H2A Central Hydrogen Production Model Users Guide
Version 1.0.10

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Background

A significant need exists for the analysis of hydrogen production and delivery technologies and systems in order to guide research and development efforts. In reviewing the public information available in this area, several common aspects of the suite of analysis efforts come to light:

- Many excellent analyses have been conducted.
- Many analyses of the same or similar routes to produce or deliver hydrogen appear on the surface to yield different results. Principal discrepancies lie in the basis and assumptions used in the analysis.

H2A, which stands for Hydrogen Analysis, was formed in 2003 to better leverage the combined talents and capabilities of analysts working on hydrogen systems, and to establish a consistent set of financial parameters and methodology for cost analyses. The foundation of H2A is to improve the transparency and consistency of the approach to analysis, to improve the understanding of the differences among analyses, and to seek better validation of analysis studies by industry. To accomplish this, a group of analysts identified the following objectives of H2A:

1. Establish a standard format and list of parameters for reporting analysis results. Do this for production, delivery, and forecourt (filling station).
2. Seek better validation of public analyses through dialog with industry.
3. Enhance understanding of the differences among current and publicly available analyses and make these differences more transparent.
4. Establish a mechanism for facile dissemination of all public analysis results.
5. Improve the understanding of the purpose of hydrogen production and delivery analyses and identify analysis gaps.
6. Work to reach consensus on specific analysis parameters for production, delivery, and forecourt.

The H2A effort has made significant progress on these objectives. This H2A Central Hydrogen Production cost analysis tool is an example of that progress.

The H2A Cost Analysis Tool

In order to address the need for transparent reporting and a consistent cost methodology, H2A developed a modeling tool to assess the minimum hydrogen selling price for central and forecourt hydrogen production technologies. This tool requests the user to define the characteristics of the process being studied, including process design, capital cost, capacity, capacity factor, efficiency, and feedstock requirements. While the tool includes agreed-upon H2A reference values for all the key financial parameters, the user is also given the opportunity to vary these parameters such as after tax internal rate of return (IRR), plant life, feedstock costs, and tax rate, to examine the technology using their own basis. The calculation part of the tool uses a standard discounted cash flow rate of return analysis methodology to determine the hydrogen selling price for the desired after tax internal rate of return (10% is the H2A reference value). More information on after tax IRR and the selection of the H2A 10% reference value, can be found on this H2A website. Other H2A parameter reference values are specified in Appendix A.

The model is set up so that the user can specify any desired plant start-up year and analysis time frame. The reference year dollars are set up as 2005 dollars. Although inflation is included in the model to properly account for tax considerations in the DCF calculations, the results are all expressed in 2005 reference year dollars. All cost input data needs to represent the plant start-up year in 2005 dollars.

The H2A analysis model uses the discounted cash flow/rate of return (DCF/ROR) analysis technique to determine a first year cost of hydrogen. Mechanistically, the model varies the first year hydrogen cost until the net present value of the cash flows, discounted at the rate of return specified in the model, is zero. This calculation is not completed automatically. Rather, the user needs to press the blue button located on the Results tab in order for the model to perform the DCF/ROR calculations.

The first year selling price calculated is equivalent to the real levelized cost of hydrogen in startup or first year dollars. In general, the nominal levelized cost of hydrogen is not calculated. However, if the inflation rate is set to zero, the first year selling calculated is also equivalent to the nominal levelized cost of hydrogen in startup or first year dollars. The resulting cost in startup or first year dollars can be inflated upward or deflated downward to give a value in another year's dollars. The H2A models deflate the start-up year hydrogen cost to the reference year specified in the Financial Parameters worksheet tab.

To set-up the DCF/ROR analysis properly, it is imperative that the user ensure that all necessary cells are filled out.

Tabs in the H2A Modeling Tool

The cells in each tab of the H2A modeling tool are color coded to show the user how the values entered are used in the tool. The color-coding convention is shown below.

COLOR CODING

Color	Meaning
(blue)	**= Calculated Cells (do not change formulas)**
(orange)	**= Input Required**
(green)	**= Optional Input; To Provide Additional Information Only**
(yellow)	**= Information Cells**

In this document, instructions on how to enter data are described in copies of the tables from the H2A cost analysis tool, in *italic text*.

Title Worksheet Tab

	Instructions:
Title:	*Enter a title for the case being analyzed and reported on.*

Authors:	*Enter the name of the original author of the analysis being entered into the H2A tool.*
Contact:	*Enter your name.*
Contact phone:	*Enter your phone number.*
Contact e-mail:	*Enter your e-mail address.*
Organization:	*Enter your company/organization name.*
Date Spreadsheet was Last Modified:	*Enter the most recent date that the spreadsheet was last modified.*
Web site:	*Enter the web site where additional information can be found for the case being entered into the H2A tool, including reports on the original analysis, if applicable.*

Reporting Spreadsheet Change History:	
Date spreadsheet created / modified	Name
	These spaces should be used to keep a log of changes made to the case studied.

Description Worksheet Tab

Purpose:

Enter a brief summary of the purpose of the analysis.

System Description:

Enter a description of how the plant operates in terms of production, storage, delivery/dispensing strategy. Briefly describe the technology being studied.

Analysis Methodology Summary:

Enter a summary of the analysis methodology in terms of developing the plant operating strategy and obtaining/calculating cost and performance inputs.

Plant Ownership and Entity Type Assumptions:

Enter the plant ownership and entity type assumed for the financial inputs.

References:

This space should be used to provide full references for the SRS input.

Feedstock and Utility Prices Worksheet Tab

The feedstock and utility prices worksheet is used by the H2A cash flow modeling tool to calculate feedstock costs throughout the analysis period. The Cash Flow Analysis Worksheet pulls information from this tab and the Cost Inputs Worksheet. If the user would prefer to use their own estimations of feedstock and utility prices, they should enter them in the Cost Inputs Worksheet under *Variable Production Costs*. No user input is required on the Feedstock and Utility Prices Worksheet.

Projections for the following feedstocks and utilities were derived from the *Annual Energy Outlook 2004* (AEO) developed by the U.S. Department of Energy's Energy Information Administration (EIA) available URL: http://www.eia.doe.gov/oiaf/aeo/index.html:

- Commercial Natural Gas
- Industrial Natural Gas
- Electric Utility Natural Gas
- Commercial Electricity
- Industrial Electricity
- Electric Utility Steam Coal
- Diesel Fuel
- Gasoline
- Biomass

EIA makes projections for every year between 2000 and 2025. These prices are provided in constant 2002 dollars per million (MM) British Thermal Unit (Btu) and in constant 2002 $ per physical unit (e.g. $/ton of coal, $/cubic foot of gas, etc.). Note that EIA does not provide the biomass prices in their published *AEO* reports, but the projected biomass prices were obtained by special request.

AEO prices in dollars per physical unit are based on standard thermal conversion factors available in Appendix H of the *AEO* publication. These 2002$ *AEO* values were converted to reference year $ using GDP Implicit Price Deflator available from EIA in *Annual Energy Review* 2003, Table A-20. They were converted from Btus to Gigajoules (GJ) using 1.055 GJ/MMBtu.

For the period between 2025 and 2035, the values were simply extrapolated using the 2015-2025 growth, i.e., the ratio of the EIA 2025 value to the EIA 2015 value was multiplied by the EIA 2025 value to obtain the 2035 value. Values between 2025 and 2035 were interpolated.

For the period between 2035 and 2070, for all feedstocks and utilities listed above except for biomass, the prices were extrapolated using price projections from the MiniCAM model developed by Pacific Northwest National Laboratory (PNNL).[1] The specific projections used are

[1] MiniCAM models the global energy and industrial system, including land use, in an economically consistent global framework. MiniCAM is referred to as a *partial equilibrium model* in that it explicitly models specific markets and solves for equilibrium prices only in its areas of focus: energy, agriculture and other land uses, and emissions. The supply and demand behaviors for all of these markets are modeled as a function market prices, technology characteristics, and demand sector preferences. Market prices, including feedbacks between energy markets, are adjusted until supply and demand for each market good are equal. At this equilibrium set of prices, production levels, demand, and market penetration are mutually consistent. For example, gas production will increase with a rise in gas price, which drives a decrease in gas demand. In equilibrium, these market clearing prices (e.g., the prices of gas, coal, electricity, etc.) are by definition internally consistent with all other prices.

found in the turquoise shaded area of the spreadsheet, in rows 158 through 164. The projected prices from MiniCAM were converted into ratios (rows 145-153) that were applied to the values derived from EIA. Wellhead gas price ratios from Mini-CAM were applied to all sectoral gas prices except utilities, which are separately projected. Average electricity price growth rates from Mini-CAM were applied to all sectoral electricity prices, and crude oil price growth rates were applied to diesel fuel and gasoline.

The biomass prices for the projected prices were based on a review of literature. Biomass prices shown for years 2001 through 2009 are the same as the EIA value for 2010. For the post-2025 biomass prices: The value for 2035 was chosen based on a review of the literature, which indicated a price of $2.50/MMBtu delivered dry English ton (in 2000$) was a reasonable mid-range projection. Values for the 2026 through 2034 were interpolated from the 2025 and 2035 values. The value of $5.00/MMBtu delivered dry English ton in 2065 was based on judgment. An EIA paper by Zia Haq entitled, "Biomass for Electricity Generation" (available from EIA's website) indicates that about 7 quads of biomass per year would be available if the price rose to $5/MMBtu.Physical Property Data Worksheet

This tab contains H2A data for many of the feedstocks and fuels that can be used to produce hydrogen. For consistency, analyses being done using the H2A modeling tool should use the values shown in this worksheet tab.

