H2A Central Hydrogen Production Model,

Version 3 User Guide (DRAFT)

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Technical Report (DRAFT)
NREL/TP-xxxx-xxxxx
April 2012

The H2A Production Model analyzes the technical and economic aspects of central and forecourt hydrogen production technologies. Using a standard discounted cash flow rate of return methodology, it determines the minimum hydrogen selling price (or levelized cost), including a specified after-tax internal rate of return from the production technology. Users have the option of accepting default technology input values—such as capital costs, operating costs, and capacity factor—from established H2A production technology cases or entering custom values. Users can also modify the model's financial inputs.

This new version (version 3) of the H2A Production Model features enhanced usability and functionality compared with version 2. The plant scaling function is more intuitive and accessible. The default reference year for cost calculations is 2007 (changed from 2005 in version 2), and users can change the reference year easily. In addition, default energy prices are from U.S. Energy Information Administration (EIA) 2009 projections (changed from 2005 projections in version 2). Appendix 3 describes other differences between versions 2 and 3 of the model. Overall, technical and financial assumptions and calculations are updated and improved in version 3.

The model is actually two models: one Microsoft Excel spreadsheet to analyze central hydrogen production technologies and another to analyze forecourt hydrogen production technologies. The two models are very similar. The primary difference is that the central model performs carbon sequestration calculations, whereas the forecourt model performs refueling station compression, storage, and dispensing calculations.[1] The models and detailed technology cases can be downloaded from www.hydrogen.energy.gov/h2a_production.html.

This *User Guide* introduces the basic elements of version 3 of the central H2A Production Model then describes the function and use of each of its worksheets. The forecourt model's *User Guide* is available at www.hydrogen.energy.gov/h2a_production.html.

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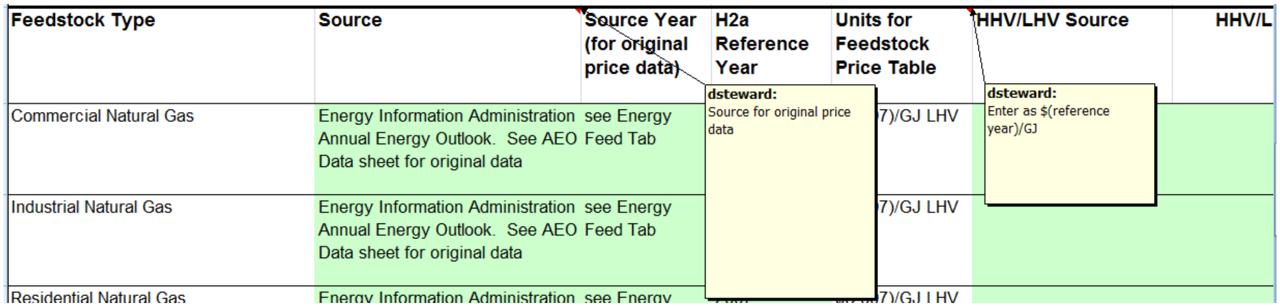
[1] The forecourt model performs compression, storage, and dispensing calculations separately from hydrogen production calculations and presents the results separately.

Tips & Troubleshooting

General Tips

- Before you start modifying the model, save the file under a new name. This will make it simple to go back to the unmodified model later if necessary.
- If the file you are working with accumulates numerous errors, or if you delete information that you later find you need, etc., it might be easier to discard the file and start afresh with the original version of the model and/or production technology case. If you have not kept an original version, download the model again from the H2A Web site: www.hydrogen.energy.gov/h2a_production.html.
- Throughout the model, orange cells are meant to accept static user-input values or user-defined equations, and blue cells are calculated automatically by the model. Use care if you overwrite the blue calculation cells with static values or your own equations; once overwritten, the original equation information is permanently deleted. Green cells are for user-input information and notes. Yellow cells contain H2A information and default values.
- Do not type values into cells with drop-down menus. Select only from values in the menu.
- If it is not obvious how to close or move on past a pop-up window, you can close it by clicking the ☒ in the upper right corner.
- Mouse over small red triangles for useful notes as shown below.



Feedstock Type	Source	Source Year (for original price data)	H2a Reference Year	Units for Feedstock Price Table	HHV/LHV Source	HHV/L
Commercial Natural Gas	Energy Information Administration Annual Energy Outlook. See AEO Data sheet for original data	see Energy Feed Tab		7)/GJ LHV		
Industrial Natural Gas	Energy Information Administration Annual Energy Outlook. See AEO Data sheet for original data	see Energy Feed Tab		7)/GJ LHV		
Residential Natural Gas	Energy Information Administration	see Energy		7)/GJ LHV		

dsteward:
Source for original price data

dsteward:
Enter as $(reference year)/GJ

- The *Input_Sheet_Template* worksheet works best (i.e., has the least likelihood of errors) when you fill it out as completely as possible, starting with the top and working down. After filling out the worksheet completely, click the *Calculate Cost* button at top to view results.

User Guide Symbols

CAUTION — Follow instructions carefully to prevent errors or unwanted results.

Advanced users — Skip this section if you are a novice user or want to perform only simple analyses.

TIP — Read for useful information.

Solutions to Commonly Encountered Problems

Problem	Possible Solution	Relevant Worksheets	User Guide Sections
1. Clicking the *Use Default Values* button unintentionally replaced some of your user-defined values.	To retain user-defined values while filling in blank cells with default values, click *No* in the *Use Default Values* pop-up window.	*Input_Sheet_Template* *Carbon Sequestration* *Refueling Station*	*Table of Contents* (p. 9)
2. After adding energy feedstocks, utilities, and byproducts in the *Input_Sheet_Template* worksheet, you received an error message and null results when you clicked the *Calculate Cost* button.	Make sure you use the same price table for each energy feedstock, utility, and byproduct you add. Using different price tables creates an error in the calculations.	*Input_Sheet_Template*	*Energy Feedstocks, Utilities, and Byproducts* (p. 11)
3. After deleting energy feedstocks, utilities, and byproducts or other materials and byproducts in the *Input_Sheet_Template* worksheet using Microsoft Excel's delete functionality, you received an error message and null results when you clicked the *Calculate Cost* button.	Do not use Excel's delete functionality to delete entries under *Energy Feedstocks, Utilities, and Byproducts* or *Other Materials and Byproducts* within the *Input_Sheet_Template* worksheet. If you have used Excel's delete functionality in one or both of these sections, discard your current file and start afresh with the original version of the model and/or production technology case. In the future, make sure to use the H2A Model's *Delete* button to delete entries within these sections.	*Input_Sheet_Template*	*Energy Feedstocks, Utilities, and Byproducts* (p. 11) *Other Materials and Byproducts* (p. 15)

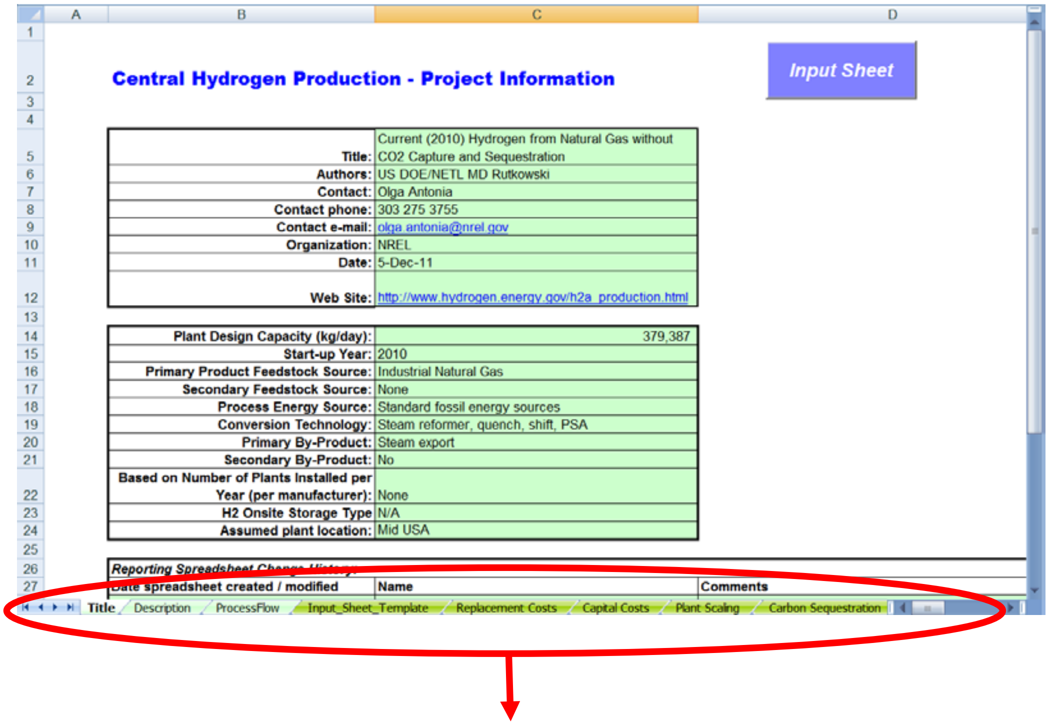
Problem	Possible Solution	Relevant Worksheets	User Guide Sections
4. You did not perform the actions described in problems 2 and 3 above, but you still received an error message when you clicked the *Calculate Cost* button.	Make sure to enter all critical values in the *Technical Operating Parameters and Specifications* and *Financial Input Values* sections before completing the rest of the *Input_Sheet_Template* worksheet and calculating cost. In particular, make sure values are present for reference year, startup year, and plant capacity.	*Input_Sheet_Template*	*Variable Operating Costs* (p. 14)
5. You used the *Delete* button to delete an entry under *Energy Feedstocks, Utilities, and Byproducts* or *Other Materials and Byproducts*, and more entries—or different entries—were deleted than you had intended.	Be careful to choose the correct item from the *Delete* drop-down menu within the *H2A Toolkit*. It deletes all entries of the selected type.	*Input_Sheet_Template* *H2A Toolkit*	*Energy Feedstocks, Utilities, and Byproducts* (p. 11) *Other Materials and Byproducts* (p. 15) *Delete Feed, Utility, and Byproduct Inputs* (p. 25)
6. You performed a sensitivity analysis, and the resulting tornado chart contained bad or nonsensical results.	Try switching the values you entered for "Value Reducing Hydrogen Price" and "Value Increasing Hydrogen Price" within the *Sensitivity Analysis* window. It is not always obvious how changing the value of a variable will affect the hydrogen price.	*H2A Toolkit* *Tornado Chart* *Sensitivity Analysis*	*Performing Sensitivity Analyses* (p. 25)

Problem	Possible Solution	Relevant Worksheets	User Guide Sections
7. You modified the *Lists* worksheet, and now the model does not work properly.	Do not add, delete, or change anything on the *Lists* worksheet. Modifying the lists can disable or introduce major errors into the model. If you have modified the lists, discard your current file and start afresh with the original version of the model and/or production technology case.	*Lists*	*Lists Worksheet* (p. 41)

Quick Start: Getting Around

The spreadsheet is organized into 19 or more worksheets, which have tabs color coded according to their function, as shown below. The schematic on the following page shows a generalized data flow among the worksheets.

Overview of H2A Production Model Tabs and Worksheets



Central Hydrogen Production - Project Information

Title:	Current (2010) Hydrogen from Natural Gas without CO2 Capture and Sequestration
Authors:	US DOE/NETL MD Rutkowski
Contact:	Olga Antonia
Contact phone:	303 275 3755
Contact e-mail:	olga.antonia@nrel.gov
Organization:	NREL
Date:	5-Dec-11
Web Site:	http://www.hydrogen.energy.gov/h2a_production.html

Plant Design Capacity (kg/day):	379,387
Start-up Year:	2010
Primary Product Feedstock Source:	Industrial Natural Gas
Secondary Feedstock Source:	None
Process Energy Source:	Standard fossil energy sources
Conversion Technology:	Steam reformer, quench, shift, PSA
Primary By-Product:	Steam export
Secondary By-Product:	No
Based on Number of Plants Installed per Year (per manufacturer):	None
H2 Onsite Storage Type	N/A
Assumed plant location:	Mid USA

Reporting Spreadsheet Change History:

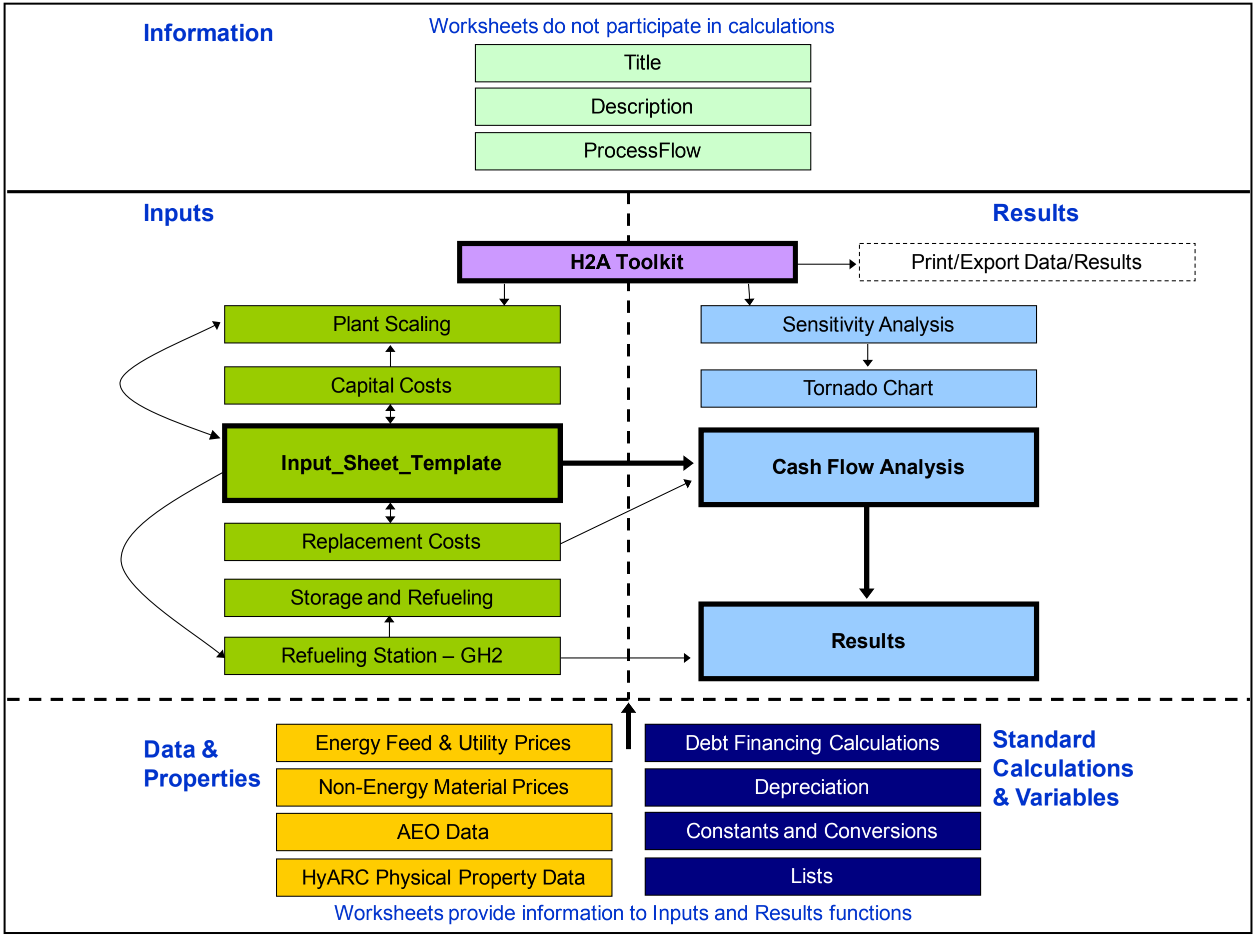
Date spreadsheet created / modified	**Name**	**Comments**

Title	**Information**
Description	
ProcessFlow	
Input_Sheet_Template	**Inputs**
Replacement Costs	
Capital Costs	
Plant Scaling	
Refueling Station [forecourt model only]	
Carbon Sequestration [central model only]	
Results	**Results**
Cash Flow Analysis	
Tornado Chart	
Sensitivity_Analysis	
Energy Feed & Utility Prices	**Data & Properties**
Non-Energy Material Prices	
AEO Data	
HyARC Physical Property Data	
Debt Financing Calculations	**Standard Calculations & Variables**
Depreciation	
Constants and Conversions	
Lists	

Most users will add/modify cells within the input worksheets (dark green tabs) only.

TIP

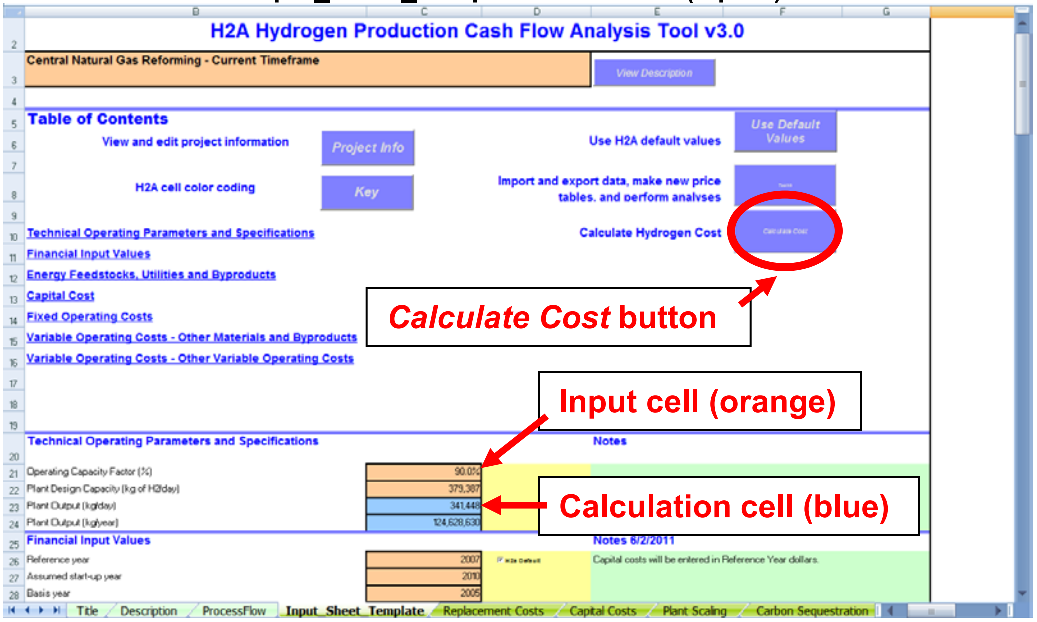
Schematic of Data Flow among H2A Worksheets



Quick Start: Performing Simple Production Cost Analyses

To perform a simple production cost analysis, select the *Input_Sheet_Template* tab. Accept the default (e.g., production technology case) values or enter new values into the orange cells. The contents of the blue cells are calculated automatically. Use the drop-down menus and buttons to enter information for *Energy Feedstocks, Utilities, and Byproducts* and *Other Materials and Byproducts*. Once all information is entered, click the *Calculate Cost* button at the top of the worksheet.

Input_Sheet_Template Worksheet (Inputs)



H2A Hydrogen Production Cash Flow Analysis Tool v3.0

Central Natural Gas Reforming - Current Timeframe

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View and edit project information

H2A cell color coding

Use H2A default values

Import and export data, make new price tables, and perform analyses

Calculate Hydrogen Cost

Technical Operating Parameters and Specifications

Financial Input Values

Energy Feedstocks, Utilities and Byproducts

Capital Cost

Fixed Operating Costs

Variable Operating Costs - Other Materials and Byproducts

Variable Operating Costs - Other Variable Operating Costs

Technical Operating Parameters and Specifications			Notes
Operating Capacity Factor (%)	90.0%		
Plant Design Capacity (kg of H2/day)	379,387		
Plant Output (kg/day)	341,448		
Plant Output (kg/year)	124,628,630		
Financial Input Values			**Notes 6/2/2011**
Reference year	2007	☑ H2a Default	Capital costs will be entered in Reference Year dollars.
Assumed start-up year	2010		
Basis year	2005		

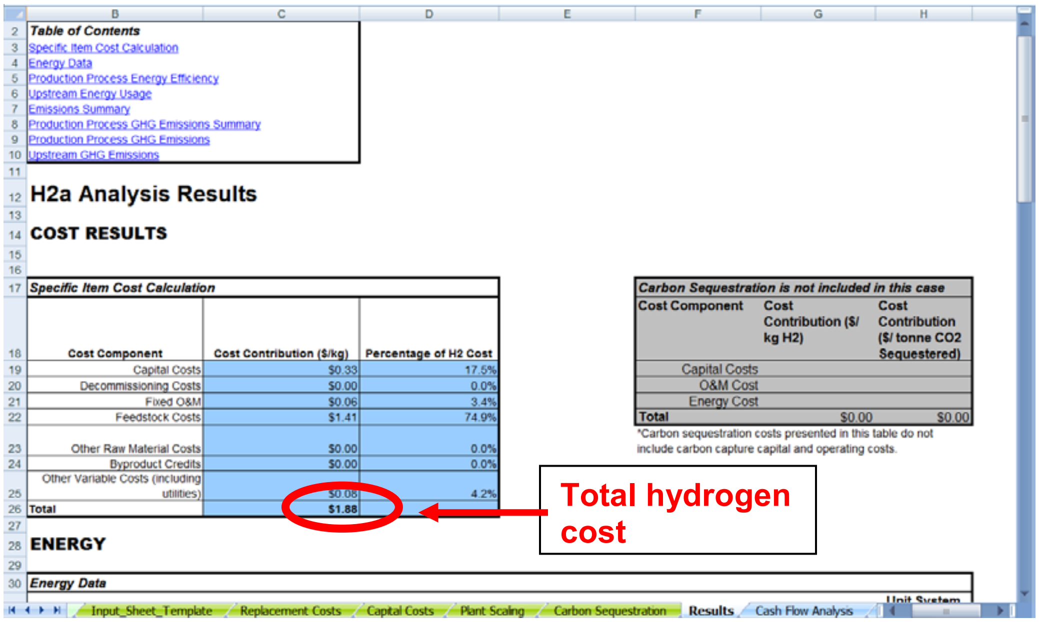
Calculate Cost button

Input cell (orange)

Calculation cell (blue)

Clicking the *Calculate Cost* button sends you to the *Results* worksheet, which displays the production cost, energy, and emissions results.

Results Worksheet



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Specific Item Cost Calculation

Energy Data

Production Process Energy Efficiency

Upstream Energy Usage

Emissions Summary

Production Process GHG Emissions Summary

Production Process GHG Emissions

Upstream GHG Emissions

H2a Analysis Results

COST RESULTS

Specific Item Cost Calculation

Cost Component	Cost Contribution ($/kg)	Percentage of H2 Cost
Capital Costs	$0.33	17.5%
Decommissioning Costs	$0.00	0.0%
Fixed O&M	$0.06	3.4%
Feedstock Costs	$1.41	74.9%
Other Raw Material Costs	$0.00	0.0%
Byproduct Credits	$0.00	0.0%
Other Variable Costs (including utilities)	$0.08	4.2%
Total	$1.88	

Carbon Sequestration is not included in this case

Cost Component	Cost Contribution ($/ kg H2)	Cost Contribution ($/ tonne CO2 Sequestered)
Capital Costs		
O&M Cost		
Energy Cost		
Total	$0.00	$0.00

*Carbon sequestration costs presented in this table do not include carbon capture capital and operating costs.

