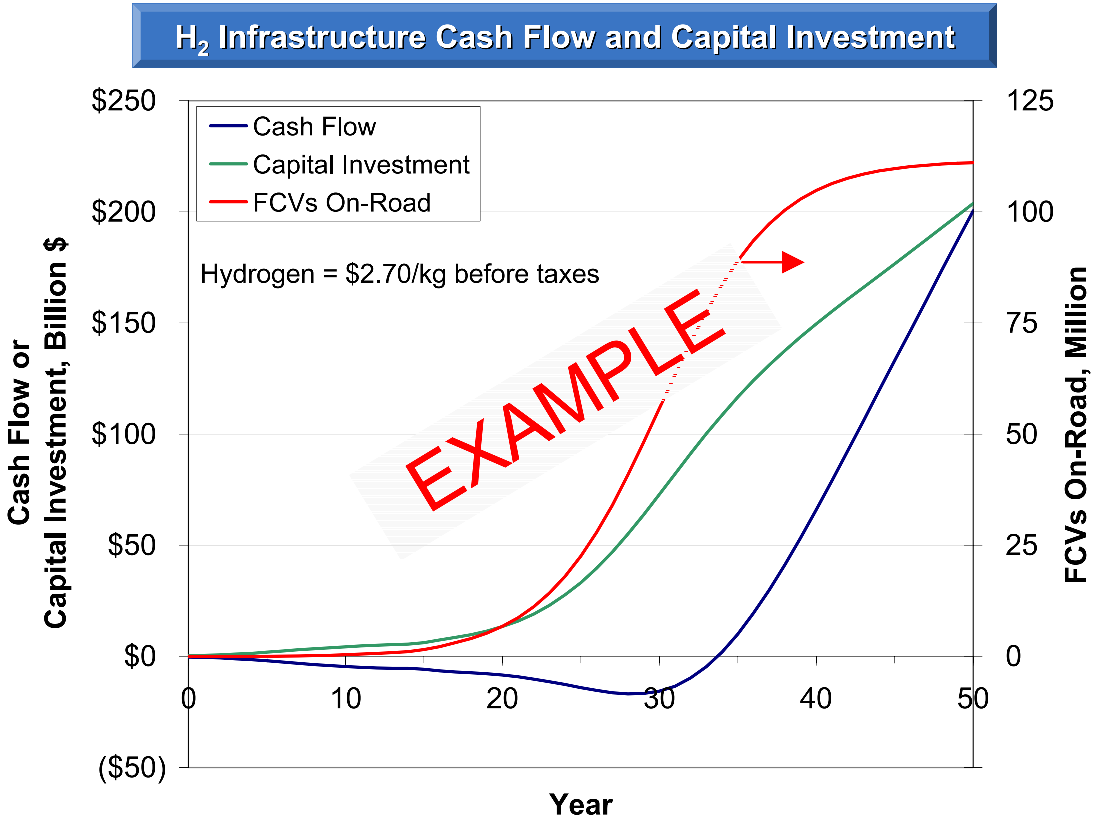
Using preliminary assumptions, H_2 production costs would ultimately reach the $2/kg projected in our previous analysis, but initial costs are high.

- Initial capital cost and utilization (capacity factors) must be improved
- A number of scenarios could help bring the initial costs down:

Utilize existing excess H_2 capacity (e.g. methanol and fertilizer plants)
FCV demonstrations and fleets (buses, government vehicles, etc)
Hydrogen ICEVs
Energy station (e.g. hydrogen for fueling and stationary power)
Alternative FCV and H_2 infrastructure introduction scenarios



Using preliminary assumptions, if H_2 were priced to provide cost-parity with conventional vehicles, break-even would be achieved in about 30 years...



In the long-run, stakeholders can turn a profit if hydrogen is sold for $2.50-$3.00/kg

- Acceptable to FCV owners if fuel economy is 2-3 times better?
- Near-term pathways are needed to improve CF and reduce capital cost

…if an initial premium of 50-100% (1.5-2x gasoline ICEV cost/mile) would be accepted, break-even may be realized in about 20 years.