Physical Property Data Worksheet Tab

Several energy sources are being considered as feedstocks for production of hydrogen. For GREET simulations of carbon emissions and evaluations of hydrogen production processes, physical properties of these feedstocks are needed. This memo documents physical properties of several feedstocks based on Argonne's research and inputs from Directed Technologies, National Renewable Energy Laboratory, and Parsons. Although feedstock properties can be different for the same feedstock from different production or consumption sites, it is intended here that national average properties be summarized for the H2A group. In this summary, physical properties for the following feedstocks are presented.

1) Biomass ─ Switchgrass
2) Biomass ─ poplar
3) Coal

And in parallel, all supply and demand behavior is consistent with assumptions about the key model parameters and drivers, including the following: (1) technology characteristics (from production to end-use), (2) fossil fuel resource bases (cost-graded resources of coal, oil, and natural gas); (3) renewable and land resources (hydroelectric potential, cropland, etc.); (4) population and economic growth (drivers of demand growth); (5) policies (about energy, emissions, etc.). The MiniCAM is based on three end-use sectors (buildings, industry, transportation) and a range of energy supply sectors, including fossil-fuels, biomass (traditional biomass such as use of wood for heat, and modern biomass that can be used as a fuel for electricity production or as a feedstock for bio-fuels or hydrogen production), electricity, hydrogen, and synthetic fuels. For electricity generation, the model's technological detail covers generation from coal, oil, natural gas, biomass, hydroelectric power, fuel cells, nuclear, wind, solar photovoltaics, electricity storage (e.g., coupled with production of electricity using solar and wind generation), and exotic technologies such as space solar and fusion.

4) Natural gas
5) Ethanol
6) Methanol
7) Gasoline (without oxygenate)
8) Conventional diesel
9) Low-sulfur diesel
10) Gaseous hydrogen
11) Liquid hydrogen

Among the 11 feedstocks and fuels, the first six are feedstocks for hydrogen production either at central plants (in the cases of switchgrass, poplar, coal, and natural gas) or at forecourt (in the cases of natural gas, ethanol, and methanol). Gasoline and diesel are presented here for calculating energy and emissions of well-to-pump activities in spreadsheet models developed through the H2A effort. Gaseous and liquid hydrogen are presented here for conversion between feedstocks and hydrogen.
A literature search, together with summary of what is already in the GREET model, was conducted to obtain the following physical properties for each of the above feedstocks:

1) Lower heating value
2) Higher heating value
3) Density
4) Carbon content by weight
5) Hydrogen content by weight.

For switchgrass, woody biomass, and coal we also investigated the typical moisture content. The literature search revealed that these physical properties have range of values. Mean values, as well as low and high values, were computed from these ranges and are presented here. Densities are provided for ethanol, methanol, and natural gas to facilitate conversion from their volumetric units to weight.

The literature survey provided only the higher heating value for biomass and coal. In H2A and GREET simulations, energy balance calculations will be conducted with lower heating values, as in many other studies. The lower heating values for switchgrass, wood, and coal were computed by using the following general relationship between higher and lower heating values (Himmelblau 1996; SAE 1998).

$$LHV = HHV - 91.23 \times H_2$$

Where,

LHV = Lower heating value in Btu/lb

HHV = Higher heating value in Btu/lb

H_2 = Hydrogen fraction by weight in percentage

References for the Physical Property Data Worksheet

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Rutkowski, M.D., 2003, *Plant Design Basis, an H2A Core Group Memorandum,* Parsons Infrastructure and Technology Group, Inc., Reading, PA.

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Performance Assumptions Worksheet Tab

Energy efficiencies for individual process steps (add rows as appropriate)	**Values**	**Basis**	**Source**
Plant Feedstock Consumption (kJ of feedstock (LHV) per kg of H2)	*Enter the total amount of feedstock consumed by the process, expressed in lower-heating value, per kg of H2 out of the plant*	*Provide information on how the value was calculated and which units the value is in.*	*Enter the reference for the energy efficiency values entered in this table. However, note that full references for the data sources should be documented in the Description tab (if any).*

Plant Hydrogen Efficiency (%)	*Enter the total hydrogen energy in LHV out of the plant divided by the total energy of all feedstocks, materials, and electricity into the plant.*		
Electricity Consumption (kWhe per kg of H2)	*Enter the total kWh of electricity consumed per kg of H2 produced*		
H2 Leaks from System (%)	*Enter the % of total hydrogen produced that is lost from the system due to hydrogen leakage*		
Process water consumption (L/kg of H2)	*Enter the total amount of water that is consumed by the plant*		

Energy efficiencies for individual process steps (add rows as appropriate)	**Value**	**Basis**	**Source**
This table should be used to record the single-step (e.g., hydrogen production, purification, storage) energy inputs and efficiencies of the plant. Energy inputs should be given in terms of lower heating values of each feedstock and process energy input per kilogram of hydrogen output from the step. Efficiencies should be given in terms of the lower heating values of the hydrogen output divided by all feedstock and process energy inputs from the step. The basis and data source for the feedstock and process energy inputs should also be recorded.		*Provide information on how the value was calculated and which units the value is in.*	*Enter the reference for the energy efficiency values entered in this table. However, note that full references for the data sources should be documented in the Description tab (if any).*

HYDROGEN PRODUCT CONDITIONS		**Comments**	**PEMFC Spec. (1)**
This table should be used to record the hydrogen product conditions from the plant. The FreedomCar PEM fuel cell specification is given as a reference point. Note: a range or maximum values can be used, and noted in the comments column.			
Pressure (psig)			
% Hydrogen			98 minimum
$C0_2$ (ppm)			< 100
CO (ppm)			< 1
Sulfer (ppb)			< 10

Ammonia (ppm)			< 1
Non-methane hydrocarbons (ppm)			< 100
Total of Oxygen, Nitrogen and Argon (%)			< 2
Water (%)			
Other (*specify*)			

Process Flowsheet Worksheet Tab

Please insert a process flow diagram (PFD) from another program (i.e. ASPEN Plus ©, MS Word), or draw a PFD. This PFD should include the major components in the process, as well as clearly numbered streams. The numbered streams should correspond with the streams shown on the Stream Summary tab. The detail of the PFD should be representative of the level of detail that went into the analysis.

Stream Summary Worksheet Tab

Please insert a stream summary from another program (i.e. ASPEN Plus ©, HySIS) or manually enter pertinent stream data. The stream numbers in the stream summary should correspond to the streams shown in the process flow diagram that is shown on the previous tab. The stream summary should include the following information for each stream: pressure (atm), temperature (°C), total stream flowrate (kg/hr and/or Nm3/hr and/or kmol/hr), total stream enthalpy, and component mole/mass fractions.

Financial Inputs Worksheet Tab

	Base Case	**H2A Guidelines**	**Values in Reference Study**	**Comments**	**Data source**
Reference $ Year	*Enter the desired reference year for the analysis. All capital and operating costs should be stated in terms of the reference year dollars. If the original cost data you are using are expressed in earlier- or later-year dollars (e.g., 1995 dollars or 2002 dollars), you should inflate them or deflate them to reference year dollars using some standard approach, such as using a GDP Implicit Price Inflator Index. This method is used by the U.S. Department of Energy's Energy Information Administration (EIA), and the inflators (as well as other macroeconomic variables that could alternatively be used) are available from Short Term Energy Outlook, Table A.2 at*	Half-decade increments, beginning with the most recent half-decade (e.g., 2005)			

	http://www.eia.doe.gov/emeu/steo/pub/a2tab.html For example, using the GDP Price Inflator, we can convert values expressed in 2002 dollars to 2000 dollars by dividing the values in 2002 dollars by 1.061H2A guidelines recommend that the reference year be consistent in half-decade increments (i.e., 2000, 2005, etc.).				
Assumed Start-up Year	*Enter the first year of partial or full operation*				
After-Tax Real IRR (%)	*Enter the desired after-tax real internal rate of return. The IRR represents the cost of capital after taxes, stated in real terms (i.e., excluding the effect of inflation) and strongly affects the results calculated by the discounted cash flow spreadsheet. Although actual projects would probably be financed with a combination of debt and equity, firms typically assume 100% equity financing for paper studies and analyses. The spreadsheet does include an option for including some portion of debt financing, in which case the user specifies the debt financing rate. Therefore, the IRR entered into the spreadsheet should represent a return on equity (ROE) value. The base case after-tax, real IRR that is recommended for government analysis is 10% (see paper entitled, "An Approach to Handling Internal Rate of Return for the H2A Analysis"). Note that the calculations will result in a levelized H_2 cost that is equal to the capital and operating cost stream, discounted to its net present value terms using the IRR.*	10%			
Depreciation Type (MACRS, Straight Line)	*Select the desired depreciation schedule from the pull-down menu in the cell. The Straight Line method depreciates (for tax purposes) the capital costs evenly over the tax life of the investment (see cell B15). MACRS is an IRS convention that allows capital to be depreciated on an accelerated schedule, allowing the owner to take more tax deductions earlier in the depreciation period, thus lowering the net present value of the cost of the plant (compared to when straight-line depreciation is used). If MACRS is chosen, the annual depreciation factors are based on the recovery period, or depreciation schedule length, entered in the following row. If the chosen*	MACRS			