ENERGY

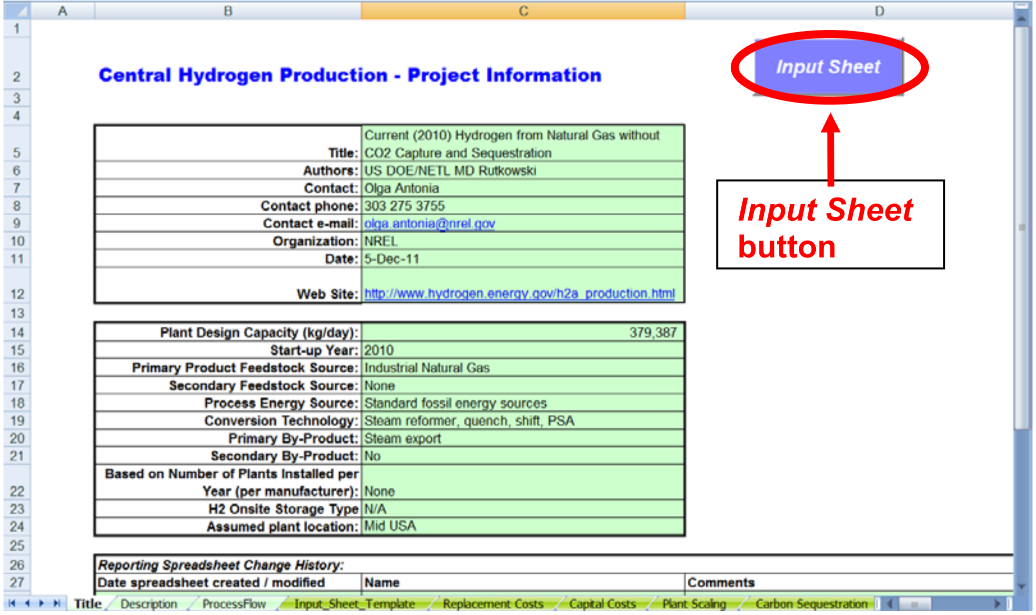
Energy Data

Total hydrogen cost

Information Worksheets

Established H2A production technology cases contain information worksheets linked from the light-green tabs. These worksheets (*Title*, *Description*, and *ProcessFlow*) do not participate in the model's calculations but contain valuable information about the project file and the hydrogen production technology being modeled. Clicking the *Input Sheet* button on any of the information worksheets sends you to the *Input_Sheet_Template* worksheet to begin using the model.

Example Title Worksheet (Central Natural Gas with no CCS)



Central Hydrogen Production - Project Information

Title:	Current (2010) Hydrogen from Natural Gas without CO2 Capture and Sequestration
Authors:	US DOE/NETL MD Rutkowski
Contact:	Olga Antonia
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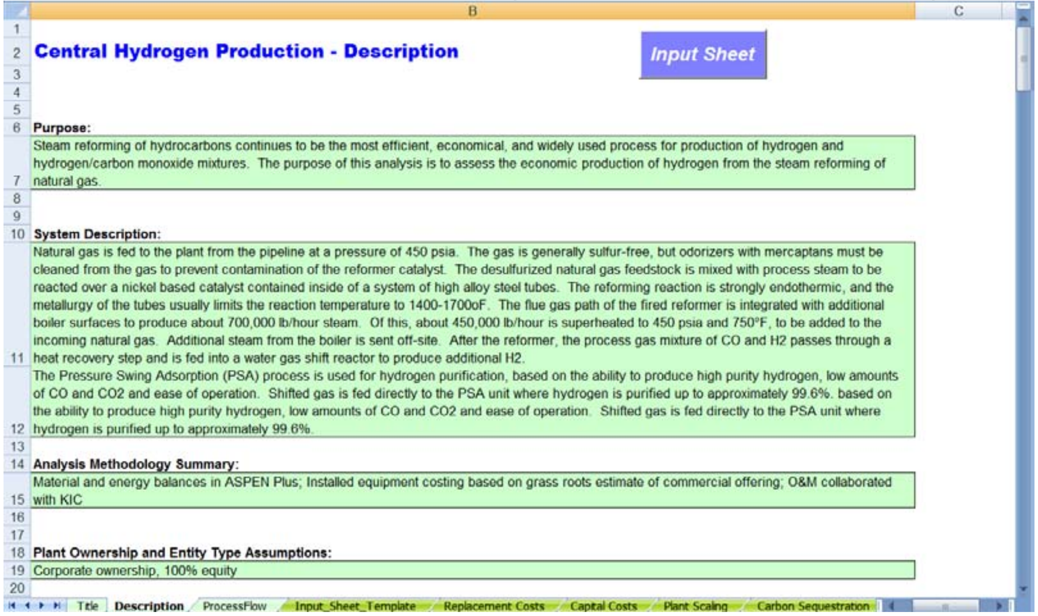
Organization:	NREL
Date:	5-Dec-11
Web Site:	http://www.hydrogen.energy.gov/h2a_production.html

Plant Design Capacity (kg/day):	379,387
Start-up Year:	2010
Primary Product Feedstock Source:	Industrial Natural Gas
Secondary Feedstock Source:	None
Process Energy Source:	Standard fossil energy sources
Conversion Technology:	Steam reformer, quench, shift, PSA
Primary By-Product:	Steam export
Secondary By-Product:	No
Based on Number of Plants Installed per Year (per manufacturer):	None
H2 Onsite Storage Type	N/A
Assumed plant location:	Mid USA

Reporting Spreadsheet Change History:

Date spreadsheet created / modified	**Name**	**Comments**

Example Description Worksheet (Central Natural Gas with no CCS)



Central Hydrogen Production - Description

Purpose:

Steam reforming of hydrocarbons continues to be the most efficient, economical, and widely used process for production of hydrogen and hydrogen/carbon monoxide mixtures. The purpose of this analysis is to assess the economic production of hydrogen from the steam reforming of natural gas.

System Description:

Natural gas is fed to the plant from the pipeline at a pressure of 450 psia. The gas is generally sulfur-free, but odorizers with mercaptans must be cleaned from the gas to prevent contamination of the reformer catalyst. The desulfurized natural gas feedstock is mixed with process steam to be reacted over a nickel based catalyst contained inside of a system of high alloy steel tubes. The reforming reaction is strongly endothermic, and the metallurgy of the tubes usually limits the reaction temperature to 1400-1700oF. The flue gas path of the fired reformer is integrated with additional boiler surfaces to produce about 700,000 lb/hour steam. Of this, about 450,000 lb/hour is superheated to 450 psia and 750°F, to be added to the incoming natural gas. Additional steam from the boiler is sent off-site. After the reformer, the process gas mixture of CO and H2 passes through a heat recovery step and is fed into a water gas shift reactor to produce additional H2.

The Pressure Swing Adsorption (PSA) process is used for hydrogen purification, based on the ability to produce high purity hydrogen, low amounts of CO and CO2 and ease of operation. Shifted gas is fed directly to the PSA unit where hydrogen is purified up to approximately 99.6%. based on the ability to produce high purity hydrogen, low amounts of CO and CO2 and ease of operation. Shifted gas is fed directly to the PSA unit where hydrogen is purified up to approximately 99.6%.

Analysis Methodology Summary:

Material and energy balances in ASPEN Plus; Installed equipment costing based on grass roots estimate of commercial offering; O&M collaborated with KIC

Plant Ownership and Entity Type Assumptions:

Corporate ownership, 100% equity

Input_Sheet_Template Worksheet

The *Input_Sheet_Template* worksheet is the H2A Model's primary user interface (see the screen capture on page 7). The sections below describe each of the seven sections of the *Input_Sheet_Template* worksheet in sequence as they appear in the worksheet and also describe the *H2A Toolkit* (see page 24 for details on the *H2A Toolkit*). You use the *Input_Sheet_Template* worksheet to input the data the model uses for calculations, perform analyses, and access the automated functions of the model through the *H2A Toolkit* utility. After filling out the worksheet, you click the *Calculate Cost* button to calculate and view results. Throughout the worksheet, entries in the *Notes* column describe calculations being performed or offer guidance on user inputs.

Project Description

The first line of the *Input_Sheet_Template* worksheet lists the name and date of the H2A file you are using. Click the *View Description* button to view a brief project description and history of updates in the *Title* worksheet (see page 8 for a sample *Title* worksheet).

Table of Contents

At the top of the *Table of Contents* are five buttons. The *Project Info* button sends you to the *Title* worksheet. The *Key* button describes the color coding used in the H2A Model.

The *Use Default Values* button links to a pop-up window, which provides two options for automatically using H2A default values. Clicking *Yes* replaces all *Input_Sheet_Template* inputs for which default values exist with the default values. Clicking *No* enters default values only for those inputs that have default values and are blank (see illustration on page 10). Be careful when using this button so as not to replace values unintentionally.

CAUTION

The *Toolkit* button brings up the *H2A Toolkit* window. Although this button is at the top of the worksheet, typically it is not the first thing you need to use—you will use it to perform a variety of important functions as described under *H2A Toolkit* (page 24) and in several other sections of this *User Guide*.

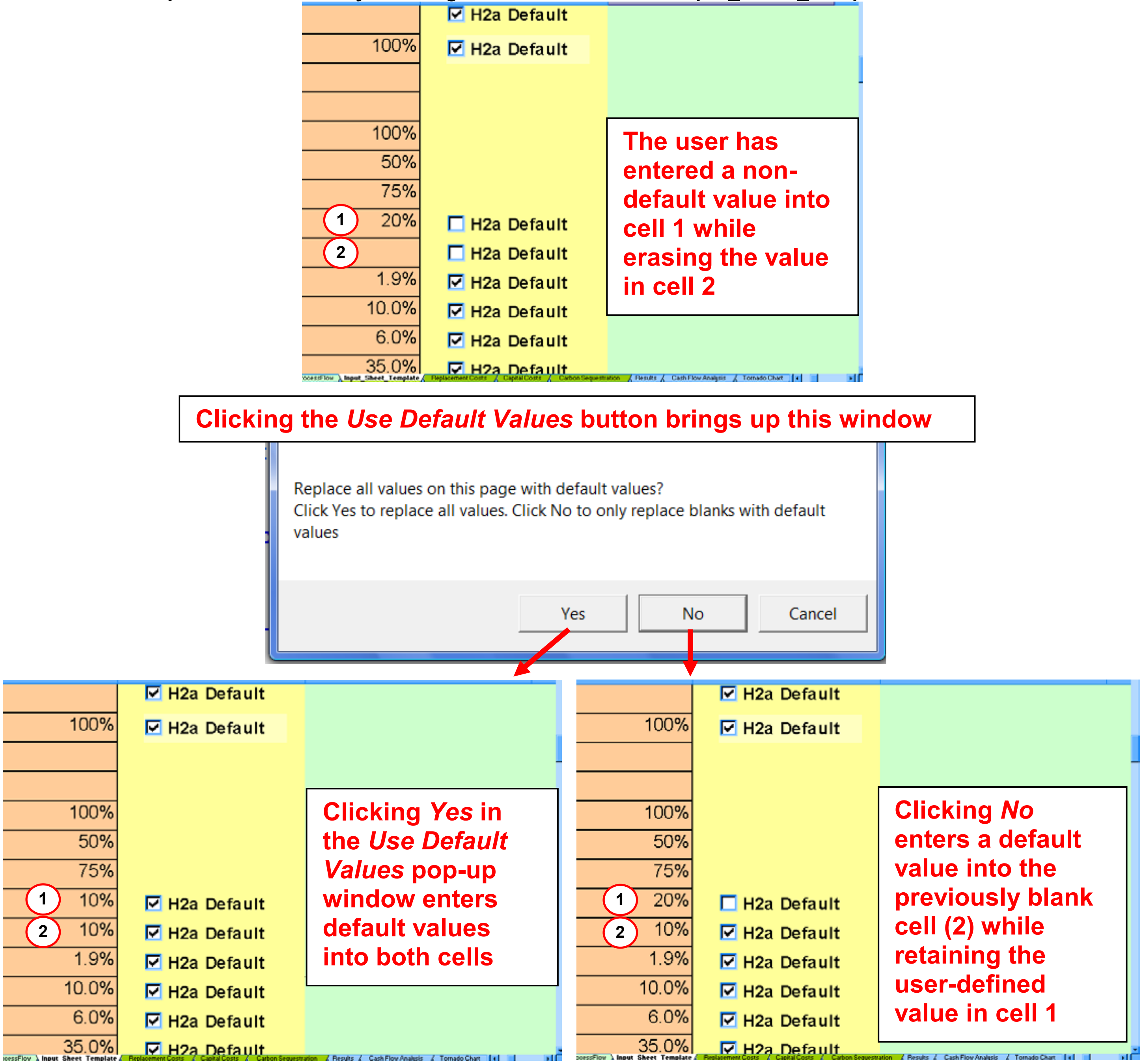
Use the *Calculate Cost* button after completing the *Input_Sheet_Template* worksheet and associated worksheets. For illustrations, read through the rest of this section or see *Quick Start: Performing Simple Production Cost Analyses* (page 7).

Beneath the row of buttons, the *Table of Contents* links to the major sections of the *Input_Sheet_Template* worksheet, which are described in the subsequent sections of this *User Guide*. These sections include the following:

- *Technical Operating Parameters and Specifications*
- *Financial Input Values*
- *Energy Feedstocks, Utilities, and Byproducts*
- *Capital Cost*
- *Fixed Operating Costs*
- *Variable Operating Costs - Other Materials and Byproducts*

- *Variable Operating Costs - Other Variable Operating Costs.*

Example of Automatically Entering Default Values in the Input_Sheet_Template Worksheet



The user has entered a non-default value into cell 1 while erasing the value in cell 2

Clicking the *Use Default Values* button brings up this window

Replace all values on this page with default values?
Click Yes to replace all values. Click No to only replace blanks with default values

Clicking *Yes* in the *Use Default Values* pop-up window enters default values into both cells

Clicking *No* enters a default value into the previously blank cell (2) while retaining the user-defined value in cell 1

Technical Operating Parameters and Specifications

Here you define the hydrogen output of your plant. Enter values for capacity factor and plant design capacity. The model uses these values to calculate plant output.

Financial Input Values

Here you define the financial characteristics of your plant. Several of the fields have an "H2a Default" checkbox adjacent to them. Checking this box automatically fills the cell with the H2A

Model default value for that input. The fields *Length of Construction Period*, *Depreciation Schedule Length*, and *Depreciation Type* have drop-down menus containing predefined values. Select a value from the drop-down menu for these fields; values not listed in the drop-down menus cannot be entered. The only field calculated by the model within the *Financial Input Values* section is *Total Tax Rate*, shown in blue.

Two very important fields in this section are *Reference Year* and *Basis Year*. Throughout the *Input_Sheet_Template* worksheet, you will enter financial values in basis year dollars, and the model will convert the values to reference year dollars. For example, if you have plant costs in 2005 dollars, you set the basis year to 2005 and enter financial values in 2005 dollars throughout the worksheet (in the appropriate orange input cells). Then, if you want cost results in, for example, 2007 dollars, you set the reference year to 2007, and the model automatically converts the 2005-dollar inputs to 2007 dollars based on plant scaling (see page 19) and escalation factors.

Energy Feedstocks, Utilities, and Byproducts

Energy feedstocks, utilities, and byproducts are variable operating costs. In the central model, the inputs for this section follow the *Financial Input Values* section (the remaining central variable operating costs are detailed at the end of the *Input_Sheet_Template* worksheet). This section allows you to define energy feedstock, utility, and byproduct costs and credits—up to four of each type. Each element is added by first defining it using the drop-down menus and data entry fields, then clicking the *Add* button.

The first drop-down menu selects the price data table that will be used to calculate feedstock, energy, and byproduct costs and credits. These EIA data are drawn from the model's *Energy Feed & Utility Prices* worksheet (see page 33). Select one of the tables from the drop-down menu:

- *AEO_2009_Reference_Case*
- *AEO_2009_High_Price_Case*
- *AEO_2010_Reference_Case*

CAUTION

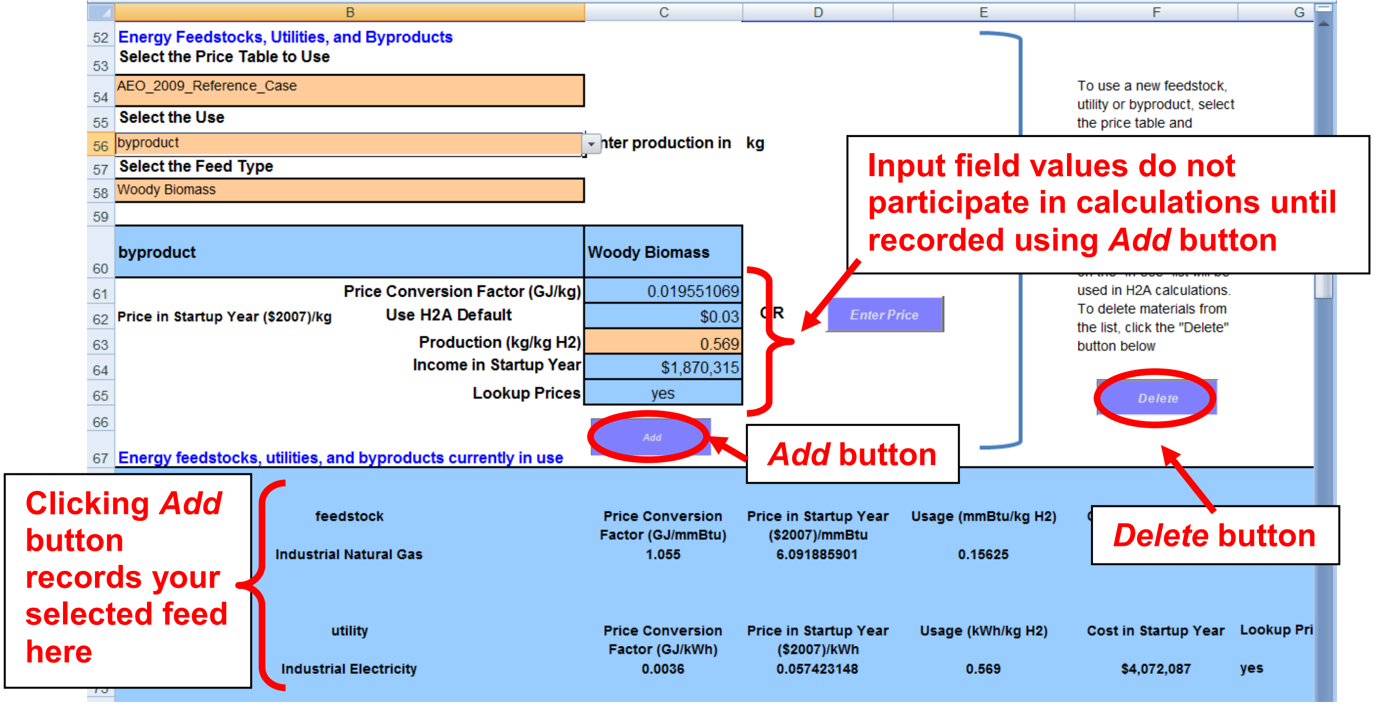
The U.S. Department of Energy (DOE) has selected the *AEO 2009 Reference Case* as the default for all H2A production technology cases. For more information on the price data, see *AEO Data Worksheet* on page 35. Note, you must use only one price table for each analysis, i.e., you must use the same price table for each energy feedstock, utility, and byproduct you enter.

Use the next two drop-down menus to select feedstocks, utility inputs, and byproducts. The lower heating value (LHV) is automatically drawn from the *HyARC Physical Property Data* worksheet, *Table A* (see page 36).

Next, accept the shown *Price in Startup Year* or click the *Enter Price* button to enter a different price (see the screen capture on page 12). If you accept the *Price in Startup Year*, the model looks up the price for each year of the analysis in the selected price table and inflates that value using the inflation rate entered in the *Financial Input Values* section. If you enter your own price, the model inflates that price over the analysis period. For *Usage/Production*, enter the amount of energy or material required to produce a kilogram of hydrogen for sale—or the amount of byproduct produced per kilogram of hydrogen produced—in the unit shown (kg, kWh, Nm3, or L). Once these fields are completed, click the *Add* button, which records your entry as shown in the screen capture on page 12.

Remember that a feedstock, utility, or byproduct does not become part of the model's calculations until you click the *Add* button and the entry is recorded. Values present in the input fields but not recorded in this manner do not participate in the calculations. Established H2A production technology cases include recorded feedstock, utility, and byproduct values. Some also include unrecorded values in the input fields (for example, see the screen capture below). You can disregard these unrecorded values or select new values (then click the *Add* button) if you wish to add your own feedstocks, utilities, or byproducts.

Energy Feedstocks, Utilities, and Byproducts (Input_Sheet_Template Worksheet)



Energy Feedstocks, Utilities, and Byproducts
Select the Price Table to Use
AEO_2009_Reference_Case
Select the Use
byproduct
nter production in kg
Select the Feed Type
Woody Biomass

byproduct		Woody Biomass
	Price Conversion Factor (GJ/kg)	0.019551069
Price in Startup Year ($2007)/kg	Use H2A Default	$0.03
	Production (kg/kg H2)	0.569
	Income in Startup Year	$1,870,315
	Lookup Prices	yes

OR

To use a new feedstock, utility or byproduct, select the price table and

used in H2A calculations. To delete materials from the list, click the "Delete" button below

Energy feedstocks, utilities, and byproducts currently in use

feedstock	Price Conversion Factor (GJ/mmBtu)	Price in Startup Year ($2007)/mmBtu	Usage (mmBtu/kg H2)
Industrial Natural Gas	1.055	6.091885901	0.15625

utility	Price Conversion Factor (GJ/kWh)	Price in Startup Year ($2007)/kWh	Usage (kWh/kg H2)	Cost in Startup Year	Lookup Pri
Industrial Electricity	0.0036	0.057423148	0.569	$4,072,087	yes

Input field values do not participate in calculations until recorded using *Add* button

***Add* button**

***Delete* button**

Clicking *Add* button records your selected feed here

To delete entries, click the *Delete* button, which pulls up the *Toolkit* menu. Use the drop-down menu under *Editing* to select the type of entry you want to delete. Then click the *Delete* button. This deletes all entries of the selected type. For example, if you had selected three energy byproducts, choosing *Energy Byproduct* from the drop-down menu and clicking the *Delete* button will delete all three.