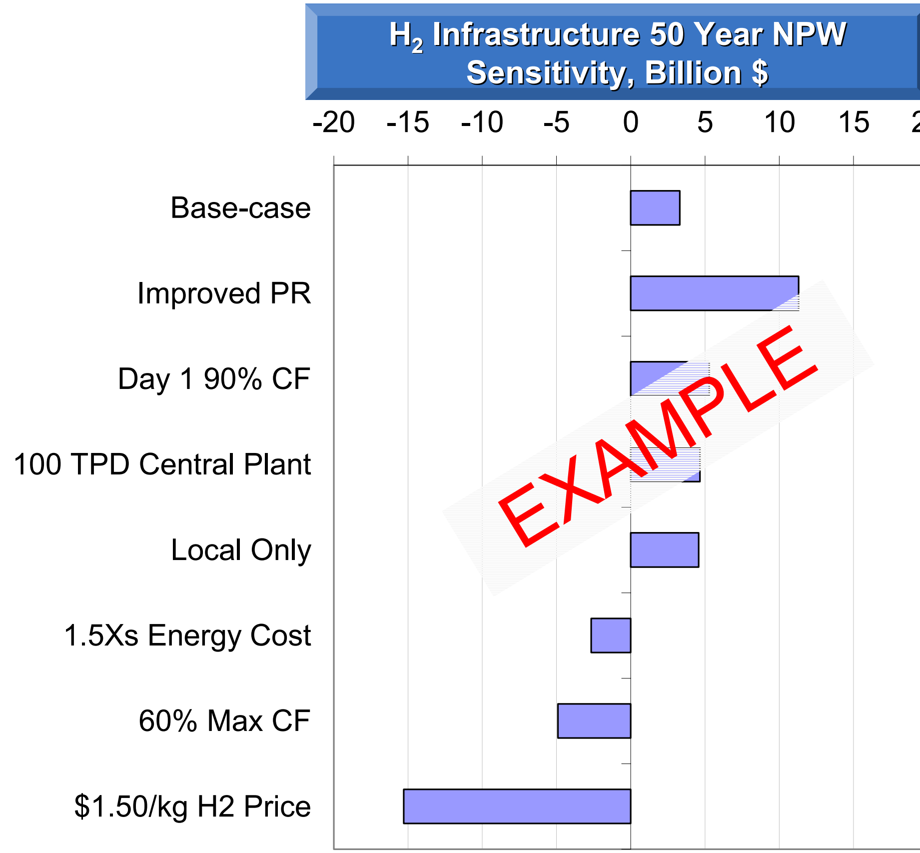
We can use the model to evaluate the sensitivity of net present worth to various input parameters.

The main drivers are:

- Hydrogen selling price - expected internal rates of return (IRR)
- Infrastructure utilization (CF)
- Production volume effects on capital cost (PR)
- Energy (i.e. natural gas) cost

Other observations:

- Local (on-site) versus central production has a smaller impact
- Tripling transportation distance negates the NPW benefits of a 3Xs larger central plant (not shown)



Once the appropriate vehicle assumptions are incorporated, we can compare the overall NPW results for various fuel and FCV types.

The preliminary assumptions used here were generated to demonstrate methodology and validate the analysis approach...

- Preliminary assumptions are based on projections of the future cost of a high efficiency hydrogen infrastructure
  - We will refine our preliminary assumptions based on discussions with stakeholders
  - Low cost pathways will be investigated in future work
- There is significant on-going work at DOE and in various industries to bring costs below those projected here
  - We did not use DOE targets
  - Using assumptions consistent with DOE target of $1.50/kg would result in a much brighter outlook
- We will conduct future work to evaluate low-cost hydrogen pathways:
  - Utilizing existing excess hydrogen capacity to reduce early capital investments, e.g. brown field expansions of ammonia and methanol plants
  - Considering the effects of FCV demos and fleets, hydrogen ICEVs, and energy stations to improve the utilization (capacity factors) of early hydrogen infrastructure

…significant additional work will be conducted to generate and vet refined assumptions for various scenarios in the final analysis.

We have meet with stakeholders and others outside of DOE to present our results/perspectives and solicit feedback on our progress.

Event	Stake-holder	Other
ASME Workshop Presentation, Rochester NY		●
Future Car Congress Presentation, Arlington VA	●	
tation, Boston MA		●
MIT Study Meeting (DOE, ANL, MIT, TAIX), Cambridge MA		●
International Hydrogen Infrastructure Group (IHIG) Presentation, Detroit MI	●	
IHIG Meeting, Cambridge MA	●	
ster, Palm Springs CA		●
	●	

We are in the process of gathering stake-holder input to define alternative introduction scenarios before evaluating overall risk for each fuel choice.

- Evaluate scenarios that could bring down the initial costs of hydrogen
  - Existing excess hydrogen, FCV demos and fleets, hydrogen ICEVs, energy stations
- Gather stakeholder input, develop additional future scenarios, and update analysis
- Validate FCV performance and cost estimates
- Evaluate the technology risk, financial exposure, and safety and regulatory risks
- Identify promising pathways to help DOE and stakeholders identify:
  - Near-term actions
  - R&D, demonstrations
  - Partnerships