	recovery period is 3, 5, 7, or 10 years, MACRS follows a 200% double-declining balance schedule. If the recovery period is 15 or 20 years, MACRS follows a 150% double-declining balance schedule. The MACRS method changes to the straight-line method once it yields a higher depreciation amount. For more information, see section 21 – Depreciation Worksheet Tab.				
Depreciation Schedule Length (No. of Years)	*Select the desired depreciation schedule length from the pull-down menu in the cell. This value should be chosen based on IRS rules for the type of equipment being installed. If no IRS category exists, estimate the depreciation period based on IRS rules about similar types of equipment. For the analysis undertaken by HFCIT within the H2A group, a 20-year depreciation period was assumed for central hydrogen production plants, and a 7-year period was assumed for forecourt plants.*	20			
Analysis Period (years)	*Enter the desired number of years for the cash flow analysis. If comparing two different projects/technologies, it is best to use the same analysis period in the two spreadsheets so that you compare them on a common basis.*	40			
Plant Life (years)	*Enter the desired number of years that the plant will be operating. This should be equal to the "typical" lifetime of the process being studied, after which it is likely to need replacement or to undergo a major refurbishment. In most cost analyses, it is best to choose an analysis period that is equal to the plant lifetime; an exception might be when conducting a comparative analysis of plants with unequal plant lifetimes. In that case, a common analysis period should be chosen; calculations can be equalized using replacement costs or salvage values.*	40			
Assumed Inflation Rate (%)	*Enter the assumed inflation rate for the escalation of prices (NOTE: this is not the same as the discount rate, which is expressed in the internal rate of return). Over the time period between 1926 and today, the average compound annual rate of inflation (based on the Consumer Price Index compiled by the U.S. Bureau of Labor Statistics, Washington) has been about 3% (based on data from*	1.90%			

	Stocks, Bonds, Bills, and Inflation 2003 Yearbook, Ibbotson Associates, 2003). Over the past decade (1993 -2002), the rate was 2.5%. Projections of discount rates with and without inflation are made in Circular No. A-94 – Appendix C by the Office of Management and Budget (OMB). The 30-year projection of inflation in the Appendix C (dated 10/14/03) was 1.9% (calculated by subtracting the 3.2% real discount rate from the 5.1% nominal discount rate). The inflation rate will be used to put the cash flows in nominal terms so that tax effects, which are based on nominal dollars, can be accurately reflected in the final results.				
State Income Taxes (%)	*Enter the state income tax rate.*	6%			-
Federal Income Taxes (%)	*Enter the federal income tax rate. Note: the cash flow methodology assumes a corporate rate structure, so federal income taxes are refunded for years in which the net income is less than zero.*	35%			-
Effective Tax Rate (%)	0.0%				-
Design Capacity at 100% Capacity (kg of H2/day)	-				
Operating Capacity Factor (%)	*Enter the percentage of time that the plant will be producing product during the year. This parameter includes down-time for repairs and maintenance, as well as turn-down.*	Varies according to case			
Plant Output (kg H2/day)	-				
Plant Output (kg H2/year)	-				
% Equity Financing	*Enter the desired percentage of the initial capital investment that will be financed with equity financing at the desired IRR, as opposed to that which will be financed using debt/loans.*	100%			
% Debt Financing	100%	0%			
Debt Period (years)	*Enter the time period (in years) for any loan that is taken to finance capital, as shown in the previous cell.*	N/A; zero debt assumed in H2A guidelines			
Interest Rate on Debt, if applicable (%)	*Enter the interest rate to be paid on loans taken to finance capital investment. This rate is usually lower than the equity rate. The interest on debt is deducted for tax purposes.*	N/A; zero debt assumed in H2A guidelines			

Length of Construction Period (years)	*Enter the number of construction years prior to operation of the plant. Model allows for a maximum of four years. You may also enter zero (0), if you want to assume instantaneous construction, in which case the capital costs will be incurred in the start up year. If a non-zero value is entered, the construction costs will be spread over the specified time period based on the fractions entered in the following cells.*	Varies according to case			
% of Capital Spent in 1st Year of Construction	*Enter the percentage of the capital costs that will be spent in the first year of construction. If the length of the construction period is only one year, this value must be equal to 100%. If there are no construction years, the value in this cell can be zero.*	Varies according to case			
% of Capital Spent in 2nd Year of Construction	*If the construction period is two years or more, enter the percentage of the capital costs that will be spent in the second year of construction. The total between these cells must be equal to 100%. Uneven amounts of spending on capital during the construction years is allowed.*	Varies according to case			
% of Capital Spent in 3rd Year of Construction	*If the construction period is three years or more, enter the percentage of the capital costs that will be spent in the third year of construction. The total between these cells must be equal to 100%. Uneven amounts of spending on capital during the construction years is allowed.*	Varies according to case			
% of Capital Spent in 4th Year of Construction	*If the construction period is four years, enter the percentage of the capital costs that will be spent in the fourth year of construction. The total between these cells must be equal to 100%. Uneven amounts of spending on capital during the construction years is allowed.*	Varies according to case			
Start-up Time (years)	*Enter the number of years during which the plant does not operate at the specified capacity factor.*	Varies according to case			
% of Revenues During Start-up (%)	*Enter the percentage of the normal operating revenues that will be generated during the start-up period.*	Varies according to case			
% of Variable Operating Costs During Start-up (%)	*Enter the percentage of the normal variable operating costs that will be incurred during the start-up period. Variable operating costs include feedstock, utility, water, chemicals and other specified inputs, the quantities of which depend on the capacity factor of*	Varies according to case			

	the plant (cell B23). See the "Cost Inputs" tab for a more complete explanation of the components of variable operating costs. Note: in the current version of the spreadsheet, the user cannot specify a value greater than 100% to reflect additional variable costs during start-up.				
% of Fixed Operating Costs During Start-up (%)	*Enter the percentage of the normal fixed operating costs that will be incurred during the start-up period. Fixed operating costs include cost of plant staff, rent, property taxes, and equipment for maintenance and repairs (see the "Cost Inputs" tab for a more complete explanation of the components of fixed operating costs. Note: in the current version of the spreadsheet, the user cannot specify a value greater than 100% to reflect additional fixed costs during start-up.*	Varies according to case			
Salvage Value of Capital (% of Total Capital Investment)	*Enter the value of the capital equipment at the end of the plant life, as a percentage of the initial total capital investment. This feature of the spreadsheet can be also used to deal with comparative analyses between two plants with unequal plant lifetimes where the same analysis time period is used. If you do not want to specify any salvage value, enter zero (0).*	10%			
Decommissioning Costs (% of Total Capital Investment)	*Enter the decommissioning costs that will be incurred at the end of the plant life, as a function of the total capital investment.* The value chosen should reflect the cost of returning the site to the condition it was in before construction of the plant.	10%, equal to salvage value			

Cost Inputs Worksheet Tab

CAPITAL INVESTMENT (Inputs REQUIRED in Reference Year, 2005 $)							
Major pieces/systems of equipment	**Uninstalled Costs**	**Installation Cost Factor**	**Installed Cost**	**Scaling Factor Exponent**	**Size Range through which Scaling Factor Exponent is Applicable**	**Comments**	**Data Source**

Capital Investment Table:

- Used to report information on the cost of major pieces of capital equipment.
- Column labeled, "Major pieces/systems of equipment"
  - *Enter the names of the pieces of process equipment for which you will be entering a capital cost. For greater transparency, use one line for each piece of equipment and avoid combining pieces into plant sections.*
- Column labeled, "Uninstalled Costs"
  - *Enter the cost of each piece of process equipment, as purchased from the manufacturer/supplier.*
  - *This cost should include profit to the manufacturer, and not represent the raw material and manufacturing cost.*
  - *Costs should be entered on a reference year-dollar basis. If the original cost data you are using are expressed in earlier- or later-year dollars (e.g., 1995 dollars or 2002 dollars), you should inflate them or deflate them to the reference year dollars using some standard approach, such as using a GDP Implicit Price Inflator Index. This method is used by the U.S. Department of Energy's Energy Information Administration (EIA), and the inflators (as well as other macroeconomic variables that could alternatively be used) are available from Short Term Energy Outlook, Table A.2 at* http://www.eia.doe.gov/emeu/steo/pub/a2tab.html
- Column labeled, "Installation Cost Factor"
  - *Enter the percentage of the purchased equipment cost that reflects the cost of installing it.*
- Column labeled, "Installed Cost"
  - *Enter the total installed cost of each piece of equipment.*
- Column labeled, "Scaling Factor Exponent"
  - *For each piece of equipment, enter the value of the scaling factor exponent that can be used to vary the cost of the capital equipment as a function of plant size, according the equation:*

    $$Cost_a = Cost_b * (Size_a/Size_b)^x$$
  - *Version 1.0 of the H2A cash flow model does not allow for automatic scaling of equipment costs, although future releases will.*
- Column labeled, "Size Range through which Scaling Factor Exponent is Applicable"
  - *Enter the size range (in kg of hydrogen capacity) for which the previously entered exponent is applicable, for each piece of equipment.*
  - *Version 1.0 of the H2A cash flow model does not allow for automatic scaling of equipment costs, although future releases will.*
- Column labeled, "Comments"
  - *Enter any comments that add to the understanding of the entries for each piece of process equipment.*