CAUTION

When deleting entries, you must use the *Delete* button. Do not delete rows using Excel's delete function. Also, be careful to choose the correct item from the *Delete* menu within the *Toolkit*. It can delete not only the energy feedstocks, utilities, and byproducts selected in this section, but also the other materials and byproducts selected in the *Variable Operating Costs* section (page 14).

The model uses the selected entries to calculate total energy feedstock and utilities costs and byproduct credits in the startup year; these values appear in the three blue cells at the bottom of the *Energy Feedstocks, Utilities, and Byproducts* section but are not used in the cash-flow calculations. You can view the values being used in the cash-flow calculations for every year of the analysis in the lowermost table of the *Cash Flow Analysis* worksheet (see the bottom screen capture in the schematic on page 14).

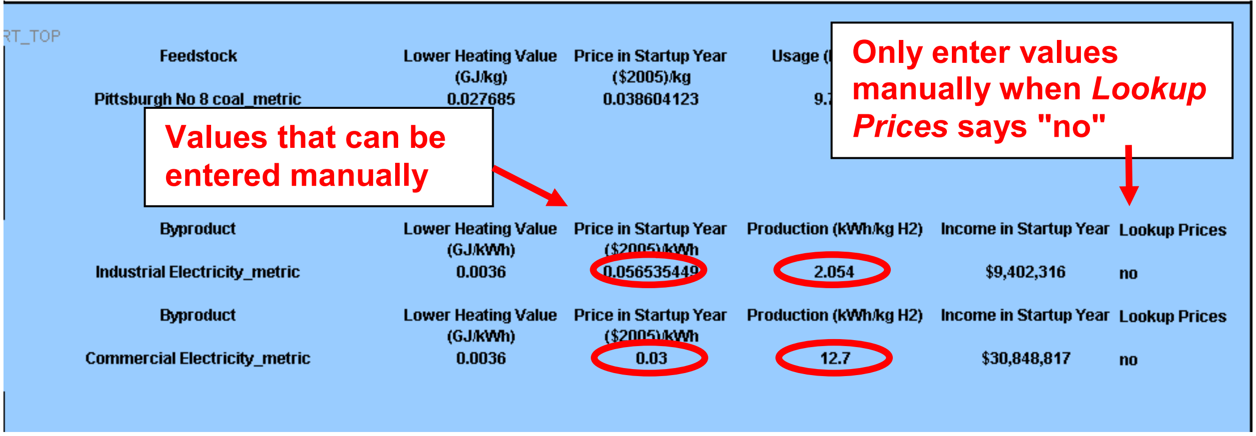
Advanced users only

If desired, advanced users can change the units applied to each material selected in this section. For example, the units for natural gas feedstock could be changed from Nm3 to scf. This requires changes be made elsewhere in the model. Go to the *HyARC Physical Property Data* worksheet, *Table A*, and change the unit in the column *H2A Usage Input Unit/ kg H2*. In the column *H2A LHV (GJ or mmBtu/ H2A usage input unit)*, enter the numerical value of the LHV corresponding to the new input unit; the LHV must be entered as GJ/usage unit for metric values and mmBtu/usage unit for English values. Check that the calculated results are consistent with the new-unit input values.

Advanced users only

Advanced users can take advantage of a shortcut in this section. If you want to perform numerous modeling runs—for example, by modeling the hydrogen costs resulting from an array of feedstock, utility, and byproduct input price and production/usage values—you can save time by typing values directly into certain Excel cells instead of using the model's *Add* and *Delete* functions every time. Initially, add your chosen feedstocks, utilities, and byproducts using the *Add* function. If you want to vary items by typing over values, click the *Enter Price* button for those items and enter your own price; this automatically changes the *Lookup Prices* field to "no." After completing the rest of the model's sections and recording the resulting hydrogen cost, return to the *Energy Feedstocks, Utilities, and Byproducts* section. For any items with "no" in the *Lookup Prices* field, you can manually replace the values for *Usage*/*Production* and *Price in Startup Year*—simply type over the existing values. Once you have finished entering values, click the *Calculate Cost* button for the resulting hydrogen cost.

Advanced Users Can Manually Enter Certain Feedstock, Utility, and Byproduct Values



Feedstock	Lower Heating Value (GJ/kg)	Price in Startup Year ($2005)/kg	Usage (
Pittsburgh No 8 coal_metric	0.027685	0.038604123	9.

Values that can be entered manually

Only enter values manually when *Lookup Prices* says "no"

Byproduct	Lower Heating Value (GJ/kWh)	Price in Startup Year ($2005)/kWh	Production (kWh/kg H2)	Income in Startup Year	Lookup Prices
Industrial Electricity_metric	0.0036	0.056535449	2.054	$9,402,316	no

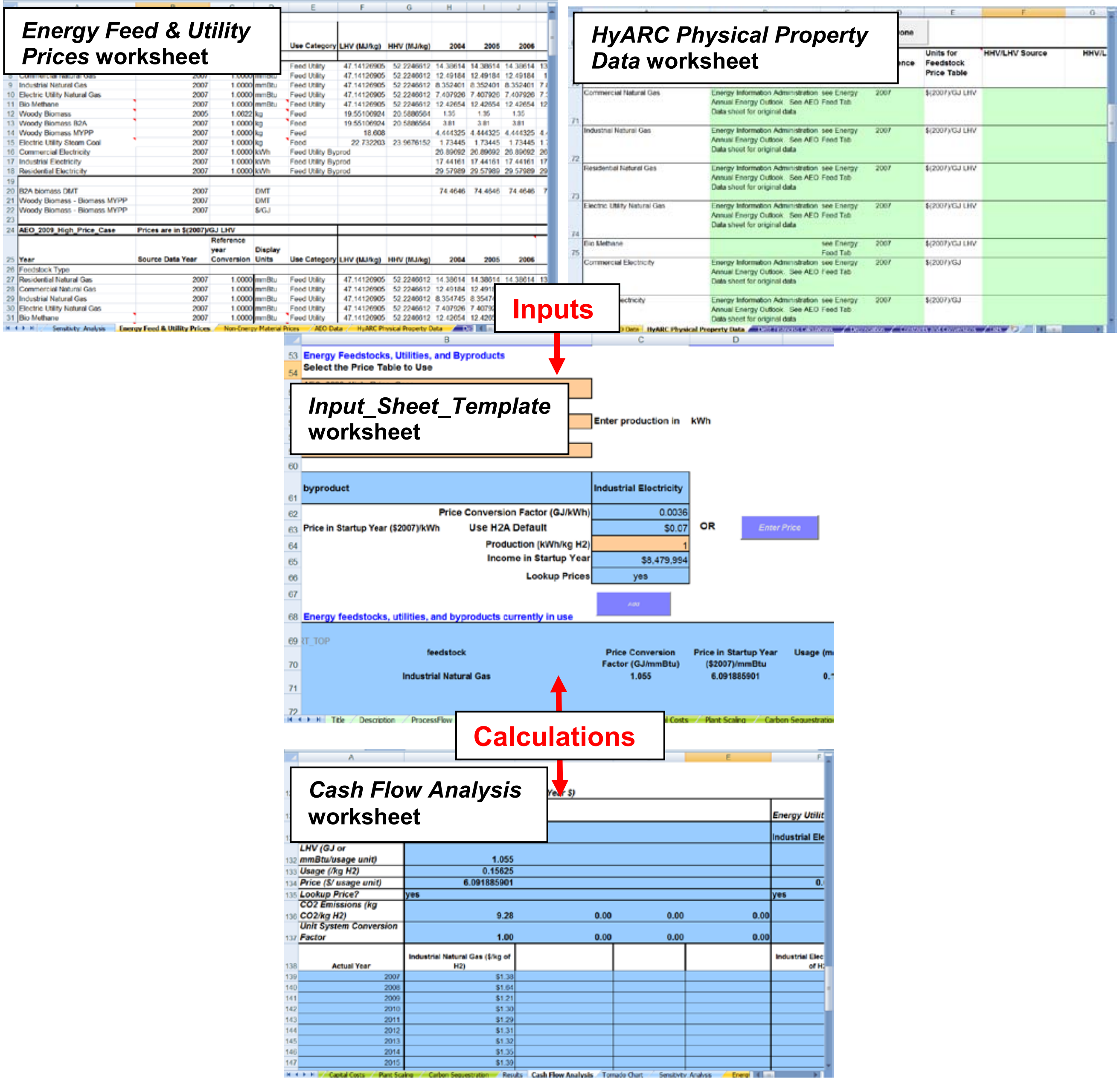
Byproduct	Lower Heating Value (GJ/kWh)	Price in Startup Year ($2005)/kWh	Production (kWh/kg H2)	Income in Startup Year	Lookup Prices
Commercial Electricity_metric	0.0036	0.03	12.7	$30,848,817	no

Capital Costs

Here you define the capital costs of your plant. Click the *View/Edit* button. This takes you to the *Capital Costs* worksheet for data entry (see page 18). Clicking the *Link to Detail Sheet* button takes you to the *Carbon Sequestration* worksheet (see page 22) to calculate detailed capital costs for that function. Note that some of the orange input fields can contain suggested equations. You can overwrite these with your own static values or equations.

Once all applicable fields are filled with inputs and calculated values, the model calculates *Total Depreciable Capital Costs*, *Total Non-Depreciable Capital Costs*, and *Total Capital Costs*.

Schematic of Data Flow to and from Energy Feedstocks, Utilities, and Byproducts Section



Fixed Operating Costs

Here you define your plant's fixed operating costs. Once values are entered or calculated for each field, the model calculates *Total Fixed Operating Costs*.

Variable Operating Costs

Here you define process material costs and other variable operating costs and the value of non-energy byproducts. The parts of the *Variable Operating Costs* section are *Other Materials and Byproducts* and *Other Variable Operating Costs*. To prevent model errors, enter all critical values in the *Technical Operating Parameters and Specifications* (page 10) and *Financial Input Values* (page 10) sections before completing these sub-sections.

Make sure values are present for reference year, startup year, & plant capacity

TIP

Other Materials and Byproducts

This sub-section (see screen capture on next page) works in a fashion similar to the *Energy Feedstocks, Utilities, and Byproducts* function described on page 11. It allows you to define up to three non-energy input materials and three byproducts. Each element is added by first defining it using the drop-down menu and data entry fields, then clicking the *Add* button.

This sub-section requires fewer user choices than the *Energy Feedstocks, Utilities, and Byproducts* function. You do not need to select price tables; prices are automatically drawn from the lists on the *Non-Energy Material Prices* worksheet, or you can enter your own price by clicking the *Enter Price* button.

The *Byproduct* check box allows you to switch between materials consumed as process inputs (which incur costs) and materials produced as byproducts (which produce income/credits). When the box is unchecked, the material in the drop-down menu (cooling water, demineralized water, etc.) is labeled as a feed or utility, and the number you input is usage per kilogram of hydrogen produced for sale. When the box is checked, the material in the drop-down menu is labeled as a byproduct, and the number you input is production per kilogram of hydrogen. Regardless of whether you classify the material as a feed/utility or byproduct, the price is drawn from the *Non-Energy Material Prices* worksheet unless you click the *Enter Price* button and enter your own price. You should always enter feed/utility and byproduct prices as positive values.

You can add materials to the drop-down menu simply by going to the *Non-Energy Material Prices* worksheet and adding information for the new material in the rows underneath the existing information. See *Non-Energy Material Prices Worksheet* on page 34 for an illustration. This is also where you can modify the material prices if desired.

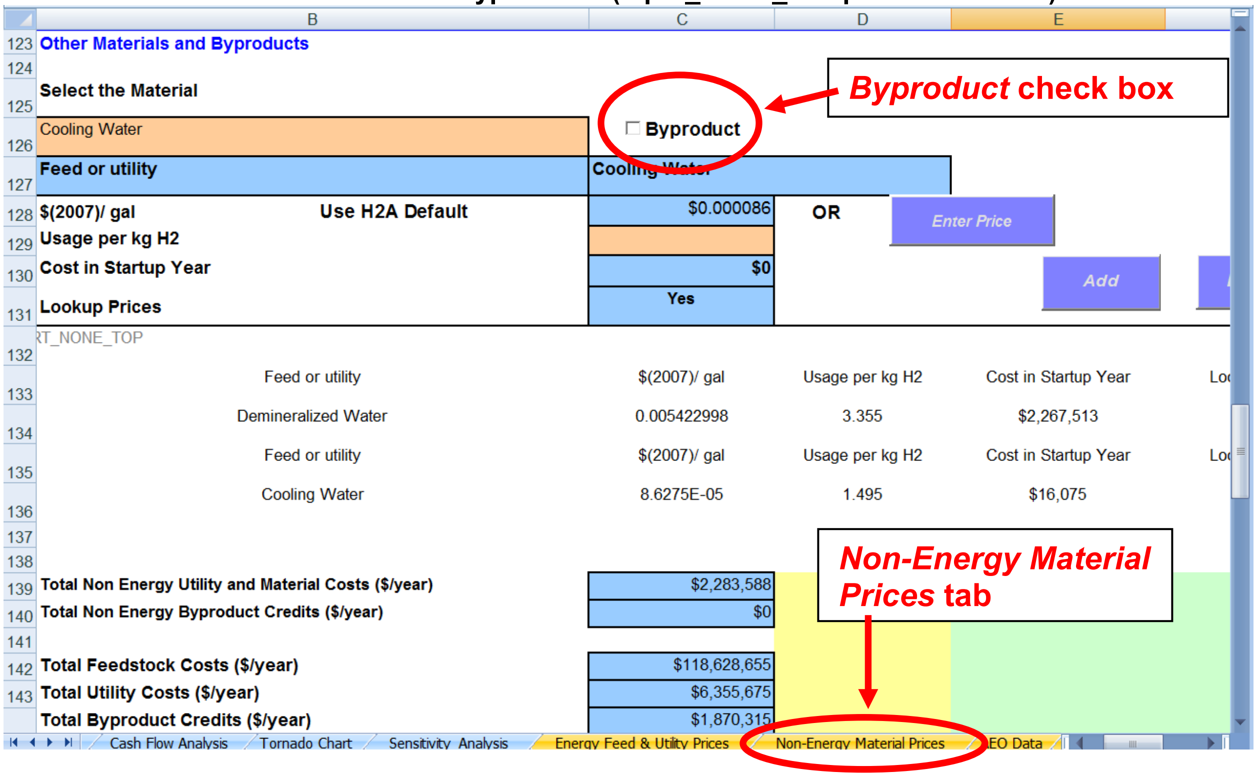
CAUTION

When deleting entries, you must use the *Delete* button. Do not delete the rows using Excel's delete functionality. Also, be careful to choose the correct item from the *Delete* drop-down menu within the *H2A Toolkit*. It can delete not only the other materials and byproducts selected in this sub-section, but also the energy feedstocks, utilities, and byproducts selected previously (see page 11).

Advanced users can take advantage of a shortcut in this section by typing values directly into certain Excel cells instead of using the model's *Add* and *Delete* functions every time. This is done in a fashion similar to that in the *Energy Feedstocks, Utilities, and Byproducts* section—see page 13 for instructions.

Advanced
users only

Other Materials and Byproducts (Input_Sheet_Template Worksheet)



	B		C	D	E
123	**Other Materials and Byproducts**				
124					
125	**Select the Material**				
126	Cooling Water		☐ **Byproduct**		
127	**Feed or utility**		**Cooling Water**		
128	**$(2007)/ gal**	**Use H2A Default**	$0.000086	**OR**	
129	**Usage per kg H2**				
130	**Cost in Startup Year**		$0		
131	**Lookup Prices**		**Yes**		
132	RT_NONE_TOP				
133	Feed or utility		$(2007)/ gal	Usage per kg H2	Cost in Startup Year
134	Demineralized Water		0.005422998	3.355	$2,267,513
135	Feed or utility		$(2007)/ gal	Usage per kg H2	Cost in Startup Year
136	Cooling Water		8.6275E-05	1.495	$16,075
137					
138					
139	**Total Non Energy Utility and Material Costs ($/year)**		$2,283,588		
140	**Total Non Energy Byproduct Credits ($/year)**		$0		
141					
142	**Total Feedstock Costs ($/year)**		$118,628,655		
143	**Total Utility Costs ($/year)**		$6,355,675		
	Total Byproduct Credits ($/year)		$1,870,315		

Byproduct check box

Non-Energy Material Prices tab

Other Variable Operating Costs

This sub-section defines additional variable operating costs. Fill in the appropriate input (orange) cells. The factor you enter in the field *Total Unplanned Replacement Capital Cost Factor* is transferred to the *Replacement Costs* worksheet (see page 17), which calculates replacement costs based on this factor and the value for total depreciable capital costs (see *Capital Costs*, page 13). Clicking the *Enter Specific Costs* button takes you to the *Replacement Costs* worksheet, where you can specify additional replacement costs.

For the central model, the field *CO2 sequestration O&M costs and credits* is filled in automatically if you linked to the *Carbon Sequestration* worksheet in the *Capital Costs* section (see page 13). Once you have entered all the information you want to enter, scroll to the top of the *Input_Sheet_Template* worksheet and click the *Calculate Cost* button. This sends you to the *Results* worksheet, which displays results as illustrated under *Quick Start: Performing Simple Cost Analyses* (page 7).

Replacement Costs Worksheet

The *Replacement Costs* worksheet is the source of replacement cost information for the cash flow analysis calculations. It accounts for planned and unplanned replacement costs.

Enter planned replacement costs in reference year dollars—do not inflate.

TIP

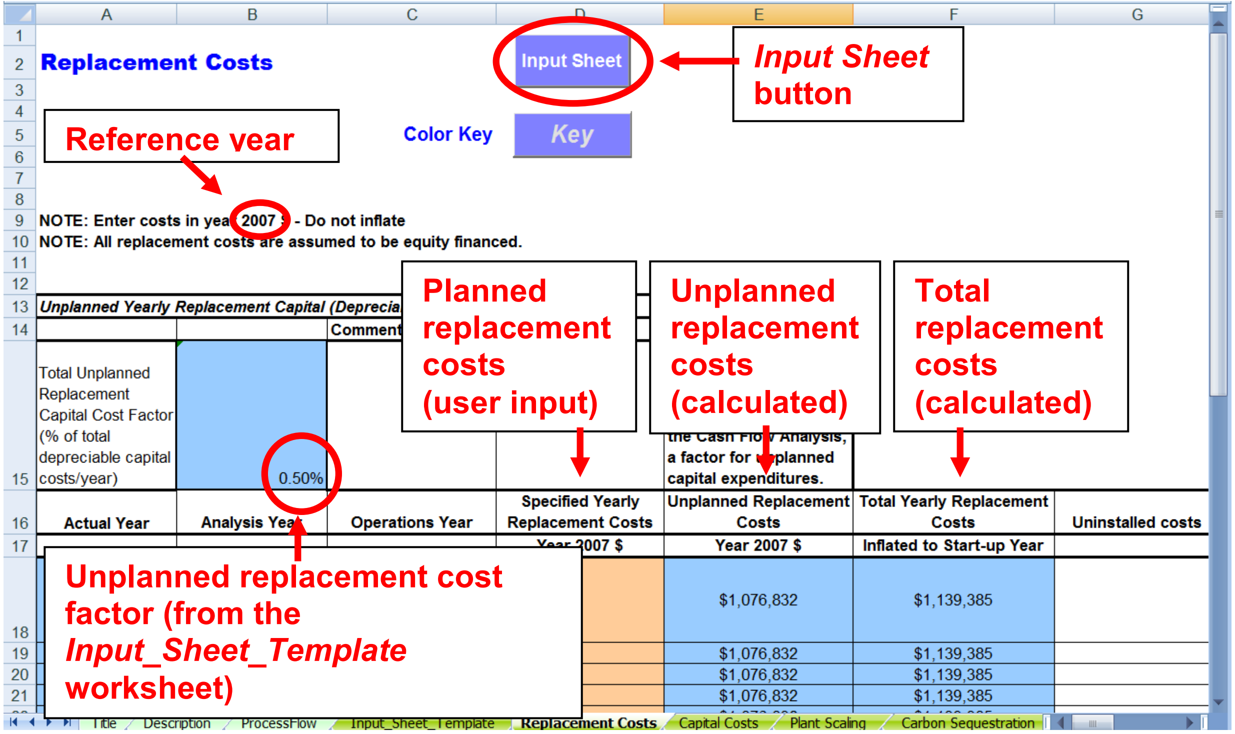
Enter planned replacement costs (in reference year $) for each year in the *Specified Yearly Replacement Costs* column. The values in the *Unplanned Replacement Costs* column are calculated automatically in the following way:

1) The *Total Unplanned Replacement Capital Cost Factor* you entered in the *Other Variable Operating Costs* sub-section of the *Input_Sheet_Template* worksheet (see page 16) is automatically imported into the *Replacement Costs* worksheet (in the uppermost blue cell; see screen capture below). Clicking the *Input Sheet* button sends you directly to the relevant cost factor cell in the *Input_Sheet_Template* worksheet.

2) This cost factor is multiplied times the *Total Depreciable Capital Costs* value from the *Input_Sheet_Template* worksheet (see page 13); the result is automatically entered for each year in the *Unplanned Replacement Costs* column.

The inflation-adjusted sum of the specified (i.e., planned) and unplanned replacement costs is automatically entered into the *Total Yearly Replacement Costs* column. When finished, click the *Input Sheet* button to return to the *Input_Sheet_Template* worksheet.

Replacement Costs Worksheet



Replacement Costs

NOTE: Enter costs in yea 2007 $ - Do not inflate

NOTE: All replacement costs are assumed to be equity financed.

Unplanned Yearly Replacement Capital (Deprecia

Comment

Total Unplanned Replacement Capital Cost Factor (% of total depreciable capital costs/year) 0.50%

the Cash Flo Analysis, a factor for planned capital expenditures.

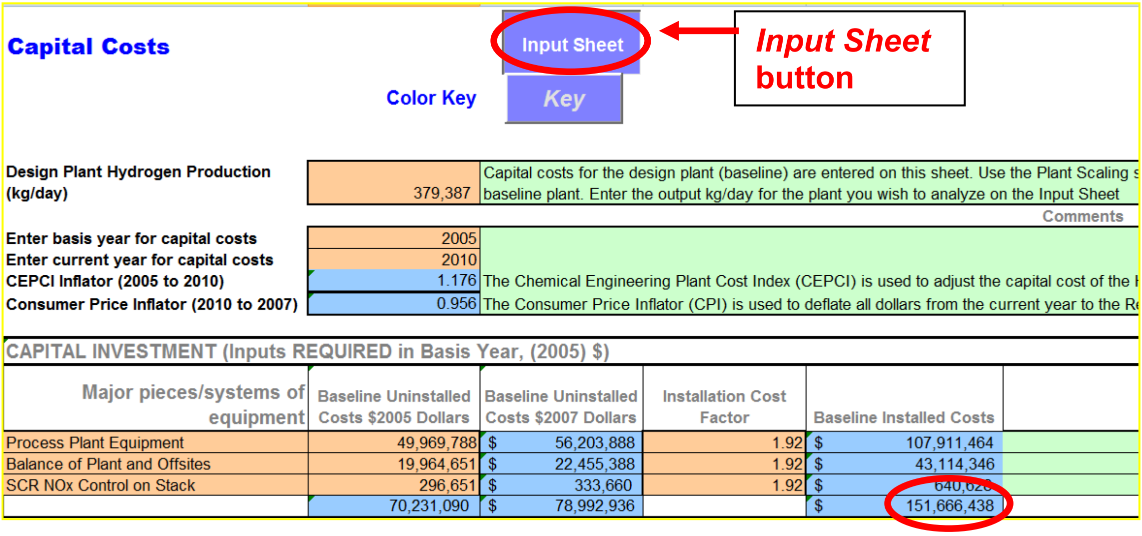
Actual Year	Analysis Yea	Operations Year	Specified Yearly Replacement Costs	Unplanned Replacement Costs	Total Yearly Replacement Costs	Uninstalled costs
			Year 2007 $	Year 2007 $	Inflated to Start-up Year	
				$1,076,832	$1,139,385	
				$1,076,832	$1,139,385	
				$1,076,832	$1,139,385	
				$1,076,832	$1,139,385	

Capital Costs Worksheet

The *Capital Costs* worksheet accepts inputs for individual capital costs and calculates total direct capital cost. This total direct capital cost is then imported into the *Capital Costs* section of the *Input_Sheet_Template* worksheet (see page 13). For the central model, this is the direct capital cost of the production equipment not including carbon sequestration equipment (see page 22 for carbon sequestration calculations).

Activate the *Capital Costs* worksheet by clicking the *View/Edit* button next to the *H2A Total Direct Capital Cost* field in the *Capital Costs* section of the *Input_Sheet_Template* worksheet. Enter the names of capital equipment items in the column *Major pieces/systems of equipment*. Enter uninstalled costs for each item in the column *Baseline Uninstalled Costs*. Under the column *Installation Cost Factor*, enter values by which the uninstalled costs of each item will be multiplied to give installed costs. The model automatically calculates total installed direct capital cost in the *Baseline Installed Costs* column. When you are finished inputting values, click the *Input Sheet* button at top to return to the *Input_Sheet_Template* worksheet, where the total capital cost will appear; the screen captures below show the link.

Capital Costs Worksheet



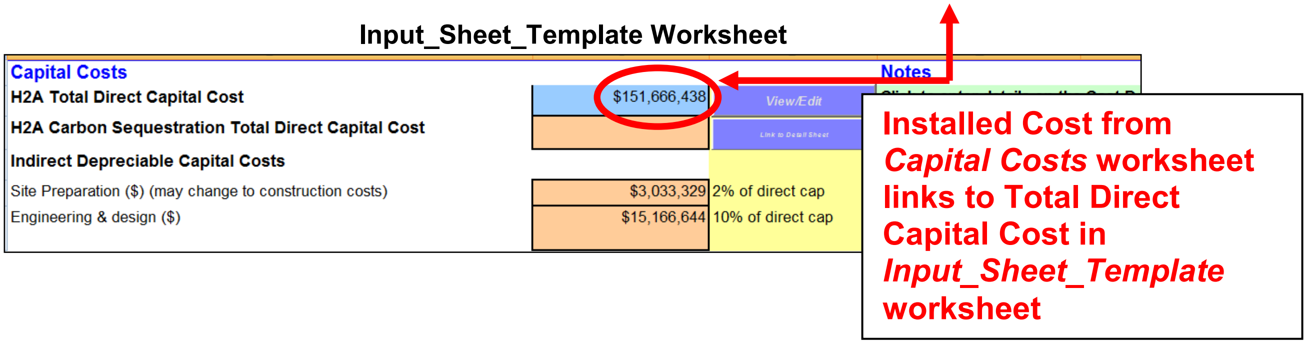
Input Sheet button

Design Plant Hydrogen Production (kg/day)	379,387	Capital costs for the design plant (baseline) are entered on this sheet. Use the Plant Scaling s baseline plant. Enter the output kg/day for the plant you wish to analyze on the Input Sheet
		Comments
Enter basis year for capital costs	2005	
Enter current year for capital costs	2010	
CEPCI Inflator (2005 to 2010)	1.176	The Chemical Engineering Plant Cost Index (CEPCI) is used to adjust the capital cost of the H
Consumer Price Inflator (2010 to 2007)	0.956	The Consumer Price Inflator (CPI) is used to deflate all dollars from the current year to the Re

CAPITAL INVESTMENT (Inputs REQUIRED in Basis Year, (2005) $)

Major pieces/systems of equipment	Baseline Uninstalled Costs $2005 Dollars	Baseline Uninstalled Costs $2007 Dollars	Installation Cost Factor	Baseline Installed Costs
Process Plant Equipment	49,969,788	$ 56,203,888	1.92	$ 107,911,464
Balance of Plant and Offsites	19,964,651	$ 22,455,388	1.92	$ 43,114,346
SCR NOx Control on Stack	296,651	$ 333,660	1.92	$ 640,628
	70,231,090	$ 78,992,936		$ 151,666,438

Input_Sheet_Template Worksheet



Capital Costs		
H2A Total Direct Capital Cost	$151,666,438	
H2A Carbon Sequestration Total Direct Capital Cost		
Indirect Depreciable Capital Costs		
Site Preparation ($) (may change to construction costs)	$3,033,329	2% of direct cap
Engineering & design ($)	$15,166,644	10% of direct cap

Installed Cost from *Capital Costs* worksheet links to Total Direct Capital Cost in *Input_Sheet_Template* worksheet

Plant Scaling Worksheet

The H2A Model is designed to determine the levelized cost of hydrogen from a facility with a specific hydrogen production capacity. Similarly, established H2A production technology cases model facilities with specific production capacities. The *Plant Scaling* worksheet makes it easy to analyze facilities with different production capacities. Complete the following steps in the order shown:

1) Set Baseline Plant Values (*Input_Sheet_Template*, *Capital Costs, and Plant Scaling* Worksheets)

Baseline plant values are imported into the *Plant Scaling* worksheet from the *Input_Sheet_Template* and *Capital Costs* worksheets, so the first step is to fill out those worksheets completely (see pages 9 and 18). Once you have finished, go to the *Plant Scaling* worksheet. Within the *Plant Scaling* worksheet, the first cell (*Baseline Design Capacity*) and the baseline value cells in the *Capital Investment* section are automatically imported from the *Capital Costs* worksheet. The baseline value cells in the *Plant Scaling Method* section are imported from the *Input_Sheet_Template* worksheet.

2) Establish Scaling Parameters (*Plant Scaling* Worksheet)

Within the *Plant Scaling* worksheet, accept or create scaling parameters. In the *Plant Scaling Factors* section, accept the *Default Scaling Factor Exponent* or enter a new one.

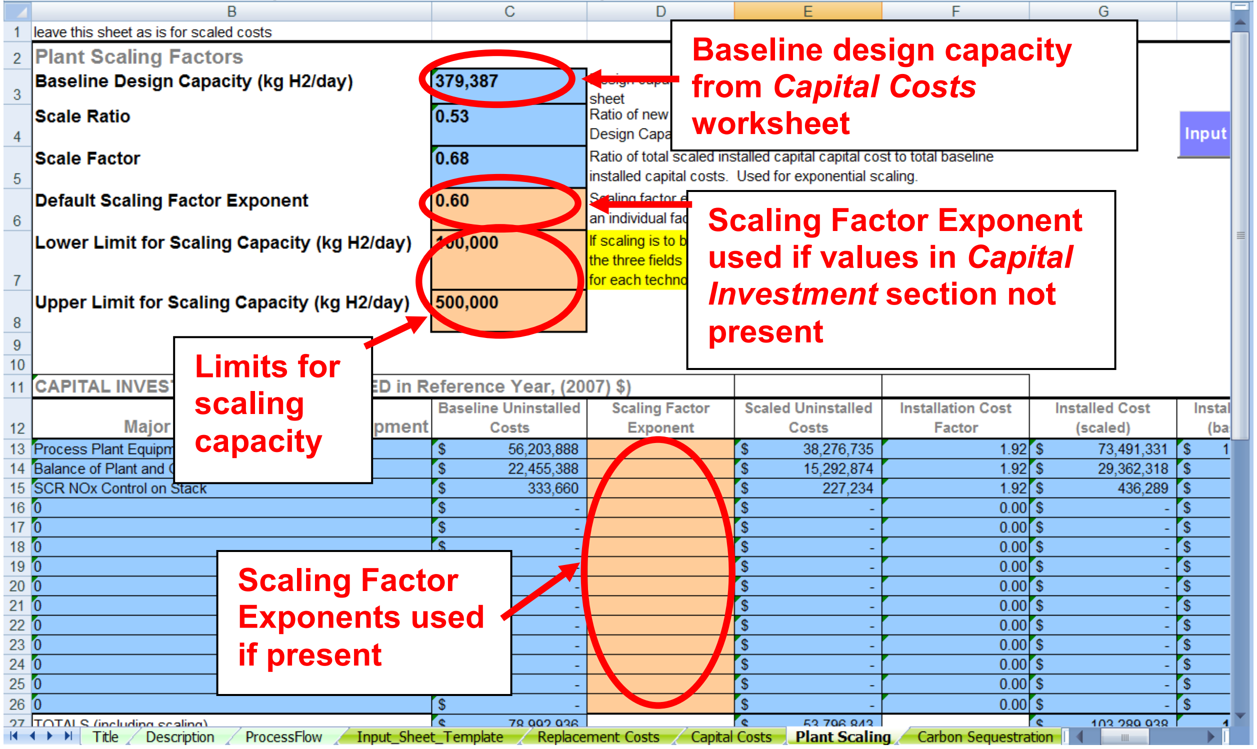
Changing the Scaling Factor Exponent changes how the cost of each item of capital equipment varies in relation to the Scale Ratio (the ratio of new design capacity to baseline design capacity) as follows:

$$\text{Scaled Cost} = \text{Baseline Cost} \times \text{Scale Ratio}^{\text{Scaling Factor Exponent}}$$

For example, a Scaling Factor Exponent of 1.0 means the cost of the equipment increases by the same ratio as the increase in plant capacity. Scaling Factor Exponents are typically 1.0 or less. If values for individual pieces of equipment are entered in the column *Scaling Factor Exponent* within the *Capital Investment* section, those values are used in the scaling calculations. If a value is not present in this column for a given item, the *Default Scaling Factor Exponent* in the *Plant Scaling Factors* section is used.

The *Lower Limit for Scaling Capacity* and *Upper Limit for Scaling Capacity* fields define the capacity range within which the scaling you are defining is valid. The model will alert you when you click the *Calculate Cost* button (in step 3, see below) if you attempt to scale your plant capacity outside the range you specify.

Plant Scaling Worksheet: Plant Scaling Factors and Capital Investment Sections



leave this sheet as is for scaled costs

Plant Scaling Factors

Baseline Design Capacity (kg H2/day)	379,387	sheet
Scale Ratio	0.53	Ratio of new Design Capa
Scale Factor	0.68	Ratio of total scaled installed capital capital cost to total baseline installed capital costs. Used for exponential scaling.
Default Scaling Factor Exponent	0.60	Scaling factor e an individual fac
Lower Limit for Scaling Capacity (kg H2/day)	100,000	If scaling is to b the three fields for each techno
Upper Limit for Scaling Capacity (kg H2/day)	500,000	

Baseline design capacity from *Capital Costs* worksheet

Scaling Factor Exponent used if values in *Capital Investment* section not present

Limits for scaling capacity

Input

CAPITAL INVES…ED in Reference Year, (2007) $)

Major …pment	Baseline Uninstalled Costs	Scaling Factor Exponent	Scaled Uninstalled Costs	Installation Cost Factor	Installed Cost (scaled)	Instal (ba
Process Plant Equipm	$ 56,203,888		$ 38,276,735	1.92	$ 73,491,331	$ 1
Balance of Plant and (	$ 22,455,388		$ 15,292,874	1.92	$ 29,362,318	$
SCR NOx Control on Stack	$ 333,660		$ 227,234	1.92	$ 436,289	$
0	$ -		$ -	0.00	$ -	$
0	$ -		$ -	0.00	$ -	$
0	$ -		$ -	0.00	$ -	$
0	-		$ -	0.00	$ -	$
0	-		$ -	0.00	$ -	$
0	-		$ -	0.00	$ -	$
0	-		$ -	0.00	$ -	$
0	-		$ -	0.00	$ -	$
0	-		$ -	0.00	$ -	$
0	-		$ -	0.00	$ -	$
0	$ -		$ -	0.00	$ -	$
TOTALS (including scaling)	$ 78,992,936		$ 53,796,843		$ 103,289,938	1

Scaling Factor Exponents used if present

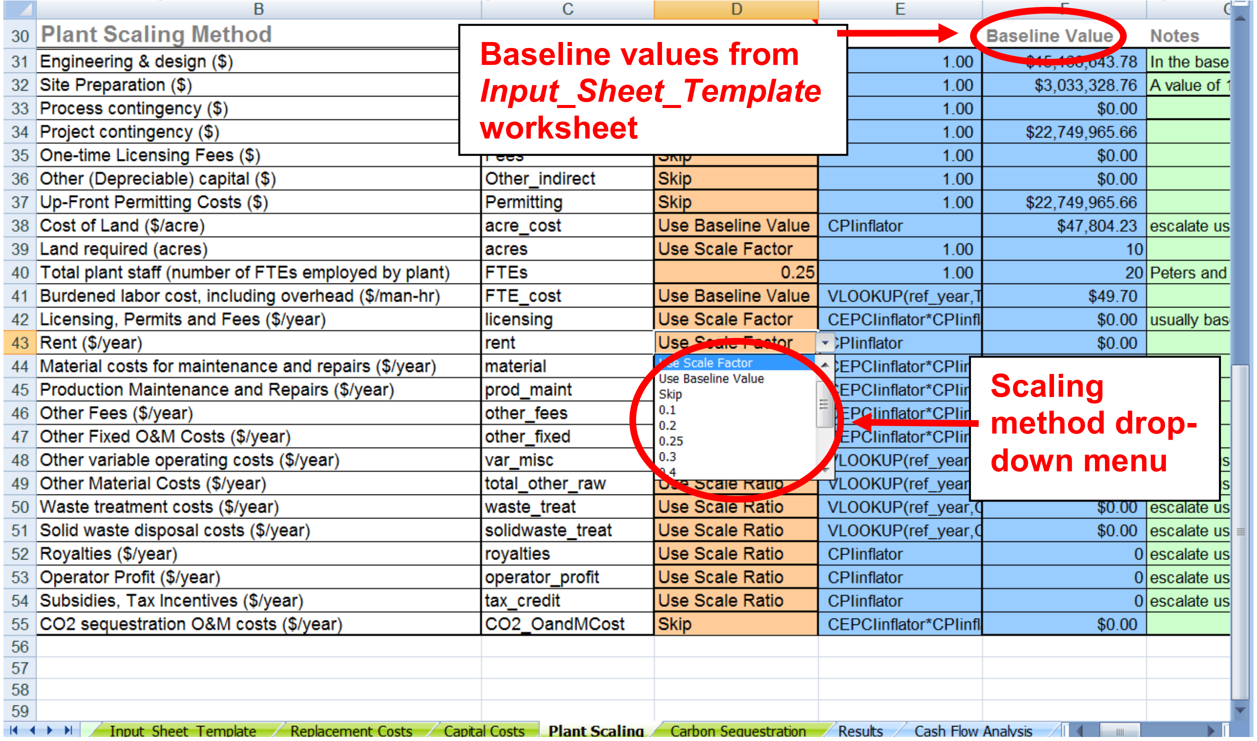
After you have added Scaling Factor Exponents to the *Plant Scaling Factors* and *Capital Investment* sections, go down to the next section to accept or define scaling parameters for indirect and non-depreciable capital costs and operating costs. The baseline values for these items (Engineering & Design, Site Preparation, etc.) are automatically imported from the *Input_Sheet_Template* worksheet.

For each item in the table, choose one of the following scaling methods from the drop-down menus in the *Select Method* column:

- *Use Scale Ratio*—uses the scale ratio to scale the item cost in relation to plant capacity (i.e., linearly) (Scaled Value = Baseline Value × Scale Ratio)
- *Use Scale Factor*—uses the scale factor (the ratio of total scaled installed capital cost to total baseline installed capital cost) to scale the item cost in relation to plant capital cost (i.e., scale with capital costs) (Scaled Value = Baseline Value × Scale Factor)
- *Use Baseline Value*—uses the shown baseline value with no scaling
- *Skip*—skips the value, does not change the cell value or equation
- Use scale ratio with scaling factor exponent—uses the number you select from the drop-down menu (0.1, 0.2, etc.) as the scaling factor exponent, to scale the value in relation to the scale ratio as follows: Scaled Value = Baseline Cost × Scale Ratio$^{\text{Scaling Factor Exponent}}$

The next column lists the escalation factors that the model will apply to each value, in addition to the plant scaling factors, to convert basis-year dollars to reference-year dollars. Once you have selected scaling methods for all items, return to the *Input_Sheet_Template* worksheet.

Plant Scaling Worksheet: Plant Scaling for Indirect & Non-Depreciable Capital and Operating Costs



	B	C	D	E	F	G
30	Plant Scaling Method				Baseline Value	Notes
31	Engineering & design ($)			1.00	[illegible]	In the base
32	Site Preparation ($)			1.00	$3,033,328.76	A value of
33	Process contingency ($)			1.00	$0.00	
34	Project contingency ($)			1.00	$22,749,965.66	
35	One-time Licensing Fees ($)	Fees	Skip	1.00	$0.00	
36	Other (Depreciable) capital ($)	Other_indirect	Skip	1.00	$0.00	
37	Up-Front Permitting Costs ($)	Permitting	Skip	1.00	$22,749,965.66	
38	Cost of Land ($/acre)	acre_cost	Use Baseline Value	CPIinflator	$47,804.23	escalate us
39	Land required (acres)	acres	Use Scale Factor	1.00	10	
40	Total plant staff (number of FTEs employed by plant)	FTEs	0.25	1.00	20	Peters and
41	Burdened labor cost, including overhead ($/man-hr)	FTE_cost	Use Baseline Value	VLOOKUP(ref_year,T	$49.70	
42	Licensing, Permits and Fees ($/year)	licensing	Use Scale Factor	CEPCIinflator*CPIinfl	$0.00	usually bas
43	Rent ($/year)	rent	Use Scale Factor	CPIinflator	$0.00	
44	Material costs for maintenance and repairs ($/year)	material		CEPCIinflator*CPIin		
45	Production Maintenance and Repairs ($/year)	prod_maint		CEPCIinflator*CPIin		
46	Other Fees ($/year)	other_fees		CEPCIinflator*CPIin		
47	Other Fixed O&M Costs ($/year)	other_fixed		CEPCIinflator*CPIin		
48	Other variable operating costs ($/year)	var_misc		VLOOKUP(ref_year		
49	Other Material Costs ($/year)	total_other_raw	Use Scale Ratio	VLOOKUP(ref_year		
50	Waste treatment costs ($/year)	waste_treat	Use Scale Ratio	VLOOKUP(ref_year,C	$0.00	escalate us
51	Solid waste disposal costs ($/year)	solidwaste_treat	Use Scale Ratio	VLOOKUP(ref_year,C	$0.00	escalate us
52	Royalties ($/year)	royalties	Use Scale Ratio	CPIinflator	0	escalate us
53	Operator Profit ($/year)	operator_profit	Use Scale Ratio	CPIinflator	0	escalate us
54	Subsidies, Tax Incentives ($/year)	tax_credit	Use Scale Ratio	CPIinflator	0	escalate us
55	CO2 sequestration O&M costs ($/year)	CO2_OandMCost	Skip	CEPCIinflator*CPIinfl	$0.00	
56						
57						
58						
59						

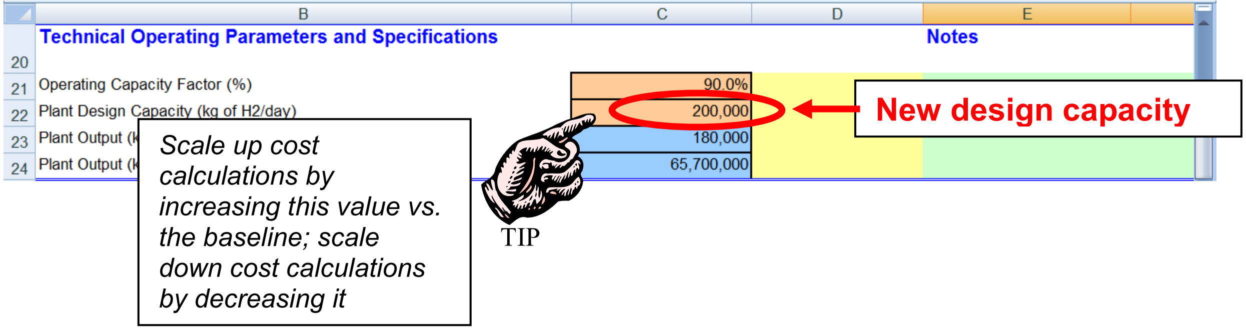
Baseline values from *Input_Sheet_Template* worksheet

Scaling method drop-down menu

3) Set Scaled Plant Capacity (*Input_Sheet_Template* Worksheet)

Within the *Input_Sheet_Template* worksheet, enter a value for your new plant's design capacity in the *Technical Operating Parameters and Specifications* section (see screen capture below). If this value is larger than the baseline design capacity (as defined in the *Capital Costs* worksheet), the scale factor and ratio will be greater than 1.00. If it is smaller, the scale factor and ratio will be less than 1.00. Once you have entered this value, the cost values in the *Input_Sheet_Template* and *Plant Scaling* worksheets are scaled automatically according to the parameters you set in the *Plant Scaling* worksheet (step 2 above). Click the *Calculate Cost* button to calculate the new hydrogen cost.