- Column labeled, "Data Source"
    - *Provide documentation on the source of the costs entered for each piece of process equipment.*
    - *Sources may include scientific literature, publicly-available reports, and presentations, or process models, e.g., ASPEN* Plus ©

Total Direct Capital Investment Table:

	Base Case:	Comments:	Data source:	Information:
TOTAL DIRECT CAPITAL INVESTMENT (DEPRECIABLE)	*This value is calculated from values entered above. Costs should be entered in reference year $,as noted above.*	*Enter comments that will enhance documentation of data being entered*	*Provide documentation on the sources of all data being entered.*	**This is not calculated from cells above and must be entered.**
Indirect Depreciable Capital Costs				
Site preparation ($)	*Enter the reference year $ cost of preparing the site for the facility.*			
Engineering & design ($)	*Enter engineering and design costs. These costs are not to include labor costs during plant operation.*			
Process contingency ($)	*Enter the amount of process contingency, defined as the adjustment to the total initial capital cost such that the result incorporates the mean or expected overall performance.*			
Project contingency ($)	*Enter the amount of project contingency, defined as the adjustment to the total initial capital cost such that the result represents the mean or expected cost value. Periodic replacement capital is included in the Replacement Capital worksheet tab.*			
Other ($)	*Enter other depreciable costs.*			
One-time licensing fees ($)	*Enter any costs for up-front licensing fees.*			

Up-front permitting costs ($)	*Enter any costs for up-front permitting costs.*			
TOTAL DEPRECIABLE CAPITAL COSTS ($)	$0			
Other (Non-Depreciable) Capital				
Land required (acres)	*Enter the number of acres required for the process facility. This acreage should not include land used in the production of feedstock, which will be reflected in the price of the feedstock.*			
Cost of land ($/acre)	*Enter the cost of the purchased land.*			**Without a reference to a case-specific value, use $5,000/acre as the suggested H2A standard for central plants.**
Total land costs ($)	$0			
Other *(add details as needed in rows below)*	*Enter other non-depreciable costs in the following rows.*			
TOTAL NONDEPRECIABLE CAPITAL COSTS	$0			
TOTAL CAPITAL INVESTMENT	$0			

Operating and Maintenance Costs (Inputs REQUIRED in Reference Year $)				
	Base Case:	**Comments:**	**Data source:**	**Information:**
Fixed O&M Costs				

Total plant staff (number of FTEs employed by plant)	*Enter the total number of full-time equivalent employees employed by the plant.*	*In this column, enter comments that will enhance documentati on of data being entered*	*In this column, provide documentati on on the sources of all data being entered.*	
Burdened labor cost, including overhead ($/man-hr)	*Enter the percentage of the labor cost that should be assumed for general and administrative costs.* In addition to operating and engineering staff, t*his would include things such as marketing and sales, and other outside the plant costs needed to support the business.*			**Without a reference to a case-specific value, use $50/hour as the suggested H2A standard for central plants.**
Labor cost, $/year	$0			
G&A rate (% of labor cost)	*Enter the percentage of the labor cost that should be assumed for general and administrative costs.*			**Without a reference to a case-specific value, use 20% of total labor cost as the suggested H2A standard for central plants.**
G&A ($/year)	$0			
Property tax and insurance rate (% of total initial capital costs)	*Enter the percentage of total initial capital costs that can be estimated to make up the property tax and insurance costs. Note that this is not an overlap with state and federal taxes entered on the Financial Inputs worksheet tab.*			**Without a reference to a case-specific value, use 2% of the total initial capital as the suggested H2A standard.**
Property taxes and insurance ($/year)	$0			
Rent or lease ($/year)	*Enter the amount paid in rent and lease charges per year.*			
Licensing, permits, and fees ($/year)	*Enter the yearly costs for technology licensing, environmental and operating permits, and fees. Note that this is a per-year charge; one-time licensing charges are entered in the indirect depreciable capital costs section.*			
Material costs for maintenance and repairs ($/year)	*Enter the yearly cost of materials required for annual maintenance and repairs. Note that this is not the same as replacement capital expenditures, which are entered on the next worksheet tab.*			
Other fees ($/year)	*Enter other yearly fees.*			

Other fixed O&M costs ($/year)	*Enter other yearly fixed operating and maintenance costs.*			
TOTAL FIXED O&M COSTS ($/year, year 2005 basis), excluding materials	$0			
VARIABLE PRODUCTION COSTS (at 100% capacity, start-up year cost in reference year, (2005) dollars)				
	Base Case:	**Comments:**	**Data source:**	**Information:**
Feedstock Costs				
Type of **electricity** feedstock used	*Select from the pull-down menu in this cell. (Note: Electricity is listed here as a feedstock for electrolysis cases only. All standard use of electricity to run pumps etc. should be placed in the utility section below. Only use this cell for electrolysis cases.)*			
Use H2A electricity feedstock cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter electricity feedstock cost if NO is selected above ($/kWh)	*If the user does not wish to use the H2A projections for yearly electricity costs, select "no" in the cell above and enter an electricity cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Electricity feedstock consumption (kWh/kg H2)	*Enter the amount of electricity consumed by the plant, per kg of hydrogen produced.*			
Electricity feedstock cost in startup year ($/kWh)				**Data taken from Feedstock and Utility cost sheet**
Electricity feedstock cost in startup year ($/year)	$0			
Type of **natural gas** feedstock used	*Select from the pull-down menu in this cell.*			
Natural gas feedstock energy content, LHV, if standard H2A value is not desired (GJ/Nm3)	*Leave this cell blank if the standard H2A value of 0.038 GJ/Nm3 is desired. Otherwise, enter a user-defined value, with the units*			**Leave blank if the H2A standard value of is .038 GJ/Nm3 is desired**

	of GJ/Nm3.			
Use H2A natural gas feedstock cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter natural gas feedstock cost if NO is selected above ($/Nm3)	*If the user does not wish to use the H2A projections for yearly natural gas costs, select "no" in the cell above and enter a natural gas cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Natural gas feedstock consumption (Nm^3/kg of H2)	*Enter the amount of natural gas consumed by the plant, per kg of hydrogen produced.*			
Natural gas feedstock cost in startup year ($/Nm3)				**Data taken from Feedstock and Utility cost sheet**
Natural gas feedstock cost in startup year ($/year)	$0			
Biomass feedstock consumption (kg/kg of H2)	*Enter the amount of biomass consumed by the plant, per kg of hydrogen produced.*			
Use H2A biomass feedstock cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter **Biomass feedstock** Cost if NO is Selected Above ($/kg)	*If the user does not wish to use the H2A projections for yearly biomass costs, select "no" in the cell above and enter a natural gas cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Biomass feedstock cost in startup year ($/kg)				**Data taken from Feedstock and Utility cost sheet**
Biomass feedstock cost in startup year ($/year)	$0			
Coal feedstock consumption (kg/kg of H2)	*Enter the amount of coal consumed by the plant, per kg of hydrogen produced.*			
Coal feedstock energy content, LHV, if standard H2A value is not desired (GJ/ metric tonne)	*Leave this cell blank if the standard H2A value of 22.38 GJ/metric tonne is desired. Otherwise, enter a user-defined value, with the units of GJ/metric tonne.*			**Leave blank if the H2A standard value of 22.37 GJ/metric tonne is desired**
Use H2A coal feedstock cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			

Enter coal feedstock cost if NO is selected above ($/kg)	*If the user does not wish to use the H2A projections for yearly coal costs, select "no" in the cell above and enter a coal cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Coal feedstock cost in startup year ($/kg)				**Data taken from Feedstock and Utility cost sheet**
Coal feedstock cost in startup year ($/year)	$0			
Diesel fuel feedstock consumption (L/kg of H2)	*Enter the amount of diesel consumed by the plant, per kg of hydrogen produced.*			
Diesel feedstock energy content, LHV, if standard H2A value is not desired (GJ/liter)	*Leave this cell blank if the standard H2A value of 0.038 GJ/liter is desired. Otherwise, enter a user-defined value, with the units of GJ/liter.*	***Is this right? The 0.038 is the same number as for ng.		**Leave blank if the H2A standard value of 0.038 GJ/liter is desired**
Use H2A diesel feedstock cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter diesel feedstock cost if NO is selected above ($/L)	*If the user does not wish to use the H2A projections for yearly diesel costs, select "no" in the cell above and enter a diesel cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Diesel fuel feedstock cost (with taxes) in startup year ($/L)				**Data taken from Feedstock and Utility cost sheet**
Diesel feedstock fuel cost (with taxes) in startup year ($/year)	$0			
Methanol feedstock consumption (L/kg of H2)	*Enter the amount of methanol consumed by the plant, per kg of hydrogen produced.*			
Use H2A methanol feedstock cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter methanol feedstock cost if NO is selected above ($/L)	*If the user does not wish to use the H2A projections for yearly methanol costs, select "no" in the cell above and enter a methanol cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Methanol feedstock cost in startup year ($/L)				**Data taken from Feedstock and**

				Utility cost sheet
Methanol feedstock cost in startup year ($/year)	$0			
Ethanol feedstock consumption (L/kg of H2)	*Enter the amount of ethanol consumed by the plant, per kg of hydrogen produced.*			
Use H2A ethanol feedstock cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter ethanol feedstock cost if NO is selected above ($/L)	*If the user does not wish to use the H2A projections for yearly ethanol costs, select "no" in the cell above and enter a ethanol cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Ethanol feedstock cost in startup year ($/L)				**Data taken from Feedstock and Utility cost sheet**
Ethanol feedstock cost in startup year ($/year)	$0			
Process water feedstock consumption (L of water/kg of H2)	*Enter the amount of process water consumed by the plant, per kg of hydrogen produced.*			
Use H2A process water feedstock cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter process water feedstock cost if NO is selected above ($/L)	*If the user does not wish to use the H2A projections for yearly process water costs, select "no" in the cell above and enter a process water cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Process water feedstock cost in startup year ($/L)				**Data taken from Feedstock and Utility cost sheet**
Process water feedstock cost in startup year ($/year)	$0			
Demineralized water feedstock consumption (L of demineralized H2O/kg of H2)	*Enter the amount of demineralized water consumed by the plant, per kg of hydrogen produced.*			
Use H2A demin. water feedstock cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			

Enter demin. water feedstock cost if NO is selected above ($/L)	*If the user does not wish to use the H2A projections for yearly demineralized water costs, select "no" in the cell above and enter a demineralized water cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Dimineralized water feedstock cost in startup year ($/L)				**Data taken from Feedstock and Utility cost sheet**
Demineralized water feedstock cost in startup year ($/year)	$0			
Other feedstock	*Enter other feedstocks here.*			
Other feedstock consumption (kg/kg of H2)	*Enter consumption rate for other feedstock here*.			
Other feedstock cost ($/kg)	*Enter other feedstock costs here.*			
Other feedstock cost ($/year)	$0			
TOTAL FEEDSTOCK COSTS ($/year)	$0			
Additional Raw Material Costs *(add details as needed in rows below)*.				
List additional raw materials and feedstocks here.	*Give costs in $/year of other feedstock and raw material costs.*			
TOTAL OTHER RAW MATERIAL COSTS ($/year)	$0			
Utility Costs				
Type of **electricity** utility used	*Select from the pull-down menu in this cell.*			
Use H2A Electricity utility Cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter Electricity utility Cost if NO is Selected Above ($/kWh)	*If the user does not wish to use the H2A projections for yearly electricity costs, select "no" in the cell above and enter an electricity cost*			**A value is required here only if escalating costs are not assumed**

	here. These costs will be escalated with inflation.			
Electricity utility consumption (kWh/kg H2)	*Enter the amount of electricity consumed by the plant, per kg of hydrogen produced.*			
Electricity utility cost in startup year ($/kWh)				**Data taken from Feedstock and Utility cost sheet**
Electricity utility cost in startup year ($/year)	$0			
Type of **Natural Gas** utility Used	*Select from the pull-down menu in this cell.*			
Natural gas utility energy content, LHV, if standard H2A value is not desired (GJ/Nm3)	*Leave this cell blank if the standard H2A value of 0.038 GJ/Nm3 is desired. Otherwise, enter a user-defined value, with the units of GJ/Nm3.*			**Leave blank if the H2A standard value of is .038 GJ/Nm3 is desired**
Use H2A Natural Gas utility Cost? (Enter Yes or No)	*Select from the pull-down menu in this cell.*			
Enter Natural Gas utility Cost if NO is Selected Above ($/Nm3)	*If the user does not wish to use the H2A projections for yearly natural gas costs, select "no" in the cell above and enter a natural gas cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Natural Gas utility Consumption (Nm^3/kg H2)	*Enter the amount of natural gas consumed by the plant, per kg of hydrogen produced.*			
Natural gas utility cost in startup year ($/Nm3)				**Data taken from Feedstock and Utility cost sheet**
Natural Gas utility cost in startup year ($/year)	$0			
Steam utility consumption (kg/kg H2)	*Enter the amount of steam consumed by the plant, per kg of hydrogen produced.*			**Assumed to be superheated steam at 11.4 bara and 200C.**
Use H2A steam utility cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter steam utility cost if NO is selected above ($/kg)	*If the user does not wish to use the H2A projections for yearly steam costs, select "no" in the cell above and enter a steam cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**

Steam utility cost in startup year ($/kg)				**Data taken from Feedstock and Utility cost sheet**
Steam utility cost in startup year ($/year)	$0			
Oyxgen utility consumption (kg/kg H2)	*Enter the amount of oxygen consumed by the plant, per kg of hydrogen produced.*			
Use H2A oxygen utility cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter oxygen utility cost if NO is selected above ($/kg)	*If the user does not wish to use the H2A projections for yearly oxygen costs, select "no" in the cell above and enter a natural gas cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Oxygen utility cost in startup year ($/kg)				
Oxygen utility cost in startup year ($/year)	$0			
Cooling water utility consumption (L/kg H2)	*Enter the amount of cooling consumed by the plant, per kg of hydrogen produced.*			
Use H2A cooling water utility cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter cooling water utility cost if NO is selected above ($/L)	*If the user does not wish to use the H2A projections for yearly cooling water costs, select "no" in the cell above and enter a cooling water cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Cooling water utility cost in startup year ($/L)				**Data taken from Feedstock and Utility cost sheet**
Cooling water cost in startup year ($/year)	$0			
Process water utility consumption (L/kg H2)	*Enter the amount of process water consumed by the plant, per kg of hydrogen produced.*			
Use H2A process water utility cost? (Enter Yes or No)	*Select from the pull-down menu in this cell.*			
Enter process water utility cost if NO is selected above ($/L)	*If the user does not wish to use the H2A projections for yearly process water costs, select "no" in the cell above and enter a process water cost here. These costs will*			**A value is required here only if escalating costs are not assumed**

	be escalated with inflation.			
Process water utility cost in startup year ($/L)				**Data taken from Feedstock and Utility cost sheet**
Process water utility cost in startup year ($/year)	$0			
Demineralized water utility consumption (L/kg H2)	*Enter the amount of demineralized water consumed by the plant, per kg of hydrogen produced.*			
Use H2A demin water utility cost? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter demin water utility cost if NO is selected above ($/L)	*If the user does not wish to use the H2A projections for yearly demineralized water costs, select "no" in the cell above and enter a cost here. These costs will be escalated with inflation.*			**A value is required here only if escalating costs are not assumed**
Dimineralized water utility cost in startup year ($/L)				**Data taken from Feedstock and Utility cost sheet**
Demineralized water utility cost in startup year ($/year)	$0			
Other Utility	*Enter other utility details and costs here. These costs will be inflated.*			
Other Utility Consumption (kg/kg H2)				
Other Utility Cost ($/kg)				
Other Utility Cost ($/year)	$0			
TOTAL UTILITY COSTS ($/year)	$0			
Other Variable O&M Costs				
Waste treatment costs ($/year)	*Enter yearly waste treatment costs.*			**Enter as a positive number**
Solid waste disposal costs ($/year)	*Enter solid waste disposal costs.*			**Enter as a positive number**
Other variable operating costs (e.g., non-feedstock fuels, environmental surcharges) ($/year)	*Enter other yearly variable operating costs.*			**Enter as a positive number**
Royalties ($/year)	*Enter yearly royalty costs.*			**Enter as a positive**

				number
Operator Profit ($/year)	*Enter yearly operator profit costs, beyond those obtained as part of the specified internal rate of return.*			**Enter as a positive number**
Subsidies, Tax Incentives ($/year)	*Enter yearly subsidies and tax incentives.*			**Enter as a positive number**
CO2 separation and sequestration costs ($/year)	*Enter any yearly CO2 separation and sequestration costs.*			**Enter as a positive number**
TOTAL OTHER VARIABLE O&M COSTS ($/year)	$0			
By-product Credits				
Type of **electricity** by-product produced	*Select from the pull-down menu in this cell.*			
Electricity by-product production (kWh/kg H2)	*Enter the amount of by-product electricity sold from plant.*			
Use H2A electricity by-product value? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter electricity by-product value ($/kWh)	*If the user does not wish to use the H2A projections for yearly electricity values, select "no" in the cell above and enter an electricity value here. These values will be escalated with inflation.*			**If electricity is sold whenever the plant is operating, use $0.03/kWh. If a decision is made to sell electricity only when a high price can be obtained, enter the time-averaged selling price.**
Electricity value in startup year ($/kWh)				**Data taken from Feedstock and Utility cost sheet**
By-product electricity value in startup year ($/year)	$0			
Oxygen by-product production (kg/kg H2)	*Select from the pull-down menu in this cell.*			
Use H2A oxygen by-product value? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter oxygen by-product value if NO is selected above ($/kg)	*If the user does not wish to use the H2A projections for yearly oxygen values, select "no" in the cell above and enter an oxygen value here. These values will be escalated with inflation.*			**The 2002 SRI PEP Yearbook shows a value of $0.07/kg**