Input_Sheet_Template Worksheet



	B	C	D	E
	Technical Operating Parameters and Specifications			Notes
20				
21	Operating Capacity Factor (%)	90.0%		
22	Plant Design Capacity (kg of H2/day)	200,000		
23	Plant Output (k	180,000		
24	Plant Output (k	65,700,000		

New design capacity

Scale up cost calculations by increasing this value vs. the baseline; scale down cost calculations by decreasing it

Turning Off Plant Scaling

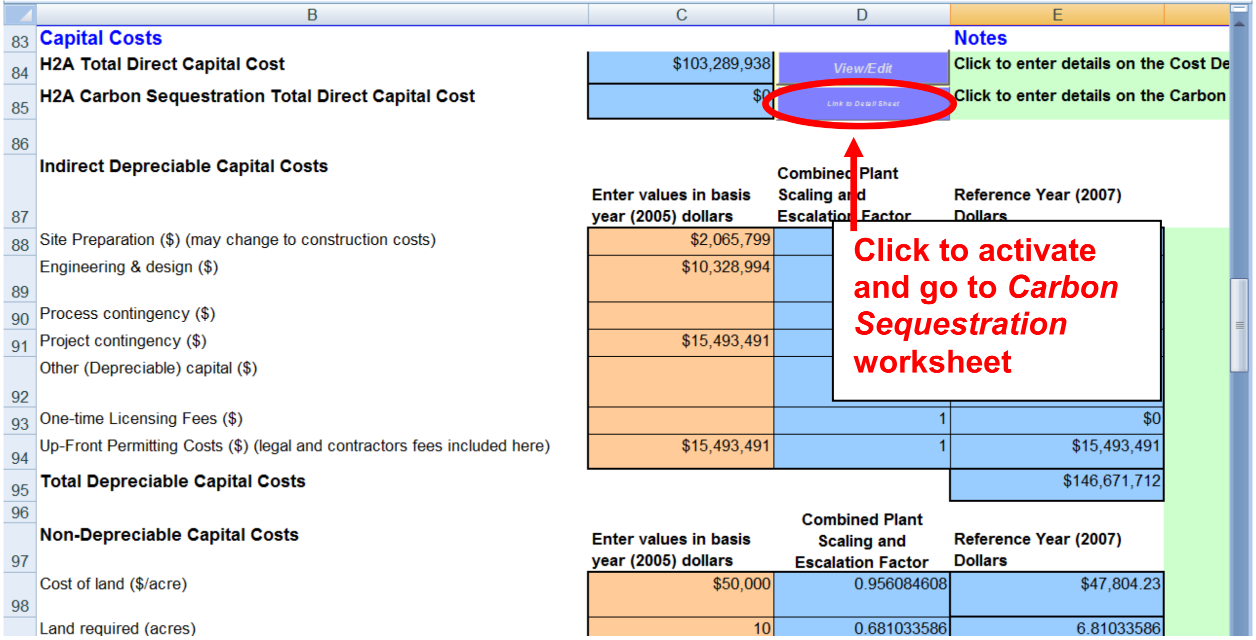
To turn off plant scaling, reset the plant design capacity in the *Technical Operating Parameters and Specifications* section of the *Input_Sheet_Template* worksheet (see screen capture above) to be equal to the *Design Plant Hydrogen Production* value within the *Capital Costs* worksheet. Your plant characteristics will revert to the previously established baseline values.

Carbon Sequestration Worksheet

This worksheet is the source of values for carbon sequestration capital, operating, and electrical costs as well as carbon sequestration efficiency (proportion of carbon emissions captured from hydrogen production feedstocks) and energy use. It calculates costs for CO_2 compression, transportation to the sequestration site, and injection. Costs for CO_2 capture are assumed to be included in the production facility's capital and operating costs and are not included in this worksheet. Further, the worksheet only covers CO_2 emissions from the hydrogen production feedstocks, not CO_2 emissions from fuels used as utilities (e.g., natural gas used in a heater).

Before completing the *Carbon Sequestration* worksheet, specify all feedstocks and utilities in the *Input_Sheet_Template* worksheet (see *Energy Feedstocks, Utilities, and Byproducts*, page 11). After you have specified the feedstocks and utilities, activate the *Carbon Sequestration* worksheet by clicking the *Link to Detail Sheet* button next to the *H2A Carbon Sequestration Total Direct Capital Cost* field in the *Capital Costs* section of the *Input_Sheet_Template* worksheet (see screen capture below).

Input_Sheet_Template Worksheet



	B	C	D	E
83	**Capital Costs**			**Notes**
84	**H2A Total Direct Capital Cost**	$103,289,938		Click to enter details on the Cost De
85	**H2A Carbon Sequestration Total Direct Capital Cost**	$0		Click to enter details on the Carbon
86				
87	**Indirect Depreciable Capital Costs**	Enter values in basis year (2005) dollars	Combined Plant Scaling and Escalation Factor	Reference Year (2007) Dollars
88	Site Preparation ($) (may change to construction costs)	$2,065,799		
89	Engineering & design ($)	$10,328,994		
90	Process contingency ($)			
91	Project contingency ($)	$15,493,491		
92	Other (Depreciable) capital ($)			
93	One-time Licensing Fees ($)		1	$0
94	Up-Front Permitting Costs ($) (legal and contractors fees included here)	$15,493,491	1	$15,493,491
95	**Total Depreciable Capital Costs**			$146,671,712
96				
97	**Non-Depreciable Capital Costs**	Enter values in basis year (2005) dollars	Combined Plant Scaling and Escalation Factor	Reference Year (2007) Dollars
98	Cost of land ($/acre)	$50,000	0.956084608	$47,804.23
	Land required (acres)	10	0.681033586	6.81033586

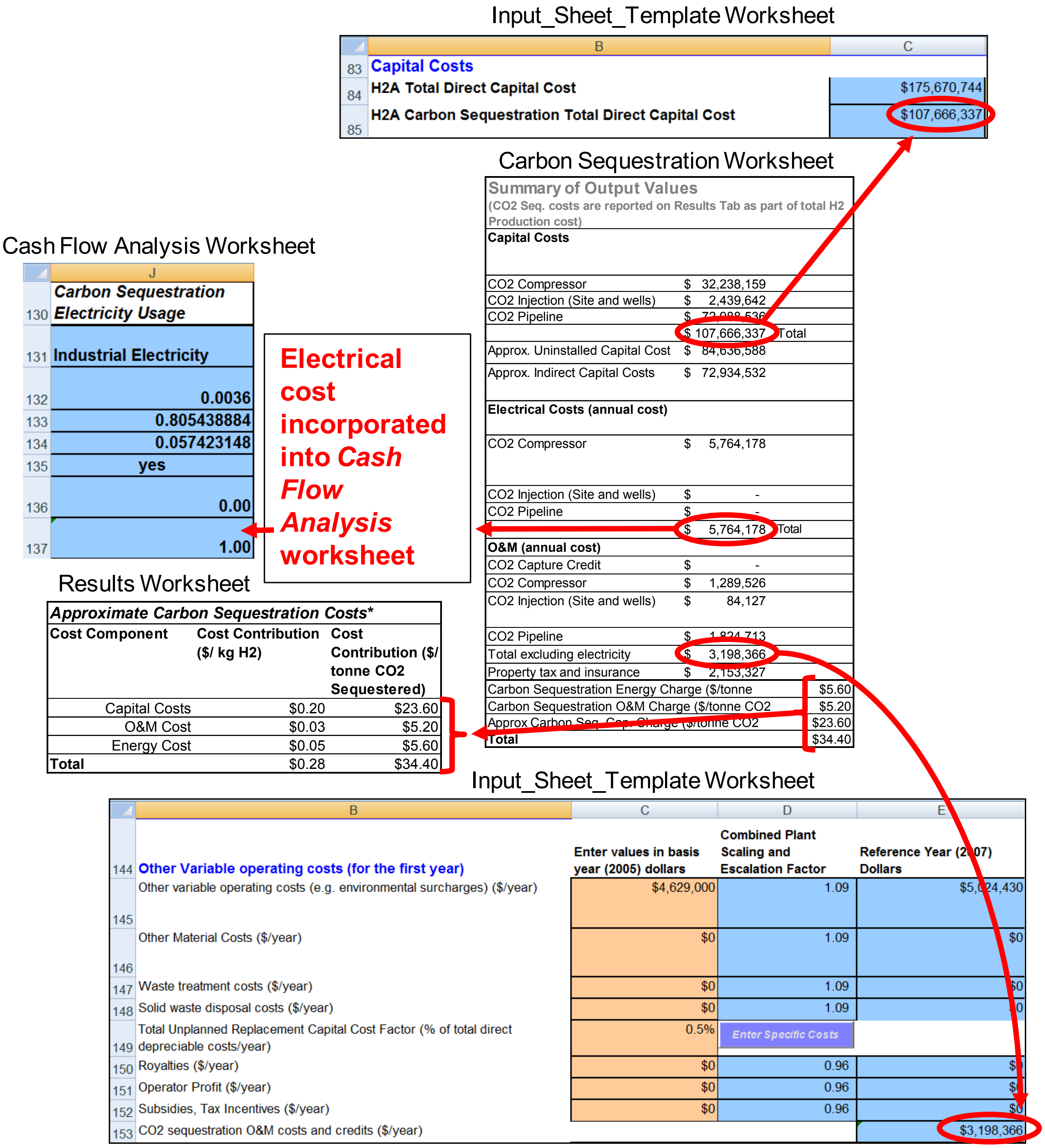
Click to activate and go to *Carbon Sequestration* worksheet

Clicking the *Link to Detail Sheet* button sends you to the *Carbon Sequestration* worksheet. At the top of the worksheet are notes, three self-explanatory buttons (see page 9 for a description of the *Use Default Values* functionality), and links to tables within the worksheet. Of the four tables, you will input values only into *Carbon Sequestration Input Values*; complete or accept the default values for the orange-shaded fields. The other tables display the calculations and results based on your inputs. When you are finished inputting values, click the *Input Sheet* button at top to return to the *Input_Sheet_Template* worksheet.

The cost results (seen in the *Summary of Output Values* table) are the source of carbon sequestration direct capital costs and CO_2 sequestration operation and maintenance costs and credits within the *Input_Sheet_Template* worksheet as well as carbon sequestration electricity use, which is used in the cash flow analysis—see the schematic below. The calculations also feed the carbon sequestration cost, energy use, and emissions results within the *Results* worksheet.

See Appendix 1 (page 43) for more information about the carbon sequestration inputs, outputs, and calculations used in this worksheet plus references for further reading.

Schematic of Cost Outputs from Carbon Sequestration Worksheet to Other H2A Worksheets



Input_Sheet_Template Worksheet

	B	C
83	**Capital Costs**	
84	**H2A Total Direct Capital Cost**	$175,670,744
85	**H2A Carbon Sequestration Total Direct Capital Cost**	$107,666,337

Carbon Sequestration Worksheet

Summary of Output Values (CO2 Seq. costs are reported on Results Tab as part of total H2 Production cost)			
Capital Costs			
CO2 Compressor	$ 32,238,159		
CO2 Injection (Site and wells)	$ 2,439,642		
CO2 Pipeline	$ 72,988,536		
	$ 107,666,337	Total	
Approx. Uninstalled Capital Cost	$ 84,636,588		
Approx. Indirect Capital Costs	$ 72,934,532		
Electrical Costs (annual cost)			
CO2 Compressor	$ 5,764,178		
CO2 Injection (Site and wells)	$ -		
CO2 Pipeline	$ -		
	$ 5,764,178	Total	
O&M (annual cost)			
CO2 Capture Credit	$ -		
CO2 Compressor	$ 1,289,526		
CO2 Injection (Site and wells)	$ 84,127		
CO2 Pipeline	$ 1,824,713		
Total excluding electricity	$ 3,198,366		
Property tax and insurance	$ 2,153,327		
Carbon Sequestration Energy Charge ($/tonne			$5.60
Carbon Sequestration O&M Charge ($/tonne CO2			$5.20
Approx Carbon Seq. Cap. Charge ($/tonne CO2			$23.60
Total			$34.40

Cash Flow Analysis Worksheet

	J
130	***Carbon Sequestration Electricity Usage***
131	**Industrial Electricity**
132	**0.0036**
133	**0.805438884**
134	**0.057423148**
135	**yes**
136	**0.00**
137	**1.00**

Electrical cost incorporated into *Cash Flow Analysis* worksheet

Results Worksheet

Approximate Carbon Sequestration Costs*		
Cost Component	**Cost Contribution ($/ kg H2)**	**Cost Contribution ($/ tonne CO2 Sequestered)**
Capital Costs	$0.20	$23.60
O&M Cost	$0.03	$5.20
Energy Cost	$0.05	$5.60
Total	$0.28	$34.40

Input_Sheet_Template Worksheet

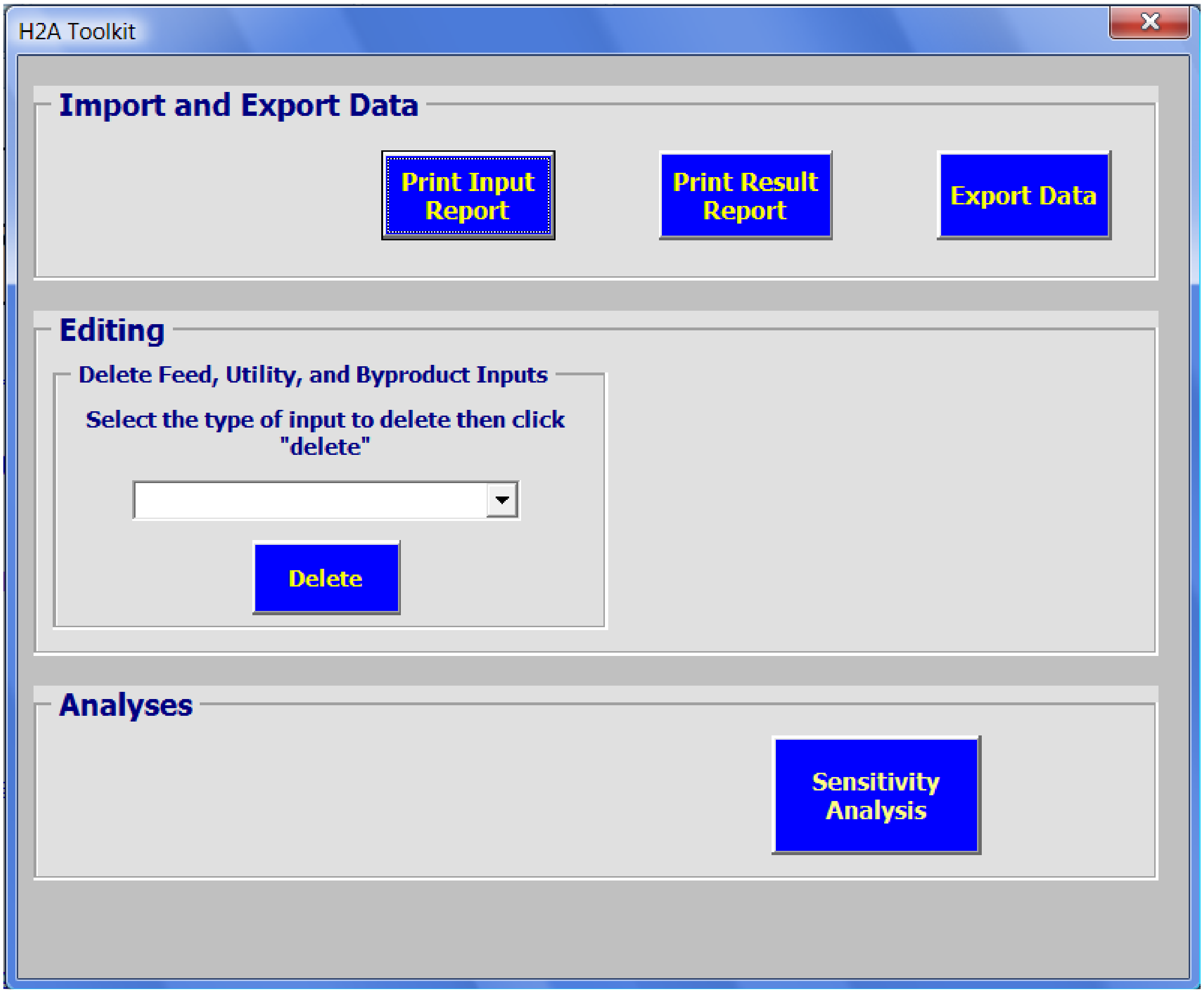
	B	C	D	E
144	**Other Variable operating costs (for the first year)**	**Enter values in basis year (2005) dollars**	**Combined Plant Scaling and Escalation Factor**	**Reference Year (2007) Dollars**
145	Other variable operating costs (e.g. environmental surcharges) ($/year)	$4,629,000	1.09	$5,[illegible]24,430
146	Other Material Costs ($/year)	$0	1.09	$0
147	Waste treatment costs ($/year)	$0	1.09	$0
148	Solid waste disposal costs ($/year)	$0	1.09	$0
149	Total Unplanned Replacement Capital Cost Factor (% of total direct depreciable costs/year)	0.5%	Enter Specific Costs	
150	Royalties ($/year)	$0	0.96	$0
151	Operator Profit ($/year)	$0	0.96	$0
152	Subsidies, Tax Incentives ($/year)	$0	0.96	$0
153	CO2 sequestration O&M costs and credits ($/year)			$3,198,366

H2A Toolkit

The *H2A Toolkit* is not an Excel worksheet—it is a pop-up window accessed by clicking the *Toolkit* button at the top of the *Input_Sheet_Template* worksheet or by clicking the *Delete* buttons within the worksheet. The *Toolkit* performs a number of functions:

- Printing and exporting inputs and results
- Editing input parameters
- Performing sensitivity analyses.

H2A Toolkit



Printing and Exporting Inputs and Results

Clicking the *Print Input Report* and *Print Result Report* buttons automatically prints information from the *Input_Sheet_Template* and *Results* worksheets, respectively. Automatic printing does not work with all printers. If it does not work for you, simply go to the worksheet you would like to print, click *File* at the top of your Excel window, and then click *Print*.

You can also export the inputs and results from your analysis to an Excel file. Click the *Export Data* button. Click *Yes* in the pop-up window that asks if you want to save your file. After you save the file, it will close automatically. The resulting file contains input and result values in an easily importable format, which you can bring into other analysis models.

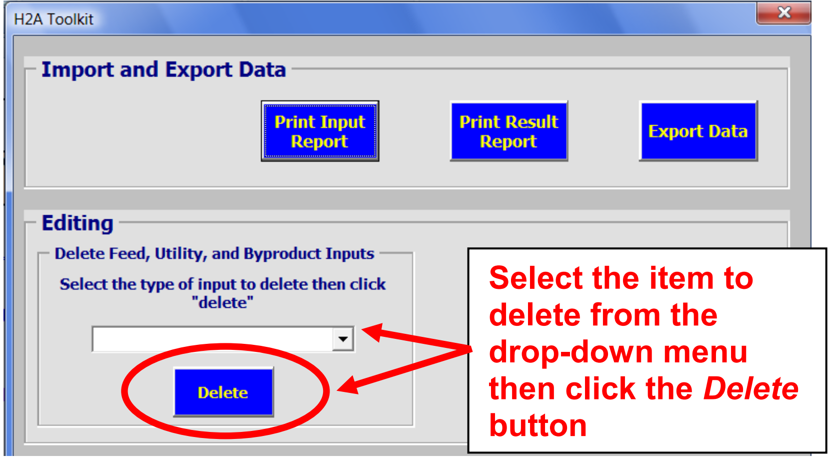
Editing: Delete Feed, Utility, and Byproduct Inputs

This function deletes items that have been added to the *Energy Feedstocks, Utilities, and Byproducts* and *Other Materials and Byproducts* sections within the *Input_Sheet_Template* worksheet (see pages 11 and 15). Use the drop-down menu under *Editing* to select the type of item you want to delete. Then click the *Delete* button. This deletes all items of the selected type. For example, if you had selected three energy byproducts, choosing *Energy Byproduct* from the drop-down menu and clicking the *Delete* button will delete all three.

CAUTION

When deleting items, it is critical to use the *Toolkit's Delete* button. Do not delete the corresponding rows within the *Input_Sheet_Template* worksheet using Excel's delete function. Also, be careful to choose the correct item from the *Delete* drop-down menu. All items of the selected type are deleted within the *Energy Feedstocks, Utilities, and Byproducts* or *Other Materials and Byproducts* sections. Choosing “All” at the bottom of the drop-down menu deletes all energy and non-energy feeds, utilities, and byproducts.

H2A Toolkit: Delete Feed, Utility, and Byproduct Inputs



Select the item to delete from the drop-down menu then click the *Delete* button

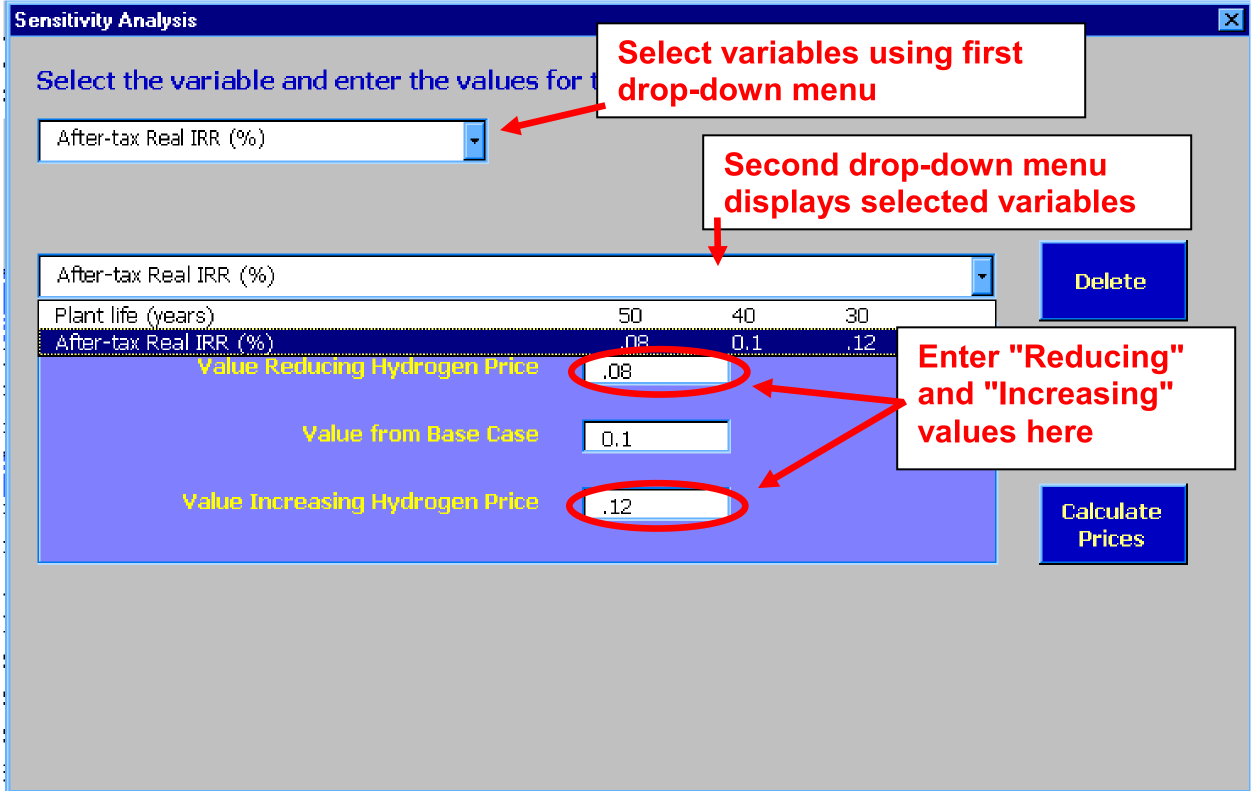
Performing Sensitivity Analyses

To perform a sensitivity analysis—which helps you understand how sensitive the cost of hydrogen is to changes in key input variables—click the *Sensitivity Analysis* button in the *H2A Toolkit*. In the *Sensitivity Analysis* window, use the first drop-down menu to select a variable you will use for the analysis (only variables that have a value in the base case will appear in the drop-down menu). Highlighting the variable selects it and adds it to the second drop-down menu. With your variable now shown in the first line of the second drop-down menu, its value from the current case is displayed in the *Value from Base Case* field. Enter a value for *Value Reducing Hydrogen Price* and a value for *Value Increasing Hydrogen Price*. For example, for *After-tax Real IRR* with a base case value of 0.1, you might enter 0.08 for the *Value Reducing Hydrogen Price* and 0.12 for the *Value Increasing Hydrogen Price* (see screen capture below). Repeat this process for up to 50 variables.