Oxygen value in startup year ($/kg)				**Data taken from Feedstock and Utility cost sheet**
Oxygen by-product value in startup year ($/year)	$0			
Steam by-product production (kg/kg H2)	*Select from the pull-down menu in this cell.*			**Assumed to be superheated steam at 11.4 bara and 200C.**
Use H2A steam by-product value? (Enter yes or no)	*Select from the pull-down menu in this cell.*			
Enter steam by-product value if NO is selected above ($/kg)	*If the user does not wish to use the H2A projections for yearly steam values, select "no" in the cell above and enter an steam value here. These values will be escalated with inflation.*			
Steam by-product value in startup year ($/kg)				**Data taken from Feedstock and Utility cost sheet**
Steam by-product value in startup year ($/year)	$0			
Other By-products Produced (e.g., nitrogen, argon, chemicals, fuels)	*Enter other by-product details and values here. These values will be inflated.*			
By-product Production (kg/kg of H2 Produced)				
Other By-product Value ($/kg)				
Other By-product Value ($/year)	$0			
TOTAL BY-PRODUCT CREDITS ($/year)	$0			
TOTAL VARIABLE PRODUCTION COSTS ($/year)	$0			

WORKING CAPITAL (% of yearly change in operating costs)	*Enter the percentage of the yearly increase in operating costs that is to be assumed for working capital.*			**Without a reference to a case-specific value, use 15% as the suggested H2A standard for central plants.**

Replacement Capital Worksheet Tab

Unplanned Yearly Replacement Capital (Depreciable)				
		Comments	Source	Information
Total Unplanned Replacement Capital Cost Factor (% of total direct depreciable costs/year)	*Enter the amount of unplanned replacement capital expenditures incurred each year of plant operation, as a percentage of the total direct depreciable costs.*			**Enter either fixed percentage. This input is meant to include, in the Cash Flow Analysis, a factor for unplanned capital expenditures.**

Actual Year	Analysis Year	Operations Year	Specified Yearly Replacement Costs	Unplanned Replaceme nt Costs	Total Yearly Replacement Costs	Uninstalled costs	Installation factor	Comments:	Data source:
			Reference Year basis	Reference Year basis	Inflated to startup year				
0	1	1	*For each year in which a major replacement capital expenditure is expected, enter the amount, in 2005 dollars. An example of this type of expenditure is when a major piece of equipment reaches the end of its useful life before the plant is decommissioned*	-	-				
	2	2		-	-				
	3	3		-	-				
	4	4		-	-				
	5	5		-	-				
	6	6		-	-				
	7	7		-	-				-

	8	8		-	-				
	9	9		-	-				
	10	10		-	-				
	11	11		-	-				

Cash Flow Analysis Worksheet Tab

No input is required on this worksheet tab. The calculations for the cash flow analysis are performed here, and major results are highlighted at the top.

Results Worksheet Tab

Error Messages:

NO ERRORS ARE PRESENT. CASH FLOW CALCULATION IS READY TO RUN.

If there are errors present in the input cells of the modeling tool, they will be displayed here.

Press this button to determine the minimum hydrogen selling price

Solve Cash Flow for Desired IRR

After all required inputs are complete, the cash flow analysis calculations can be performed by pressing this button. The model will adjust the selling price of hydrogen until the specified internal rate of return is achieved.

Discounted Cash Flow Rate of Return Results	
Real After-tax Internal Rate of Return (%)	
Nominal After-tax Internal Rate of Return (%)	

Hydrogen Selling Price and Cost Contributions (Year 2005 $)	
Required Hydrogen Selling Price ($(Reference Year)/kg of H2)	
Capital Cost Contribution ($/kg of H2)	
Decommissioning Cost Contribution ($/kg of H2)	
Fixed O&M Cost Contribution ($/kg of H2)	
Feedstock Cost Contribution ($/kg of H2)	
Other Raw Material Cost Contribution ($/kg of H2)	
Byproduct Credit Cost Contribution ($/kg of H2)	
Other Variable Costs (including utilities) Contribution ($/kg of H2)	

Energy Efficiency

Energy efficiency results should be given in terms of the lower heating values of the hydrogen and all fuels and feedstocks

	Gate to Gate	**Cradle to Front Plant Gate**	**Cradle to End-of-Plant-Gate**
Process energy efficiency: H2 product plus energy product (i.e., electricity, steam, other fuels) divided by all feedstock and process energy inputs. (%)	*Enter the efficiency of the production process as the energy in the hydrogen product and any coproducts (on a LHV basis) divided by the total energy inputs into the process.*	*Enter the efficiency of producing the feedstock for the production process as the energy in the feedstock divided by the total energy needed to deliver the feedstock to the front plant gate.*	*Enter the life cycle efficiency of the process as the energy in the hydrogen product and any coproducts (on a LHV basis) divided by the total energy that was consumed to make the production process operate. This includes feedstock production, transportation, recycling, waste disposal, plant operation, plant energy production, etc.*
H2 product energy efficiency: H2 product divided by all feedstock and process energy inputs. (%)	*Enter the efficiency of the production process as the energy in the hydrogen product (on a LHV basis) divided by the*	N/A	*Enter the life cycle efficiency of the process as the energy in the hydrogen product and*

	total energy inputs into the process. This value will be the same as the process energy efficiency above if no coproducts are produced.		*any coproducts (on a LHV basis) divided by the total energy that was consumed to make the production process operate. This includes feedstock production, transportation, recycling, waste disposal, plant operation, plant energy production, etc. This value will be the same as the process energy efficiency above if no coproducts are produced.*
Life cycle net energy ratio (non-renewable energy only):H2 product plus energy product (i.e., electricity, steam, other fuels) divided by all feedstock and process energy inputs.	*This is the ratio of the energy in the hydrogen product (LHV basis) to the fossil energy used by the plant.*	*This is the ratio of the energy in the feedstock (LHV basis) to the fossil energy used to produce the feedstock.*	*This is the ratio of the energy in the hydrogen product (LHV basis) to the fossil energy used by the entire system, including feedstock production, transportation, recycling, waste disposal, etc.*
Life cycle net energy ratio (non-renewable energy only):H2 product divided by all feedstock and process energy inputs.	*This is the ratio of the energy in the hydrogen product (LHV basis) to the total amount of energy used by the plant.*	*This is the ratio of the energy in the feedstock (LHV basis) to the total amount of energy used to produce the feedstock.*	*This is the ratio of the energy in the hydrogen product (LHV basis) to the total amount of energy used by the entire system, including feedstock production, transportation, recycling, waste disposal, etc.*

Processing Energy Inputs			
	Gate to Gate	**Cradle to Front Plant Gate**	**Cradle to End-of-Plant-Gate**
Electricity (kWh/kg of H2)	*Enter the amount of electricity that is consumed per kg of hydrogen in the production facility.*	*Enter the amount of electricity that is consumed per kg of hydrogen, to deliver fuel to the production facility*	*Enter the life cycle electricity consumption per kg of hydrogen, including feedstock production, transportation, recycling, waste*

			disposal, etc.
Natural Gas (kJ/kg of H2)	*Enter the energy of natural gas (LHV) that is consumed per kg of hydrogen in the production facility.*	*Enter the energy of natural gas (LHV) that is consumed per kg of hydrogen, to deliver fuel to the production facility*	*Enter the life cycle natural gas consumption (LHV) per kg of hydrogen, including feedstock production, transportation, recycling, waste disposal, etc.*
Other Fuels (*specify and add rows as needed)* (kJ/kg of H2)	*Enter the energy of other fuels (LHV) that is consumed per kg of hydrogen in the production facility.*	*Enter the energy of other fuels (LHV) that is consumed per kg of hydrogen, to deliver fuel to the production facility*	*Enter the life cycle energy consumption of other fuels (LHV) per kg of hydrogen, including feedstock production, transportation, recycling, waste disposal, etc.*
Total (kJ/kg of H2)	-		-

Mass Yields from Feedstock

	Gate to Gate	Cradle to Front Plant Gate	Cradle to End-of-Plant-Gate
Mass Yield (kg of H2/kg of feedstock excluding water)	*Enter the amount of hydrogen that is produced per kg of feedstock consumed, within the production facility.*		

Greenhouse Gas Emissions (kg CO_2-equiv / kg H_2)

Greenhouse gas emissions should be normalized based on IPCC 100-year numbers

	Gate to Gate	Cradle to Front Plant Gate	Cradle to End-of-Plant-Gate
Process CO_2 emissions	*In this column, enter the specified emission, waste generation, or water consumption due to the operation within the production facility.*	*In this column, enter the specified emission, waste generation, or water consumption that results from delivering feedstock to the production facility.*	*In this column, enter the specified life cycle emission, waste generation, or water consumption that results from the operation of this production pathway. This includes feedstock production, transportation, recycling, waste disposal, plant operation, plant*

			energy production, etc. This value will be the same as the process energy efficiency above if no coproducts are produced.
Process CH_4 emissions			
Process other greenhouse gas emissions			
Total process greenhouse gas emissions			

Other emissions	**Gate to Gate**	**Cradle to Front Plant Gate**	**Cradle to End-of-Plant-Gate**
SO_2 (g/kg H_2)			
NO_x (g/kg H_2)			
VOCs (g/kg H_2)			
Particulates (g/kg H_2) PM-10			

Solid Waste			
	Gate to Gate	**Cradle to Front Plant Gate**	**Cradle to End-of-Plant-Gate**
(List type and add rows as appropriate)			

Water Use			
	Gate to Gate	**Cradle to Front Plant Gate**	**Cradle to End-of-Plant-Gate**
Total water use (kg/kg H2)			
Net water use (kg/kg H2)			

IRR Graph Worksheet Tab

This tab will automatically graph the sensitivity of the selling price of hydrogen to the internal rate of return.

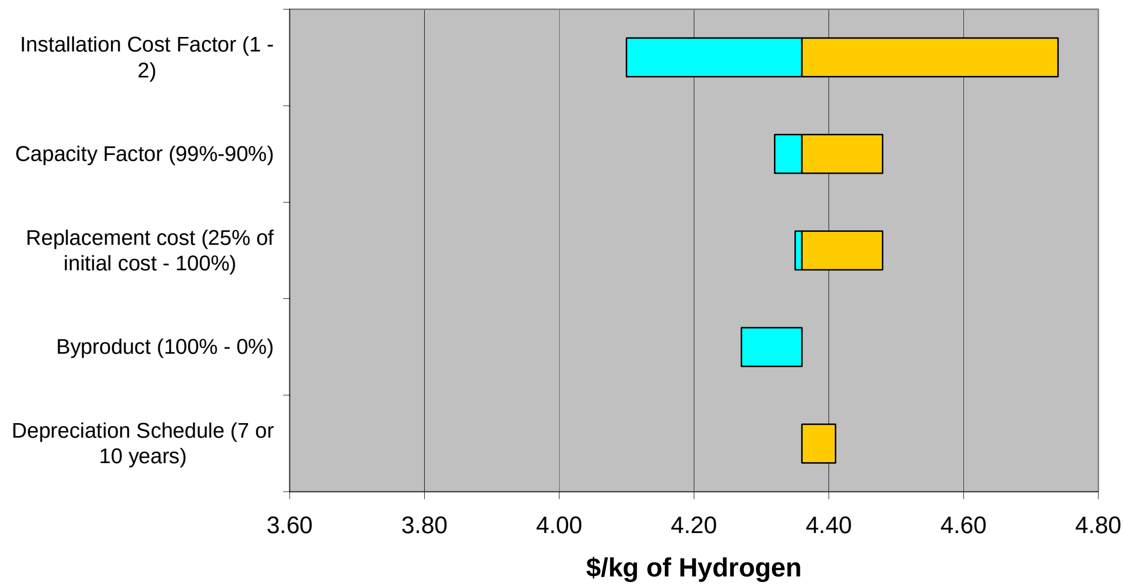
IRR %	Hydrogen $/kg
0	
5	
10	
15	
20	
25	

Run a case for each IRR shown in this table, by entering the IRR on the Financial Inputs worksheet tab. Manually enter the hydrogen selling price from the Results worksheet tab into the right-hand column of this table. Other IRRs can be tested and placed into the rows of this table.

Sensitivity – Tornado Worksheet Tab

The "Sensitivity - Tornado Chart" worksheets allows the user to run sensitivity analyses on different parameters once the base case has been completed. Sensitivity analyses should be run after the user is confident that the base case is valid because tornado plots show how the price of hydrogen changes as different parameters are varied, and the tornado plot is centered on the base case.

This worksheet allows the user to enter sensitivity data, which will be displayed in automatically generated tornado plot on tab "Sensitivity - Tornado Chart". A tornado chart allows a user to see to which parameters the results are most sensitive, and display them in a chart, which resembles a tornado, with the most sensitive parameters on the top, and the least sensitive parameters on the bottom: see below for an example.



For the technology shown in the example tornado plot above, the base case price is $4.36/kg of hydrogen. The sensitivity parameter values that cause an increase in the price of hydrogen are shown as orange bars to the right of the base price, and the sensitivity parameter values that cause a decrease in hydrogen price can be seen as blue bars to the left of the base case price. So, consider the top sensitivity parameter, "Installation Cost Factor." For this parameter, the base case installation cost factor was 1.2 (not shown on the graph). The sensitivity analysis varied this parameter from 1 to 2. When the installation cost factor was 1, the price of hydrogen was $4.10/kg, which is seen as the farthest left value on the top blue bar, and when the installation cost factor was 2, the price of hydrogen increased to $4.74/kg, the farthest right value on the top orange bar.

In order to create the tornado chart, data must be entered on the "Sensitivity-Tornado" tab. The first five columns (A:E) on this tab are displayed below:

Sensitivity Parameters				
	Upper bound		**Lower bound**	
Parameter varied	**Parameter value**	**H2 Price**	**Parameter Value**	**H2 Price**
This column will be used as the y-axis description for each parameter. For example, in the top parameter above, the text "Installation Cost Factor (1 - 2)" would be entered.	*In this column, the upper value of the parameter varied should be entered. In the top parameter in the example above, this value would be "2". Note that this value is the parameter value that leads to the highest hydrogen price, not the highest parameter value. If the hydrogen price were*	*In this column, the resulting hydrogen price from varying the upper bound parameter is entered. Note that the model does not automate this process. The parameter needs to be changed in the model, and the "Solve Cash Flow for Desired IRR' needs to be pushed to calculate the hydrogen*	*In this column, the lower value of the parameter varied should be entered. In the top parameter in the example above, this value would be "1". Note that this value is the parameter value that leads to the lowest hydrogen price, not the highest parameter value. If the hydrogen price were inversely*	*In this column, the resulting hydrogen price from varying the lower bound parameter is entered. Note that the model does not automate this process. The parameter needs to be changed in the model, and the "Solve Cash Flow for Desired IRR' needs to be pushed to calculate the hydrogen*

	inversely proportional to hydrogen price, this would be the lower parameter value.	*price. Then the resultant price needs to be manually entered here.*	*proportional to hydrogen price, this would be the lower parameter value.*	*price. Then the resultant price needs to be manually entered here.*
Example from above is shown below				
Installation Cost Factor (1 - 2)	*2*	*4.74*	*1*	*4.10*
…				

The next four columns of the spreadsheet (F:I) are calculations needed to produce the tornado chart. No changes should be made to this section. The final column J, is optional, and can be used for references and justifications as to why the parameter was chosen to vary. This is for documentation only, and will not be seen on the graph.

Price diff	Lower Dif	Upper Dif	Lower Dif	Reference/justification
0.05	0.000	0.05	0.000	Used for references and justifications as to why the parameter was chosen to vary
0.09	0.090	0.00	0.090	

Note that after all tornado chart parameters have been entered, the values should be sorted so that the largest price difference, "Price diff" seen in column F, is the last parameter in the table. So the parameters should be organized from smallest to largest, from top to bottom, in order to make the tornado chart appear correctly.

The final cell of importance is found under the chart, in column E, and is labeled "H2 Price – Base Case".

H2 Price – Base Case	*In this cell, the price calculated by the base case run in the model should be entered. This price will be the value to which all resulting prices from varying parameters will be compared. In the example above, this price is $4.36*

The tab following the Sensitivity – Tornado worksheet tab charts the results of the data entered.

The tab labeled "Sensitivity – Monte Carlo" is not required input in this version of the H2A model, but performing Monte Carlo sensitivity runs may enhance the analysis.

Debt Financing Calculations Worksheet Tab

No input is required on this worksheet tab. All calculations for any debt financing assumed on the Financial Inputs tab are carried out here.

Depreciation Worksheet Tab

No inputs are required on this worksheet tab.

In the H2A cash flow model, there are two methods that can be used for depreciating the capital expenditures: Modified Accelerated Cost Recovery System (MACRS) or straight-line. The MACRS method is prescribed by the IRS for use in tax accounting. The H2A spreadsheet uses the 200%/half-year convention MACRS method. However, many companies use the straight-line method for their book accounting.

The H2A spreadsheets are designed so that multiple capital investments can be depreciated. For example, replacement capital costs, which may occur at any time after plant start-up, are depreciated in the same method as the initial capital investment. The one shortfall of the H2A depreciation method is that there can only be one defined depreciation period (i.e. there cannot be a different depreciation period for the initial capital investment and the replacement capital costs).

H2A analysts assigned a depreciation period to a particular asset based on IRS guidelines. In Publication 946 (available at http://www.irs.gov/pub/irs-pdf/p946.pdf), the IRS lists the assigned lifetimes for specific assets.

APPENDIX A

Summary of Common Assumptions and Groundrules for H2A Central and Forecourt Production Analyses

September 30, 2004

The following common cost assumptions are applied for all H2A Central and Forecourt supply options, unless a case for any different values is provided otherwise:

- Analysis Methodology - Discounted Cash Flow (DCF) model that calculates a levelized H2 price that yields prescribed IRR
- Reference Financial Structure – 100% equity with 10% IRR – Include levelized H2 price plot for 0 to 25% IRR - Model allows debt financing
- Reference Year Dollars – 2005, to be adjusted at half-decade increments (e.g., 2005, 2010)
- Technology Development Stage - All Central and Forecourt cost estimates are based on mature, commercial facilities
- Inflation Rate – 1.9%, but with resultant price of H2 in reference year constant dollars
- Income Taxes – 35% Federal; 6% State; 38.9% Effective
- Property Taxes and Business Insurance – 2%/year of the total initial capital cost
- Sales Tax – Not included on basis that facilities and related purchases are wholesale and through a general contractor entity
- Working Capital Rate – 15% of the annual change in the total operating costs
- Analysis Period – 40 years for Central; 20 years for Forecourt
- Facility Life – 40 years for Central with case exceptions; 20 years for Forecourt with case exceptions
- Depreciation Type and Schedule for Initial Depreciable Capital Cost – MACRS – 20 years for Central with case exceptions; 7 years for Forecourt
- Construction Period and Cash Flow- Varies per case for Central; 0 for Forecourt

- Planned Replacement Capital– Post startup capital costs spread over time based on specific replacement estimates. Depreciation is based on MACRS schedule and 7 years or the same as the replacement period if it is shorter than 7 years.
- Unplanned Replacement Capital – Specified percentage of initial depreciable capital cost meant to handle unplanned replacement capital expenses that occur during an operating year of the plant. Depreciation is based on MACRS schedule and 7 years

- Project Contingency – % adjustment to the total initial capital cost such that the result represents the mean or expected cost value. Periodic replacement capital includes project contingency.