It's not always obvious what will reduce vs. increase hydrogen price; if you get bad results (e.g., a blank tornado chart), switch your "Reducing" & "Increasing" values and try again.

TIP

H2A Toolkit: Sensitivity Analysis Window



Select the variable and enter the values for t

After-tax Real IRR (%)

After-tax Real IRR (%)

Plant life (years)	50	40	30
After-tax Real IRR (%)	.08	0.1	.12

Value Reducing Hydrogen Price: .08

Value from Base Case: 0.1

Value Increasing Hydrogen Price: .12

Select variables using first drop-down menu

Second drop-down menu displays selected variables

Enter "Reducing" and "Increasing" values here

To delete a variable from the analysis, select the variable in the second drop-down menu and click the *Delete* button. Click *Yes* in the pop-up window that asks if you want to delete the variable. Remember, variables are added simply by highlighting them in the first drop-down menu, so check the second drop-down menu and delete unwanted variables before running your analysis. Also, make sure that three values are entered for each variable you want to analyze.

Once you are satisfied with the variables you have selected and the "Reducing" and "Increasing" values you have entered, click the *Calculate Prices* button. A pop-up window will state, "Data may exist in the sheet(s) selected for deletion. To permanently delete the data, press Delete." Click the *Delete* button. Next, close the *Sensitivity Analysis* window and *H2A Toolkit*. You are now in the *Sensitivity Analysis* worksheet (see page 32), where you see how much the minimum hydrogen selling price varies when your "Reducing" and "Increasing" values are entered into the model while holding all other variables constant at their base values. To the left of the *Sensitivity Analysis* tab is the *Tornado Chart* tab. The *Tornado Chart* worksheet shows the results of the sensitivity analysis graphically (see page 31).

If there were values in the *Sensitivity Analysis* and *Tornado Chart* worksheets before you performed your sensitivity analysis, they will be overwritten with your new results. Each time you perform a sensitivity analysis, the values in these worksheets are overwritten with the new values, so you can only have one set of values and one valid tornado chart at a time. If you want to create multiple sensitivity analyses/tornado charts, perform your first analysis then save your Excel file under a new name, perform your second analysis then save this file under a different name, and so forth.

Results Worksheet

The *Results* worksheet tabulates the results of your H2A Model analysis. No user input is required within this worksheet. You are sent here after you click the *Calculate Cost* button in the *Input_Sheet_Template* worksheet. The hydrogen cost results are in the *Specific Item Cost Calculation* table at the top (see screen captures below). Note that, in the central model, the costs shown in the *Approximate Carbon Sequestration Costs* table are included in the total cost shown in the *Specific Item Cost Calculation* table.

Central Model Cost Results Including (Top) and not Including (Bottom) Carbon Sequestration

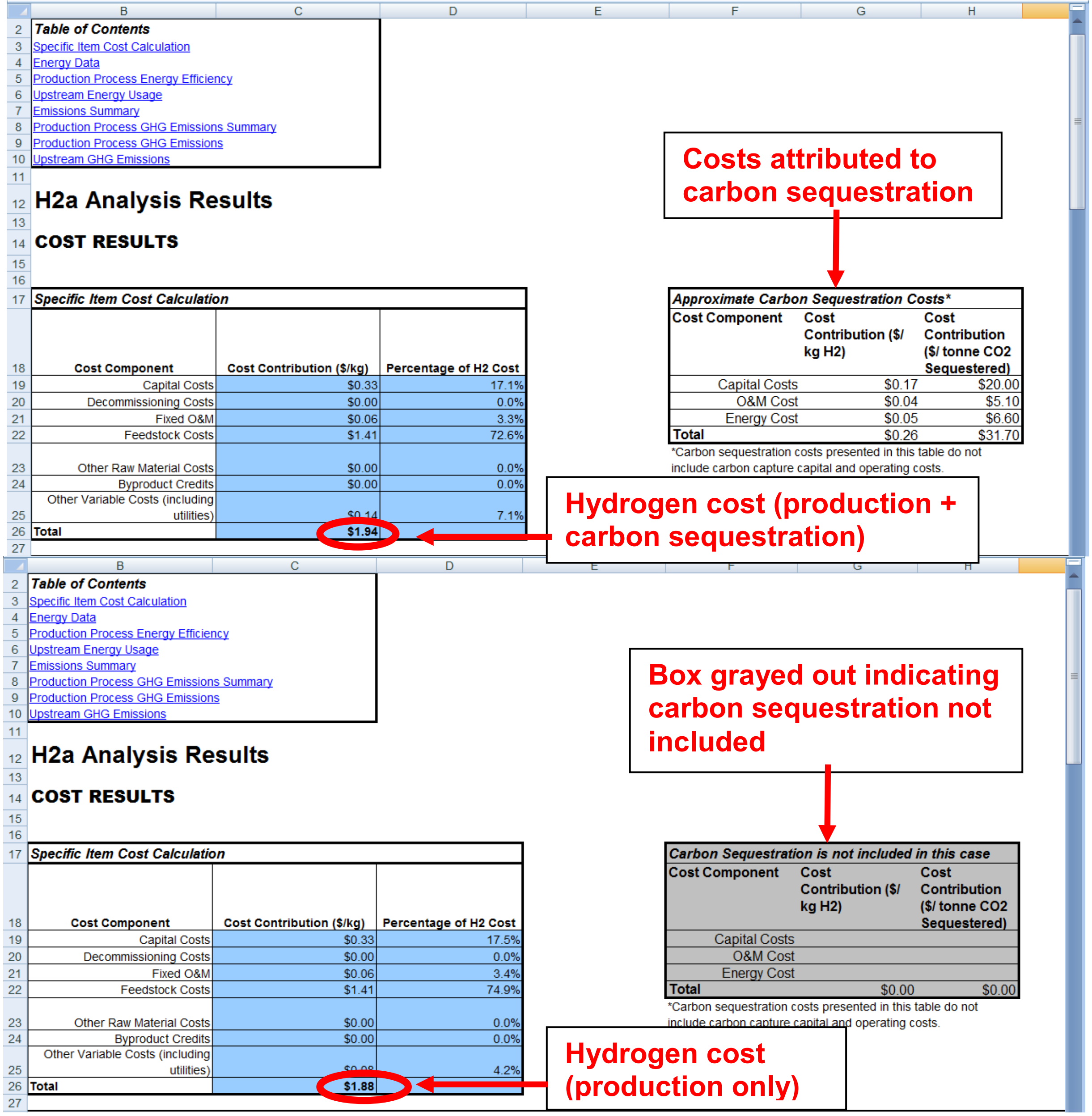


Table of Contents
- Specific Item Cost Calculation
- Energy Data
- Production Process Energy Efficiency
- Upstream Energy Usage
- Emissions Summary
- Production Process GHG Emissions Summary
- Production Process GHG Emissions
- Upstream GHG Emissions

H2a Analysis Results

COST RESULTS

Specific Item Cost Calculation

Cost Component	Cost Contribution ($/kg)	Percentage of H2 Cost
Capital Costs	$0.33	17.1%
Decommissioning Costs	$0.00	0.0%
Fixed O&M	$0.06	3.3%
Feedstock Costs	$1.41	72.6%
Other Raw Material Costs	$0.00	0.0%
Byproduct Credits	$0.00	0.0%
Other Variable Costs (including utilities)	$0.14	7.1%
Total	$1.94	

*Approximate Carbon Sequestration Costs**

Cost Component	Cost Contribution ($/ kg H2)	Cost Contribution ($/ tonne CO2 Sequestered)
Capital Costs	$0.17	$20.00
O&M Cost	$0.04	$5.10
Energy Cost	$0.05	$6.60
Total	$0.26	$31.70

*Carbon sequestration costs presented in this table do not include carbon capture capital and operating costs.

Table of Contents
- Specific Item Cost Calculation
- Energy Data
- Production Process Energy Efficiency
- Upstream Energy Usage
- Emissions Summary
- Production Process GHG Emissions Summary
- Production Process GHG Emissions
- Upstream GHG Emissions

H2a Analysis Results

COST RESULTS

Specific Item Cost Calculation

Cost Component	Cost Contribution ($/kg)	Percentage of H2 Cost
Capital Costs	$0.33	17.5%
Decommissioning Costs	$0.00	0.0%
Fixed O&M	$0.06	3.4%
Feedstock Costs	$1.41	74.9%
Other Raw Material Costs	$0.00	0.0%
Byproduct Credits	$0.00	0.0%
Other Variable Costs (including utilities)	$0.08	4.2%
Total	$1.88	

Carbon Sequestration is not included in this case

Cost Component	Cost Contribution ($/ kg H2)	Cost Contribution ($/ tonne CO2 Sequestered)
Capital Costs		
O&M Cost		
Energy Cost		
Total	$0.00	$0.00

*Carbon sequestration costs presented in this table do not include carbon capture capital and operating costs.

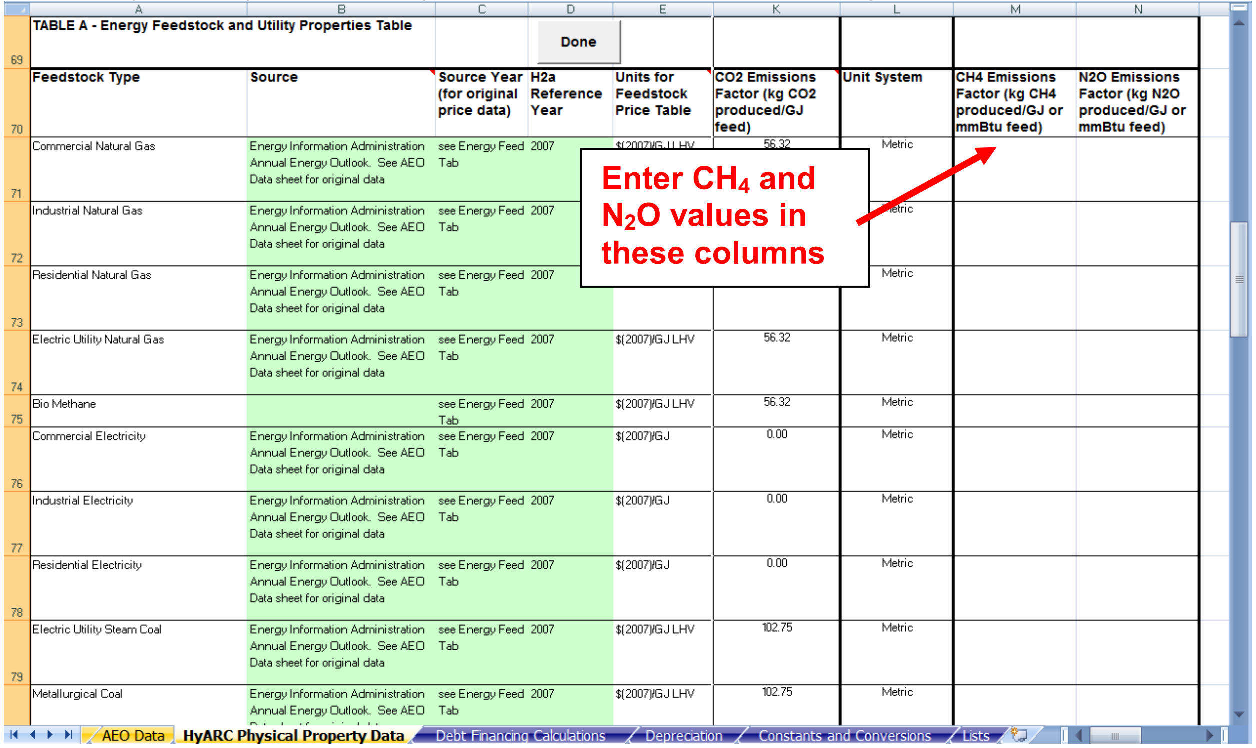
The remaining tables show energy and emissions results. The *Energy Data* table summarizes the energy inputs in the form of feedstocks, utilities, and carbon sequestration. It also summarizes the energy outputs in the form of hydrogen and byproducts. The *Production*

Process Energy Efficiency table shows a percentage efficiency calculated by dividing energy outputs by energy inputs. Unless otherwise specified, efficiencies are reported on an LHV basis.

The *Upstream Energy Usage* table shows total, fossil fuel, and petroleum energy consumed by energy inputs during their upstream processing (e.g., natural gas extraction or coal-fired electricity generation). These estimates of upstream energy use are calculated based on the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) Model, version 1.86. The GREET Model is continually being updated. For the most accurate upstream energy results, download and use the most recent GREET version at www.transportation.anl.gov/modeling_simulation/GREET.

The *Emissions Summary* table summarizes upstream and process greenhouse gas emissions. The next two tables—*Production Process GHG Emissions Summary* and *Production Process GHG Emissions*—detail the process greenhouse gas emissions. Note that the default is to have all process emissions counted as CO_2, as defined in the *HyARC Physical Property Data worksheet*, *Table A*. If you want to add information about CH_4 and N_2O emissions to the energy feeds, enter values in the last two columns of *Table A* (see screen capture below).

HyARC Physical Property Data Worksheet, Table A: Entering CH_4 and N_2O Values



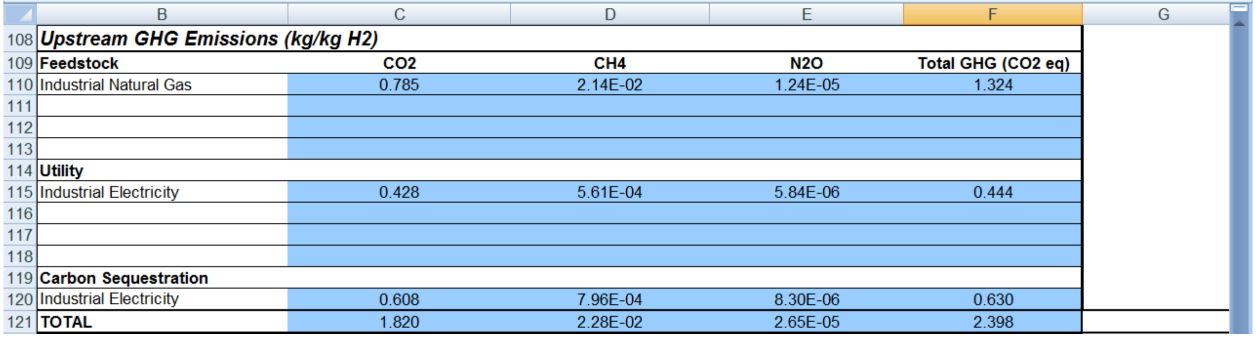
Enter CH_4 and N_2O values in these columns

	A	B	C	D	E	K	L	M	N
69	TABLE A - Energy Feedstock and Utility Properties Table								
70	Feedstock Type	Source	Source Year (for original price data)	H2a Reference Year	Units for Feedstock Price Table	CO2 Emissions Factor (kg CO2 produced/GJ feed)	Unit System	CH4 Emissions Factor (kg CH4 produced/GJ or mmBtu feed)	N2O Emissions Factor (kg N2O produced/GJ or mmBtu feed)
71	Commercial Natural Gas	Energy Information Administration Annual Energy Outlook. See AEO Data sheet for original data	see Energy Feed Tab	2007	$(2007)/GJ LHV	56.32	Metric		
72	Industrial Natural Gas	Energy Information Administration Annual Energy Outlook. See AEO Data sheet for original data	see Energy Feed Tab	2007			etric		
73	Residential Natural Gas	Energy Information Administration Annual Energy Outlook. See AEO Data sheet for original data	see Energy Feed Tab	2007			Metric		
74	Electric Utility Natural Gas	Energy Information Administration Annual Energy Outlook. See AEO Data sheet for original data	see Energy Feed Tab	2007	$(2007)/GJ LHV	56.32	Metric		
75	Bio Methane		see Energy Feed Tab	2007	$(2007)/GJ LHV	56.32	Metric		
76	Commercial Electricity	Energy Information Administration Annual Energy Outlook. See AEO Data sheet for original data	see Energy Feed Tab	2007	$(2007)/GJ	0.00	Metric		
77	Industrial Electricity	Energy Information Administration Annual Energy Outlook. See AEO Data sheet for original data	see Energy Feed Tab	2007	$(2007)/GJ	0.00	Metric		
78	Residential Electricity	Energy Information Administration Annual Energy Outlook. See AEO Data sheet for original data	see Energy Feed Tab	2007	$(2007)/GJ	0.00	Metric		
79	Electric Utility Steam Coal	Energy Information Administration Annual Energy Outlook. See AEO Data sheet for original data	see Energy Feed Tab	2007	$(2007)/GJ LHV	102.75	Metric		
	Metallurgical Coal	Energy Information Administration Annual Energy Outlook. See AEO	see Energy Feed Tab	2007	$(2007)/GJ LHV	102.75	Metric		

Note: some table columns have been hidden for illustrative purposes.

The *Upstream GHG Emissions* table shows greenhouse gas emissions (CO_2, CH_4, N_2O, and total) produced by energy inputs during their upstream processing. These estimates of upstream emissions are calculated based on the GREET Model, version 1.7. The GREET Model is continually being updated. For the most accurate upstream emissions results, download and use the most recent GREET version at www.transportation.anl.gov/modeling_simulation/GREET.

Results Worksheet, Upstream GHG Emissions Table



	B	C	D	E	F	G
108	***Upstream GHG Emissions (kg/kg H2)***					
109	**Feedstock**	**CO2**	**CH4**	**N2O**	**Total GHG (CO2 eq)**	
110	Industrial Natural Gas	0.785	2.14E-02	1.24E-05	1.324	
111						
112						
113						
114	**Utility**					
115	Industrial Electricity	0.428	5.61E-04	5.84E-06	0.444	
116						
117						
118						
119	**Carbon Sequestration**					
120	Industrial Electricity	0.608	7.96E-04	8.30E-06	0.630	
121	**TOTAL**	1.820	2.28E-02	2.65E-05	2.398	

Cash Flow Analysis Worksheet

The *Cash Flow Analysis* worksheet shows the inputs, outputs, and calculations of the discounted cash flow analysis used to generate the hydrogen cost results (see page 27). No user input is required within this worksheet.

The worksheet contains the following information, which is linked from a table of contents at the top:

- Discounted Cash Flow (DCF) Calculations
- Yearly Cash Flow Calculations
- Specific Item Cost Calculation
- Feedstock, Utility, and Byproduct Cost Information.

Cash Flow Analysis Worksheet

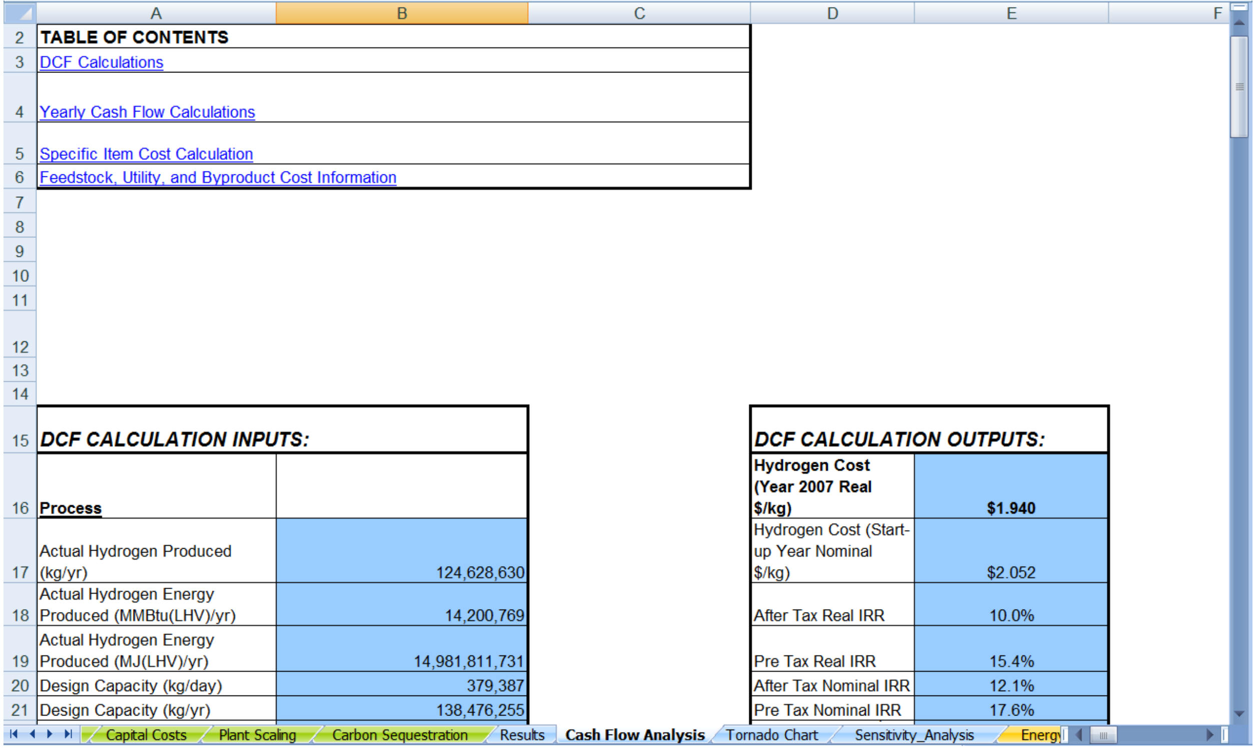


TABLE OF CONTENTS

DCF Calculations
Yearly Cash Flow Calculations
Specific Item Cost Calculation
Feedstock, Utility, and Byproduct Cost Information

DCF CALCULATION INPUTS:

Process	
Actual Hydrogen Produced (kg/yr)	124,628,630
Actual Hydrogen Energy Produced (MMBtu(LHV)/yr)	14,200,769
Actual Hydrogen Energy Produced (MJ(LHV)/yr)	14,981,811,731
Design Capacity (kg/day)	379,387
Design Capacity (kg/yr)	138,476,255

DCF CALCULATION OUTPUTS:

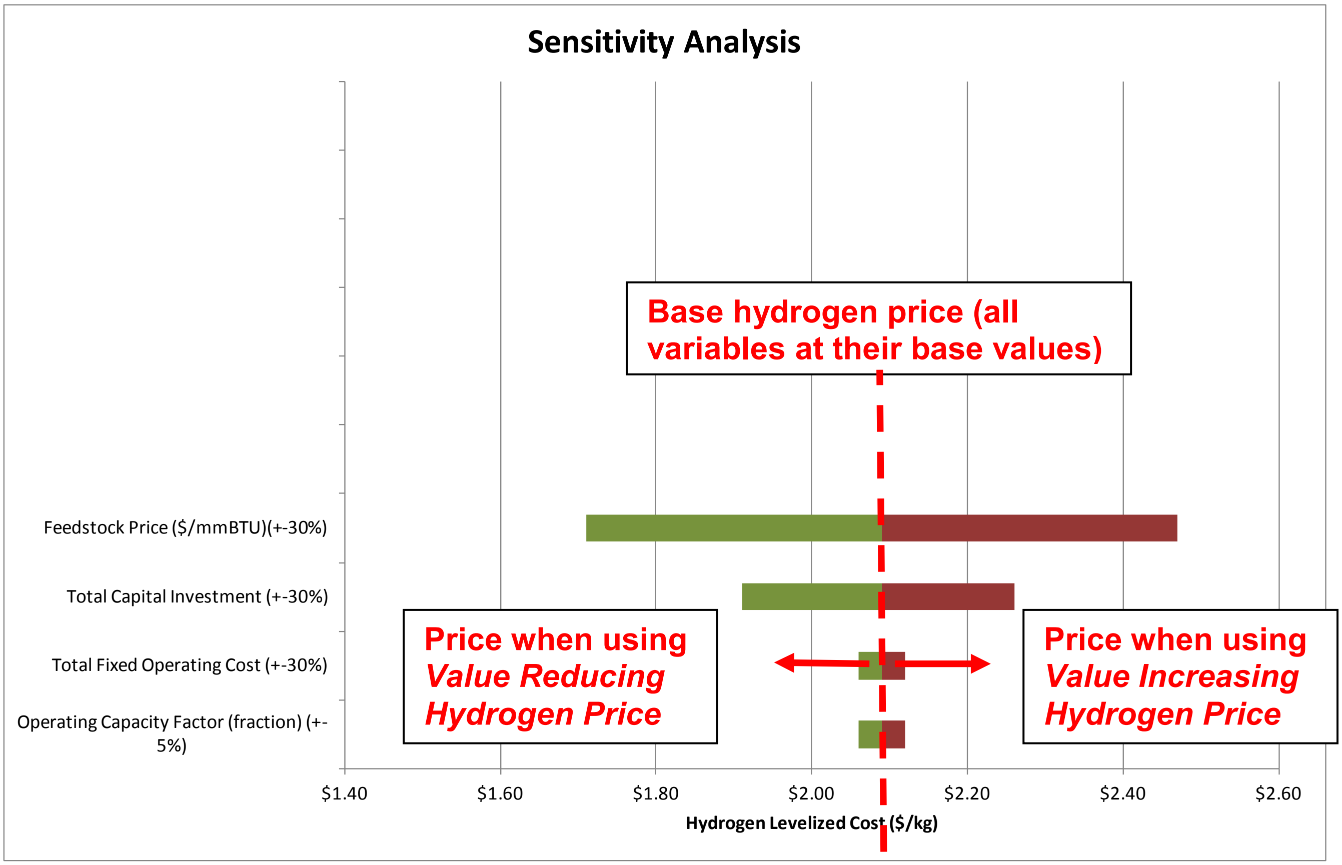
Hydrogen Cost (Year 2007 Real $/kg)	**$1.940**
Hydrogen Cost (Start-up Year Nominal $/kg)	$2.052
After Tax Real IRR	10.0%
Pre Tax Real IRR	15.4%
After Tax Nominal IRR	12.1%
Pre Tax Nominal IRR	17.6%

Tornado Chart Worksheet

The *Tornado Chart* worksheet shows sensitivity analysis results graphically; see page 25 for information about performing sensitivity analyses and page 32 for the *Sensitivity_Analysis* worksheet, which shows the results numerically. The bars within the tornado chart show the range of minimum hydrogen selling price values obtained by entering—for each specified variable—a base value, a "reducing" value (i.e., a value that reduces the hydrogen price), and an "increasing" value (i.e., a value that increases the hydrogen price) while holding all other variables constant at their base values. No user input is required within this worksheet.

For established H2A production technology cases, a default sensitivity analysis/tornado chart is included. The input value ranges used in these analyses are based on feedback from analysts consulted as part of the H2A development process and on ongoing DOE research into the uncertainties inherent to the various hydrogen production variables.

Tornado Chart Worksheet



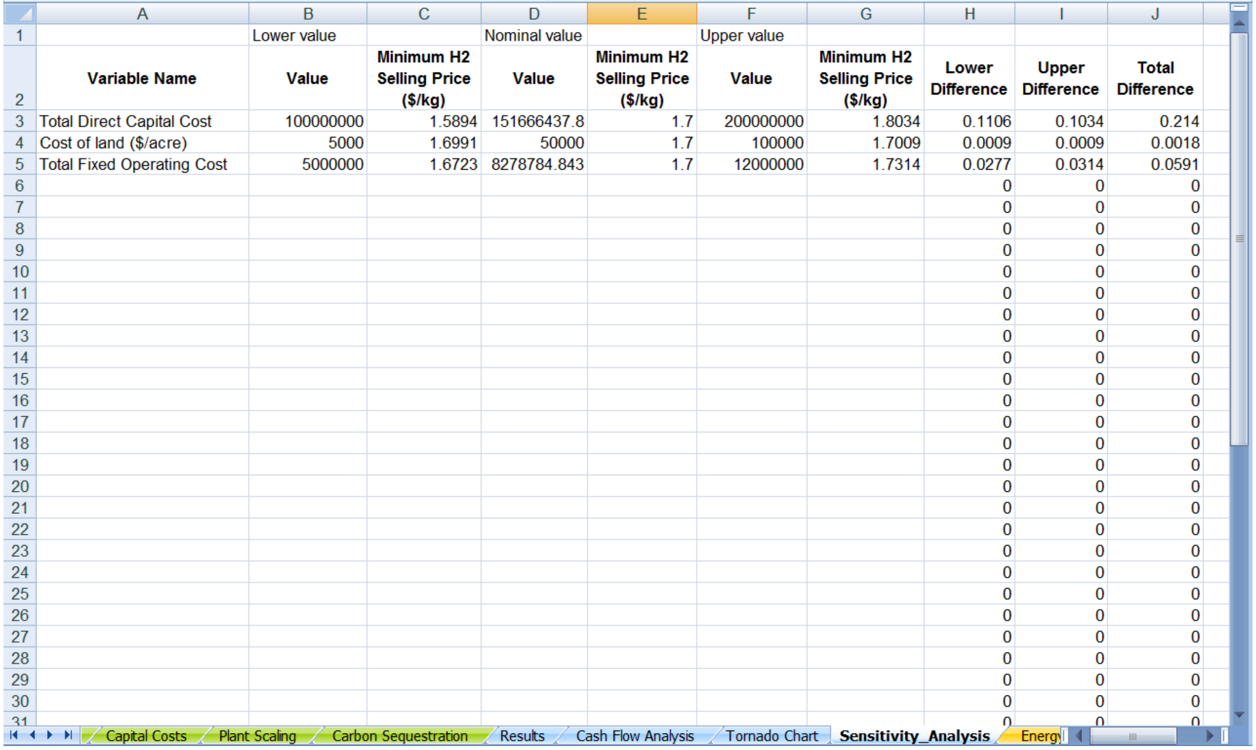
Sensitivity_Analysis Worksheet

The *Sensitivity_Analysis* worksheet shows sensitivity analysis results numerically; see page 25 for information about performing sensitivity analyses and page 31 for the *Tornado Chart* worksheet, which shows the results graphically.

The worksheet's columns show the range of minimum hydrogen selling price values obtained by entering—for each specified variable—a nominal (i.e., base) value, a lower value (i.e., a value that reduces the hydrogen price), and an upper value (i.e., a value that increases the hydrogen price) while holding all other variables constant at their base values. The columns at the far right show the difference in price between the lower-value and upper-value hydrogen prices and the nominal-value price.

It is best not to modify anything directly within this worksheet. Use the *H2A Toolkit's* sensitivity analysis function (page 25) to make changes.

Sensitivity_Analysis Worksheet



	A	B	C	D	E	F	G	H	I	J
1		Lower value		Nominal value		Upper value				
2	**Variable Name**	**Value**	**Minimum H2 Selling Price ($/kg)**	**Value**	**Minimum H2 Selling Price ($/kg)**	**Value**	**Minimum H2 Selling Price ($/kg)**	**Lower Difference**	**Upper Difference**	**Total Difference**
3	Total Direct Capital Cost	100000000	1.5894	151666437.8	1.7	200000000	1.8034	0.1106	0.1034	0.214
4	Cost of land ($/acre)	5000	1.6991	50000	1.7	100000	1.7009	0.0009	0.0009	0.0018
5	Total Fixed Operating Cost	5000000	1.6723	8278784.843	1.7	12000000	1.7314	0.0277	0.0314	0.0591
6								0	0	0
7								0	0	0
8								0	0	0
9								0	0	0
10								0	0	0
11								0	0	0
12								0	0	0
13								0	0	0
14								0	0	0
15								0	0	0
16								0	0	0
17								0	0	0
18								0	0	0
19								0	0	0
20								0	0	0
21								0	0	0
22								0	0	0
23								0	0	0
24								0	0	0
25								0	0	0
26								0	0	0
27								0	0	0
28								0	0	0
29								0	0	0
30								0	0	0
31								0	0	0

Energy Feed & Utility Prices Worksheet

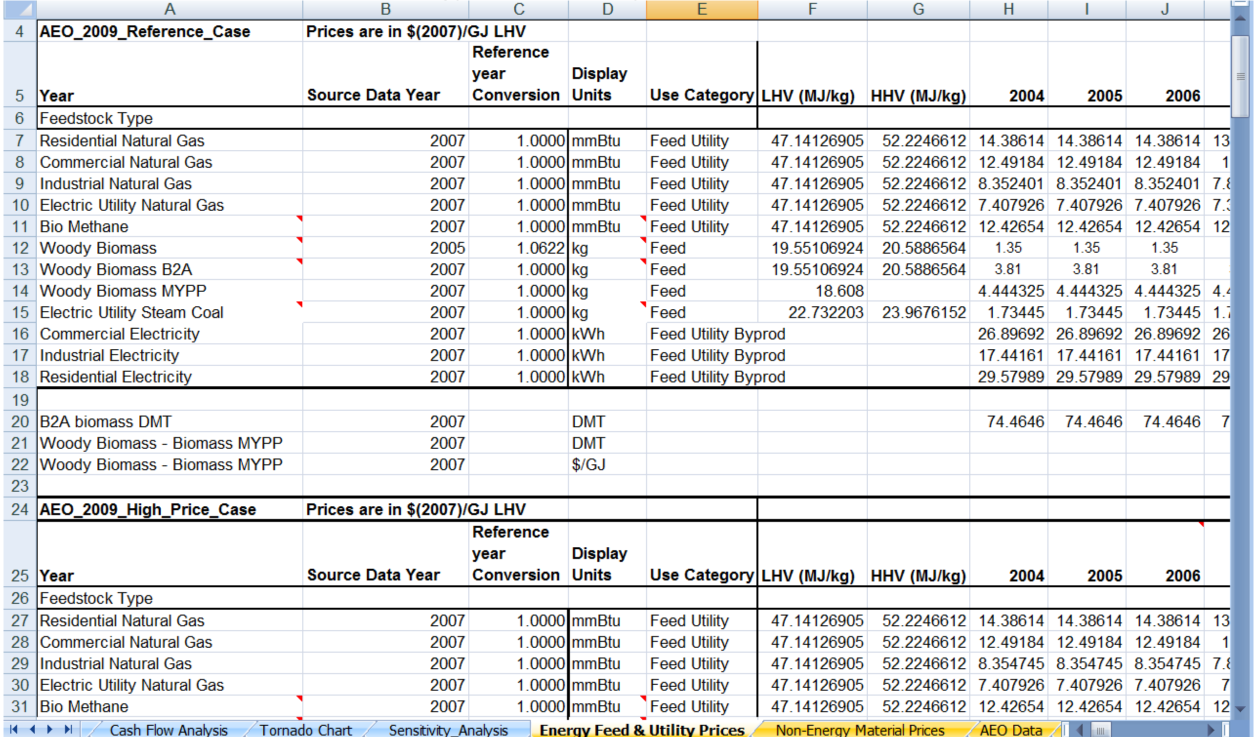
The *Energy Feed & Utility Prices* worksheet is the source of price information for the *Energy Feedstocks, Utilities, and Byproducts* calculations within the *Input_Sheet_Template* worksheet (see page 11). It contains three tables, which list projected prices in $2007 for energy inputs/byproducts through the year 2070:

- *AEO_2009_Reference_Case*
- *AEO_2009_High_Price_Case*
- *AEO_2010_Reference_Case*

The *AEO_2009_Reference_Case* is the default for all established H2A production technology cases.

The raw prices used to make these tables, through the year 2030, were drawn from the EIA's Annual Energy Outlook (AEO). Archived AEOs are available at www.eia.gov/oiaf/archive.html. The most recent AEO is available at www.eia.gov/forecasts/aeo. The year 2031–2070 prices were projected using the Joint Global Change Research Institute's GCAM (formerly MiniCAM) model. See *AEO Data Worksheet* (page 35) for more information.

Energy Feed & Utility Prices Worksheet

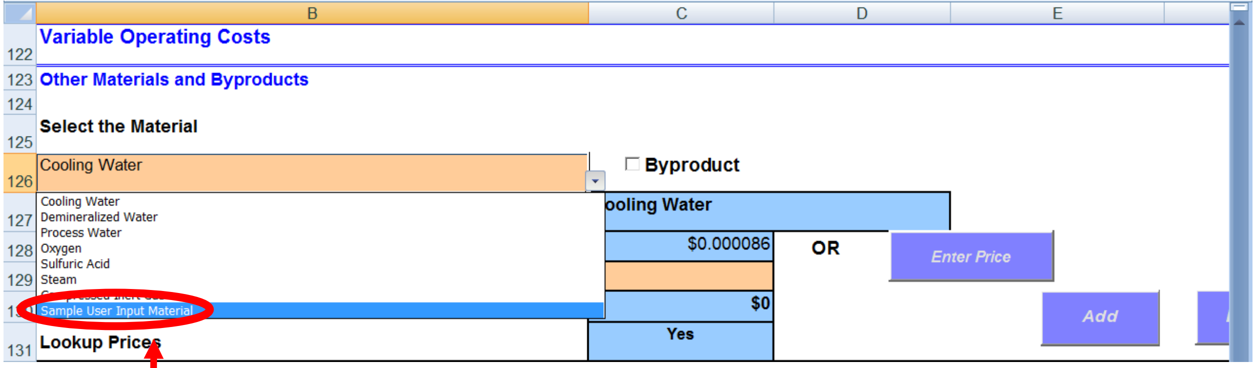


	A	B	C	D	E	F	G	H	I	J	
4	**AEO_2009_Reference_Case**	**Prices are in $(2007)/GJ LHV**									
5	**Year**	**Source Data Year**	**Reference year Conversion**	**Display Units**	**Use Category**	**LHV (MJ/kg)**	**HHV (MJ/kg)**	**2004**	**2005**	**2006**	
6	Feedstock Type										
7	Residential Natural Gas	2007	1.0000	mmBtu	Feed Utility	47.14126905	52.2246612	14.38614	14.38614	14.38614	13
8	Commercial Natural Gas	2007	1.0000	mmBtu	Feed Utility	47.14126905	52.2246612	12.49184	12.49184	12.49184	1
9	Industrial Natural Gas	2007	1.0000	mmBtu	Feed Utility	47.14126905	52.2246612	8.352401	8.352401	8.352401	7.
10	Electric Utility Natural Gas	2007	1.0000	mmBtu	Feed Utility	47.14126905	52.2246612	7.407926	7.407926	7.407926	7.
11	Bio Methane	2007	1.0000	mmBtu	Feed Utility	47.14126905	52.2246612	12.42654	12.42654	12.42654	12
12	Woody Biomass	2005	1.0622	kg	Feed	19.55106924	20.5886564	1.35	1.35	1.35	
13	Woody Biomass B2A	2007	1.0000	kg	Feed	19.55106924	20.5886564	3.81	3.81	3.81	
14	Woody Biomass MYPP	2007	1.0000	kg	Feed	18.608		4.444325	4.444325	4.444325	4.
15	Electric Utility Steam Coal	2007	1.0000	kg	Feed	22.732203	23.9676152	1.73445	1.73445	1.73445	1.
16	Commercial Electricity	2007	1.0000	kWh	Feed Utility Byprod			26.89692	26.89692	26.89692	26
17	Industrial Electricity	2007	1.0000	kWh	Feed Utility Byprod			17.44161	17.44161	17.44161	17
18	Residential Electricity	2007	1.0000	kWh	Feed Utility Byprod			29.57989	29.57989	29.57989	29
19											
20	B2A biomass DMT	2007		DMT				74.4646	74.4646	74.4646	7
21	Woody Biomass - Biomass MYPP	2007		DMT							
22	Woody Biomass - Biomass MYPP	2007		$/GJ							
23											
24	**AEO_2009_High_Price_Case**	**Prices are in $(2007)/GJ LHV**									
25	**Year**	**Source Data Year**	**Reference year Conversion**	**Display Units**	**Use Category**	**LHV (MJ/kg)**	**HHV (MJ/kg)**	**2004**	**2005**	**2006**	
26	Feedstock Type										
27	Residential Natural Gas	2007	1.0000	mmBtu	Feed Utility	47.14126905	52.2246612	14.38614	14.38614	14.38614	13
28	Commercial Natural Gas	2007	1.0000	mmBtu	Feed Utility	47.14126905	52.2246612	12.49184	12.49184	12.49184	1
29	Industrial Natural Gas	2007	1.0000	mmBtu	Feed Utility	47.14126905	52.2246612	8.354745	8.354745	8.354745	7.
30	Electric Utility Natural Gas	2007	1.0000	mmBtu	Feed Utility	47.14126905	52.2246612	7.407926	7.407926	7.407926	7
31	Bio Methane	2007	1.0000	mmBtu	Feed Utility	47.14126905	52.2246612	12.42654	12.42654	12.42654	12

Non-Energy Material Prices Worksheet

The *Non-Energy Material Prices* worksheet is the source of price information for the *Other Materials and Byproducts* calculations within the *Input_Sheet_Template* worksheet (see page 15). Add new materials simply by adding information in the rows underneath the existing information. You can also modify the prices of materials here if desired.

Other Materials and Byproducts (Input_Sheet_Template Worksheet)



Variable Operating Costs

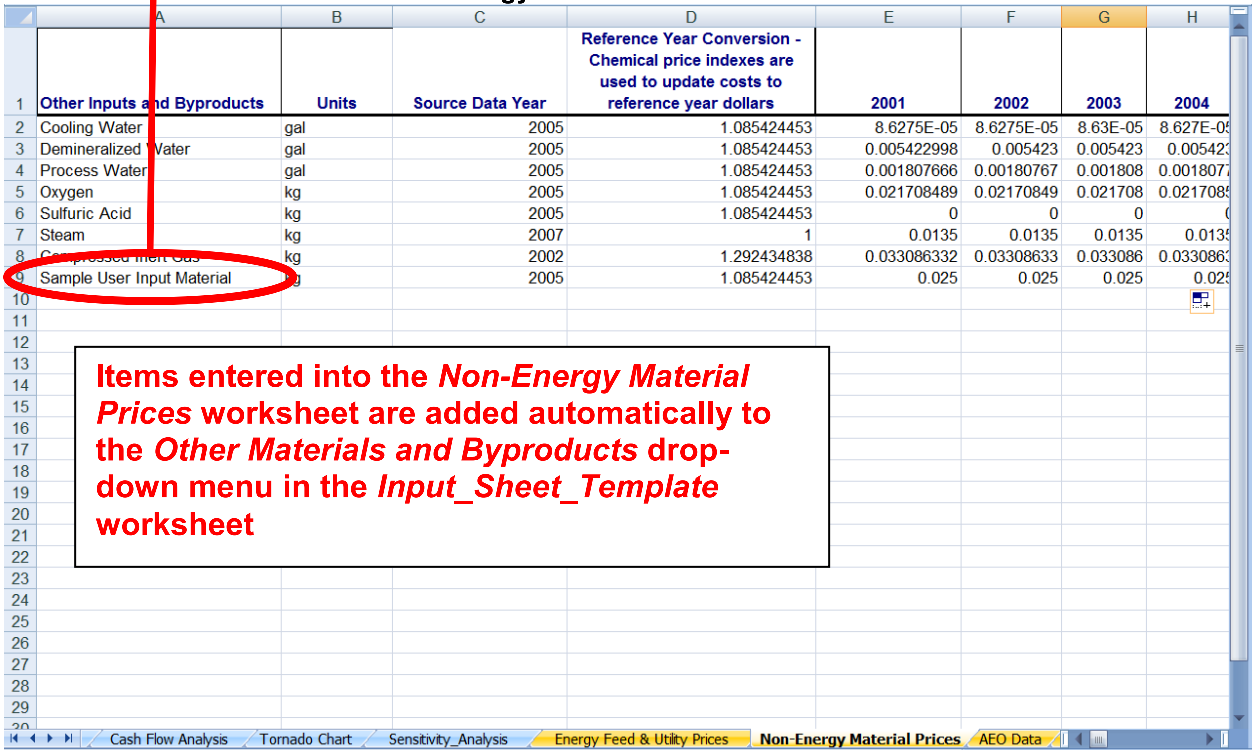
Other Materials and Byproducts

Select the Material

Cooling Water

☐ **Byproduct**

Non-Energy Material Prices Worksheet



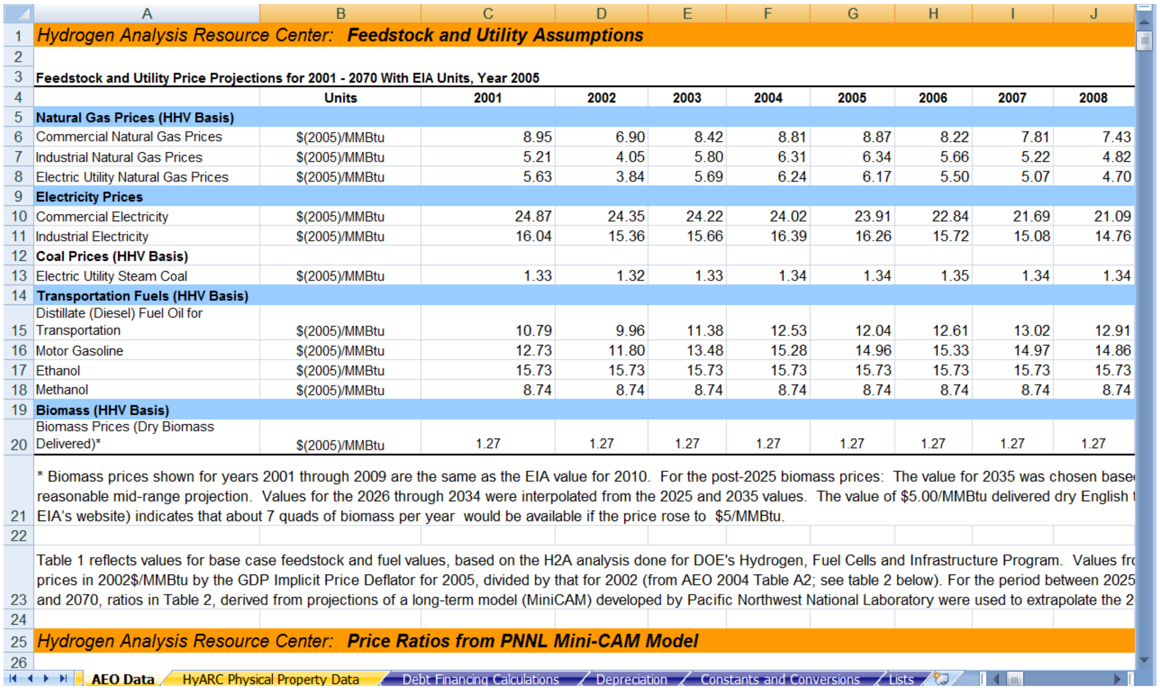
	A	B	C	D	E	F	G	H
1	Other Inputs and Byproducts	Units	Source Data Year	Reference Year Conversion - Chemical price indexes are used to update costs to reference year dollars	2001	2002	2003	2004
2	Cooling Water	gal	2005	1.085424453	8.6275E-05	8.6275E-05	8.63E-05	8.627E-0
3	Demineralized Water	gal	2005	1.085424453	0.005422998	0.005423	0.005423	0.00542
4	Process Water	gal	2005	1.085424453	0.001807666	0.00180767	0.001808	0.001807
5	Oxygen	kg	2005	1.085424453	0.021708489	0.02170849	0.021708	0.021708
6	Sulfuric Acid	kg	2005	1.085424453	0	0	0	
7	Steam	kg	2007	1	0.0135	0.0135	0.0135	0.013
8	Compressed Inert Gas	kg	2002	1.292434838	0.033086332	0.03308633	0.033086	0.033086
9	Sample User Input Material	kg	2005	1.085424453	0.025	0.025	0.025	0.02

Items entered into the *Non-Energy Material Prices* worksheet are added automatically to the *Other Materials and Byproducts* drop-down menu in the *Input_Sheet_Template* worksheet

AEO Data Worksheet

The data in the *AEO Data* worksheet are the source of the energy price tables in the *Energy Feed & Utility Prices* worksheet (page 33). The tables include EIA AEO data and projections through year 2030 and projections for years 2031–2070 extrapolated using the AEO projections and GCAM model results. For typical users, no actions are required or recommended within this worksheet.