- Process Contingency - % adjustment to the total initial capital cost such that the result incorporates the mean or expected overall performance.

- Land Cost – 5000$/acre purchased for Central; $0.5/sqft/month for long-term lease for Forecourt

- Capacity Factor – 90% for Central, with case exceptions; 70% for Forecourt

- Average Burdened Labor Rate for Staff – 50$/hour for Central; 15$/hour for Forecourt

- G&A Rate – 20% of the staff labor costs above

- Forecourt Maintenance and Repair – 5%/yr of initial depreciable capital cost for small capacity and 3%/yr for large capacity

- Co-produced and Cogenerated Electricity Price - $30/MWh with sensitivities based on 20$/MWh low and 50$/MWh high

- CO2 tax (when CO2 sequestration is not plausible) – not included in Base cases, sensitivity included at 100$/tonne C (27.3$/tonne CO2) for Central and Forecourt.

- O2 Credit – Not included in Base cases, sensitivity included at 20$/tonne for Central and Forecourt.

- Salvage Value – 10% of initial capital, with case exceptions; 0% for Forecourt

- Decommissioning – 10% of initial capital, with case exceptions; 0% for Forecourt

- Hydrogen Pressure at Central Gate – 300 psig. If higher pressure is inherent to the process, apply pumping power credit for pressure >300psig.

- Central Storage – Buffer only as required for efficient operations

- Hydrogen Storage Pressure at Forecourt - 6250 psig

- Forecourt Compressed H2 Storage – 87.5% of maximum daily production (based on 35% of production divided by an assumed 40% dispensable hydrogen fraction)

- Hydrogen Purity – 98% minimum; CO < 10ppm, sulfur < 10ppm

- Sensitivity Variables and Ranges – Based on applying best judgment of 10% and 90% confidence limit extremes to the most significant baseline cost and performance parameters

APPENDIX B

An Approach to Handling Internal Rate of Return for the H2A Analysis

March 24, 2004

In cases where the capital cost component is a large fraction of the total cost of producing hydrogen, the assumed internal rate of return (IRR) strongly affects the results calculated by the H2A discounted cash flow spreadsheet. The base case IRR that H2A has been using to date is 12.1% (nominal), 10% (real). This rate is linked to another H2A assumption -- used for calculation purposes -- of 100% equity financing.[2] The 10% real value was derived from return on equity statistics (adjusted for inflation) for large company stocks over the long term (see attached spreadsheet entitled "Inflation Adjusted Rates)..[3] Because returns already account for corporate taxes, this value is an after-tax return. The use of the 10% real IRR is intended to reflect a steady-state situation in the future in which hydrogen is no longer a novel concept and a significant demand for hydrogen exists.

In addition to looking at historical stock market returns on equity, H2A also investigated official Office of Management and Budget (OMB) guidance on discount rates. OMB estimated the **pre-tax** "rate of return to corporate capital" to be 9.1% (real) for the period from 1947 through 2001, and 9.9 percent over the most recent 10-year period – 1992 through 2001. The after-tax value would be considerably lower.

Another source of relevant information is the database that the Energy Information Administration (EIA) compiles for major energy producers.[4] The tables in the attached Excel file show after-tax return on investment or ROI (Table 1) and return on equity (ROE) values (Table 2) for both energy producers and S&P industrials for the 1987-2002 period from the series of

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[2] Although actual projects would probably be financed with a combination of debt and equity, H2A believes that firms typically assume 100% equity financing for paper studies and analyses. The H2A spreadsheet does include an option for assuming debt financing, in which case the user specifies the debt financing rate. Therefore, the IRR in the spreadsheet is equivalent to a return on equity (ROE).

[3] Based on long-term data back to 1926 compiled in *Stocks, Bonds, Bills and Inflation 2003 Yearbook*, Ibbotson Associates, 2003, the inflation-adjusted return on large company stocks, averaged over the 1926-2002 period, was approximately 9%. This is equivalent to a long-term rate of return on equity for large companies. For the base case calculations, the H2A project has been assuming 100% equity financing and a 10% discount rate that is slightly higher than 9% historical stock market return.

[4] Data is reported in *Performance Profiles of Major Energy Producers*, a comprehensive annual financial review and analysis of major US-based energy-producing companies based on data collected in Form EIA-28. These data provide unique information across energy lines of business (e.g., refining versus petroleum product pipelines). The data collection activity responds to requirements of the Financial Reporting System set forth in P.L 95-91, the Department of Energy Organization Act of 1977. EIA supplemented the data collected by EIA in the FRS with data from company annual reports, U.S. Security and Exchange Commission disclosures, and various complementary energy industry data sets, etc. An example of an annual report can be found at:
http://tonto.eia.doe.gov/FTPROOT/financial/020601.pdf
There is a report like this for every year back to 1993. The financial tables are in Appendix B.

EIA reports called *Performance Profiles of Major Energy Producers*.[5] These ROI and ROE values can also be used to help H2A set an IRR for the H2A analyses. Observations from these data include:

- The petroleum industry averaged a ROI of about 7% (nominal) over the last 15 years; yearly values in that period ranged from 3.8 to 13.5. Adjusting for inflation, the average is equivalent to a real rate of between 4% and 5%.
- The ROI for refining operations was lower than the ROI for pipelines and exploration.
- Other energy industries had even lower returns than the petroleum industry.
- Energy producers had somewhat lower returns than the S&P industrials, which averaged around 8.7% nominal in recent years.

ROE is naturally higher than overall ROI, because the cost of debt is factored into the overall ROI (and debt rates are lower than equity rates, because debt has a more guaranteed, or less risky, return). Nominal ROE values averaged about 11% for energy producers and about 12% for S&P industrials. (The annual values for both energy and other ranged between 1% and almost 20%.) Subtracting a rough value of 2.5% for inflation, this translates into real rates of 8.5% - 9.5%. These values are only slightly lower than the value of 10% H2A is using for its IRR (given the way the spreadsheet is set up, the IRR is really equivalent to a ROE – see footnote 1 on previous page).

Key Industrial Collaborator (KIC) Feedback on the IRR Assumption

The H2A team has engaged a set of Key Industrial Collaborators (KIC) in the process of reviewing key assumptions being used in the discounted cash flow analysis. The H2A team has received input from the KIC during several group meetings and is very serious about being responsive to their feedback.

Several KIC members have consistently expressed concern that the 10% real IRR assumption is too low and does not appropriately reflect the risk associated with hydrogen projects or the rates of return expected by their management. Some have suggested that H2A use discount rates on the order of 15%-25% in the calculations. Some KIC team members have explained that they would not put much credence in an analysis that used a 10% real IRR.

On the other hand, some other KIC members voiced agreement with the H2A's approach of estimating a long-term cost of hydrogen[6] in the "real world," where the average return would reflect a mixture of projects, some with high rates of return and others with lower rates of return. Some contend that, over the long run, a commodity product (similar to gasoline) would earn a rate of return similar to the rates of return historically obtained by the chemical and petroleum industries, and that a rate of return of 15-25% would not be sustainable over a long time period for a commodity product. However, these same KIC members would likely agree that when making a decision on a **specific project** with a high risk, use of an IRR of 15%-25% would be appropriate.

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[5] **Return on equity statistics were only available back to 1991.**
[6] **The H2A spreadsheet calculates a hydrogen cost that includes all operating costs, as well as capital recovery and a real return on the capital investment equal to the IRR.**

The H2A team concluded that the IRR used in any analysis should reflect the purpose of the analysis; there is no single “right answer” to the question of what IRR should be used.

H2A Approach

The H2A team would like to accommodate the KIC members who have expressed both views. The team would also like to choose a base case IRR that is in keeping with official OMB guidance. Therefore, H2A proposes to examine a wide range of IRRs and present the results of the calculations graphically, so that users of the information can choose an IRR appropriate for their uses and can easily find the hydrogen cost corresponding to any given IRR.

A series of IRR “cases” would be estimated for each hydrogen technology. The resulting point estimates would be used to develop a smoothed curve representing the cost of hydrogen along the full continuum of IRR values between 0% and 25%. (Note: In all cases, the inflation rate will be assumed to be 1.9%. Some sensitivity runs around the inflation rate may be conducted.) The case using a 10% real IRR will continue to be the reference value used to estimate the cost of hydrogen that reflects long-term average returns in a national hydrogen economy where hydrogen is a commodity product. It will also serve as the basis for the primary series of sensitivity runs that will be conducted by H2A around factors such as feedstock prices, capacity factors, and others.

Since the H2A effort is providing a working spreadsheet tool, any user can change the after-tax IRR value in the spreadsheet and easily compute the corresponding cost of hydrogen for that assumption. Similarly, sensitivity analyses that examine the sensitivity of various parameters could be run around any IRR case.