AEO Data Worksheet



	A	B	C	D	E	F	G	H	I	J
1	*Hydrogen Analysis Resource Center:* ***Feedstock and Utility Assumptions***									
2										
3	**Feedstock and Utility Price Projections for 2001 - 2070 With EIA Units, Year 2005**									
4		**Units**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
5	**Natural Gas Prices (HHV Basis)**									
6	Commercial Natural Gas Prices	$(2005)/MMBtu	8.95	6.90	8.42	8.81	8.87	8.22	7.81	7.43
7	Industrial Natural Gas Prices	$(2005)/MMBtu	5.21	4.05	5.80	6.31	6.34	5.66	5.22	4.82
8	Electric Utility Natural Gas Prices	$(2005)/MMBtu	5.63	3.84	5.69	6.24	6.17	5.50	5.07	4.70
9	**Electricity Prices**									
10	Commercial Electricity	$(2005)/MMBtu	24.87	24.35	24.22	24.02	23.91	22.84	21.69	21.09
11	Industrial Electricity	$(2005)/MMBtu	16.04	15.36	15.66	16.39	16.26	15.72	15.08	14.76
12	**Coal Prices (HHV Basis)**									
13	Electric Utility Steam Coal	$(2005)/MMBtu	1.33	1.32	1.33	1.34	1.34	1.35	1.34	1.34
14	**Transportation Fuels (HHV Basis)**									
15	Distillate (Diesel) Fuel Oil for Transportation	$(2005)/MMBtu	10.79	9.96	11.38	12.53	12.04	12.61	13.02	12.91
16	Motor Gasoline	$(2005)/MMBtu	12.73	11.80	13.48	15.28	14.96	15.33	14.97	14.86
17	Ethanol	$(2005)/MMBtu	15.73	15.73	15.73	15.73	15.73	15.73	15.73	15.73
18	Methanol	$(2005)/MMBtu	8.74	8.74	8.74	8.74	8.74	8.74	8.74	8.74
19	**Biomass (HHV Basis)**									
20	Biomass Prices (Dry Biomass Delivered)*	$(2005)/MMBtu	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27
21	* 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 base 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 EIA's website) indicates that about 7 quads of biomass per year would be available if the price rose to $5/MMBtu.									
22										
23	Table 1 reflects values for base case feedstock and fuel values, based on the H2A analysis done for DOE's Hydrogen, Fuel Cells and Infrastructure Program. Values fr prices in 2002$/MMBtu by the GDP Implicit Price Deflator for 2005, divided by that for 2002 (from AEO 2004 Table A2; see table 2 below). For the period between 2025 and 2070, ratios in Table 2, derived from projections of a long-term model (MiniCAM) developed by Pacific Northwest National Laboratory were used to extrapolate the 2									
24										
25	*Hydrogen Analysis Resource Center:* ***Price Ratios from PNNL Mini-CAM Model***									
26										

HyARC Physical Property Data Worksheet

The *HyARC Physical Property Data* worksheet contains constants and conversions used in energy feedstock, utility, and greenhouse gas emissions calculations. Most users will not need to add or change information in this worksheet; however, *Tables A*, *C1*, and *C2* contain fields designed to accept user input.

Advanced users

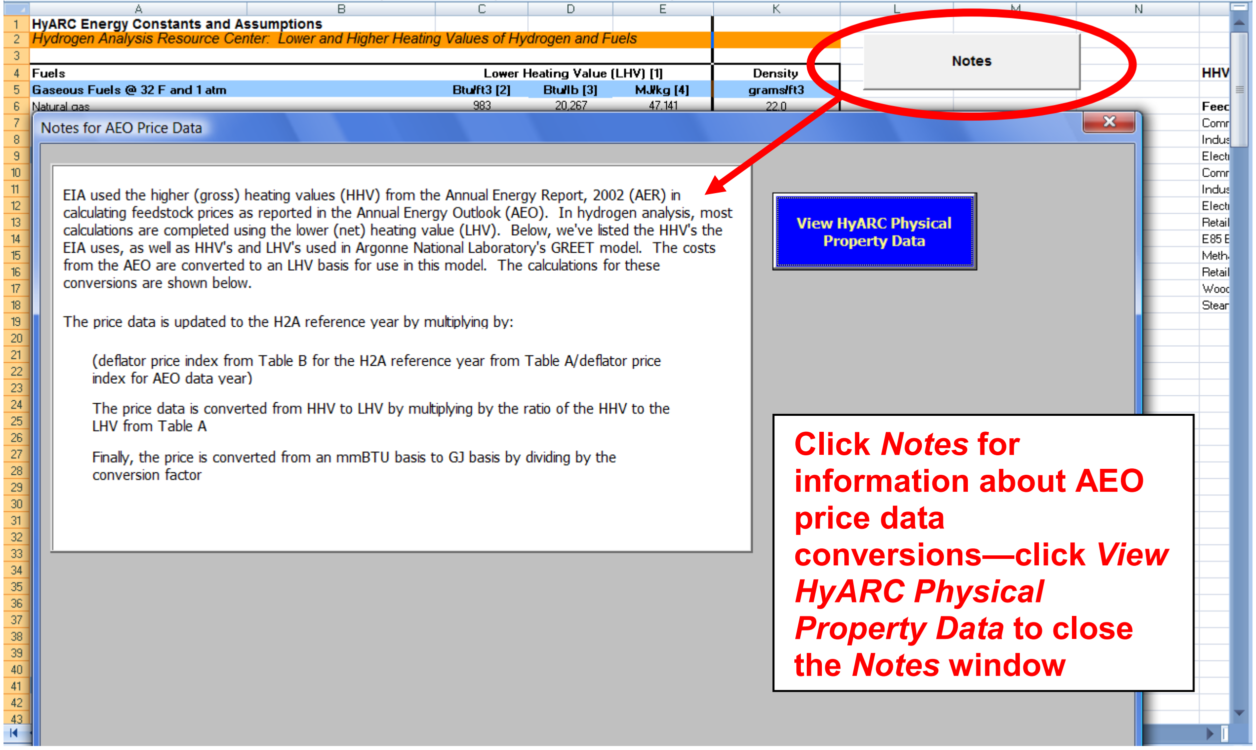
only

Advanced users might have occasion to change information in *Table A*, the *Energy Feedstock and Utility Properties* table. For an example, see the "Advanced user" segment under *Energy Feedstocks, Utilities, and Byproducts* (page 13). Although you can add and modify items within *Table A*, do not delete any fields from the table completely; this could create serious errors.

CAUTION

Table C1 contains upstream energy and greenhouse gas emissions values for hydrogen feedstocks for hydrogen production facilities starting operations in years 2005–2019. *Table C2* contains the same information for plants starting operations in years 2020 and beyond. These tables are used to calculate the upstream energy use and greenhouse gas emissions shown on the *Results* worksheet (see page 27). Unless otherwise noted, all values in these tables are given as LHV.

HyARC Physical Property Data Worksheet



EIA used the higher (gross) heating values (HHV) from the Annual Energy Report, 2002 (AER) in calculating feedstock prices as reported in the Annual Energy Outlook (AEO). In hydrogen analysis, most calculations are completed using the lower (net) heating value (LHV). Below, we've listed the HHV's the EIA uses, as well as HHV's and LHV's used in Argonne National Laboratory's GREET model. The costs from the AEO are converted to an LHV basis for use in this model. The calculations for these conversions are shown below.

The price data is updated to the H2A reference year by multiplying by:

> (deflator price index from Table B for the H2A reference year from Table A/deflator price index for AEO data year)
>
> The price data is converted from HHV to LHV by multiplying by the ratio of the HHV to the LHV from Table A
>
> Finally, the price is converted from an mmBTU basis to GJ basis by dividing by the conversion factor

Click *Notes* for information about AEO price data conversions—click *View HyARC Physical Property Data* to close the *Notes* window

References

U.S. Department of Energy Hydrogen Program. *Hydrogen Analysis Resource Center—Hydrogen Properties*. Web Site, accessed 11/9/07. Washington, DC: U.S. Department of Energy. http://hydrogen.pnl.gov/cocoon/morf/hydrogen/article/401.

The values for the *HyARC Energy Constants and Assumptions* table were downloaded from this Web site.

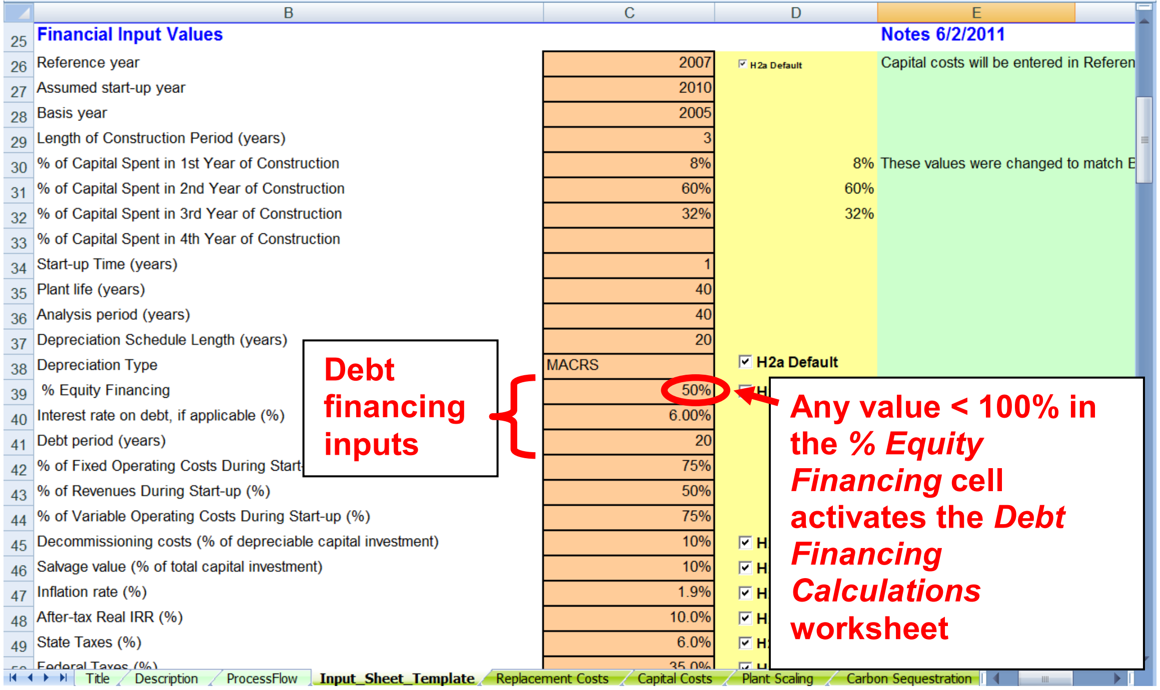
U.S. Department of Energy Hydrogen Program. *Hydrogen Delivery Component Model version 2.0*. Washington, DC: U.S. Department of Energy.

The upstream energy and greenhouse gas emissions information in *Tables C1* and *C2* came from the Hydrogen Delivery Component Model, *Table 4a*. The ultimate source of the information is the GREET Model, version 1.8b.

Debt Financing Calculations Worksheet

If debt financing is selected on the *Input_Sheet_Template* worksheet, the *Debt Financing Calculations* worksheet amortizes the loan. The results are used in the H2A Model's cash flow analysis (see page 30). No user input is required within this worksheet.

Input_Sheet_Template Worksheet

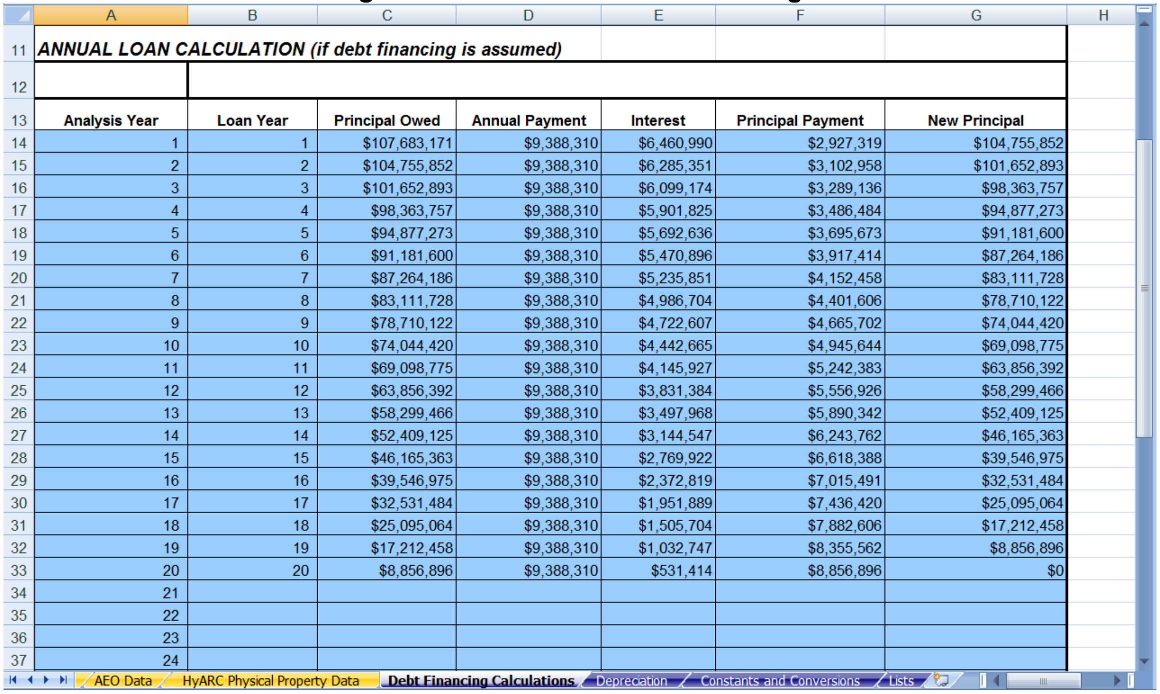


	B	C	D	E
25	**Financial Input Values**			**Notes 6/2/2011**
26	Reference year	2007	☑ H2a Default	Capital costs will be entered in Referen
27	Assumed start-up year	2010		
28	Basis year	2005		
29	Length of Construction Period (years)	3		
30	% of Capital Spent in 1st Year of Construction	8%	8%	These values were changed to match E
31	% of Capital Spent in 2nd Year of Construction	60%	60%	
32	% of Capital Spent in 3rd Year of Construction	32%	32%	
33	% of Capital Spent in 4th Year of Construction			
34	Start-up Time (years)	1		
35	Plant life (years)	40		
36	Analysis period (years)	40		
37	Depreciation Schedule Length (years)	20		
38	Depreciation Type	MACRS	☑ H2a Default	
39	% Equity Financing	50%	☐ H	
40	Interest rate on debt, if applicable (%)	6.00%		
41	Debt period (years)	20		
42	% of Fixed Operating Costs During Start	75%		
43	% of Revenues During Start-up (%)	50%		
44	% of Variable Operating Costs During Start-up (%)	75%		
45	Decommissioning costs (% of depreciable capital investment)	10%	☑ H	
46	Salvage value (% of total capital investment)	10%	☑ H	
47	Inflation rate (%)	1.9%	☑ H	
48	After-tax Real IRR (%)	10.0%	☑ H	
49	State Taxes (%)	6.0%	☑ H	
50	Federal Taxes (%)	35.0%	☑ H	

Debt financing inputs

Any value < 100% in the *% Equity Financing* cell activates the *Debt Financing Calculations* worksheet

Debt Financing Calculations Worksheet Showing Amortization

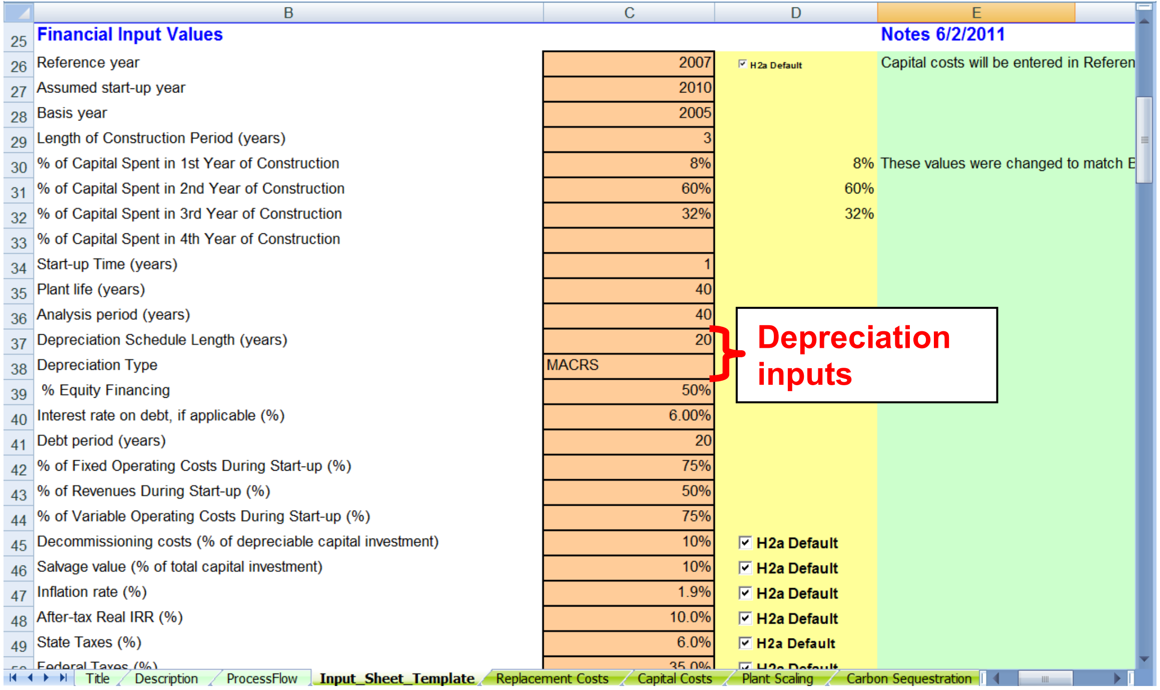


	A	B	C	D	E	F	G
11	***ANNUAL LOAN CALCULATION (if debt financing is assumed)***						
12							
13	**Analysis Year**	**Loan Year**	**Principal Owed**	**Annual Payment**	**Interest**	**Principal Payment**	**New Principal**
14	1	1	$107,683,171	$9,388,310	$6,460,990	$2,927,319	$104,755,852
15	2	2	$104,755,852	$9,388,310	$6,285,351	$3,102,958	$101,652,893
16	3	3	$101,652,893	$9,388,310	$6,099,174	$3,289,136	$98,363,757
17	4	4	$98,363,757	$9,388,310	$5,901,825	$3,486,484	$94,877,273
18	5	5	$94,877,273	$9,388,310	$5,692,636	$3,695,673	$91,181,600
19	6	6	$91,181,600	$9,388,310	$5,470,896	$3,917,414	$87,264,186
20	7	7	$87,264,186	$9,388,310	$5,235,851	$4,152,458	$83,111,728
21	8	8	$83,111,728	$9,388,310	$4,986,704	$4,401,606	$78,710,122
22	9	9	$78,710,122	$9,388,310	$4,722,607	$4,665,702	$74,044,420
23	10	10	$74,044,420	$9,388,310	$4,442,665	$4,945,644	$69,098,775
24	11	11	$69,098,775	$9,388,310	$4,145,927	$5,242,383	$63,856,392
25	12	12	$63,856,392	$9,388,310	$3,831,384	$5,556,926	$58,299,466
26	13	13	$58,299,466	$9,388,310	$3,497,968	$5,890,342	$52,409,125
27	14	14	$52,409,125	$9,388,310	$3,144,547	$6,243,762	$46,165,363
28	15	15	$46,165,363	$9,388,310	$2,769,922	$6,618,388	$39,546,975
29	16	16	$39,546,975	$9,388,310	$2,372,819	$7,015,491	$32,531,484
30	17	17	$32,531,484	$9,388,310	$1,951,889	$7,436,420	$25,095,064
31	18	18	$25,095,064	$9,388,310	$1,505,704	$7,882,606	$17,212,458
32	19	19	$17,212,458	$9,388,310	$1,032,747	$8,355,562	$8,856,896
33	20	20	$8,856,896	$9,388,310	$531,414	$8,856,896	$0
34	21						
35	22						
36	23						
37	24						

Depreciation Worksheet

This worksheet calculates depreciation for use in the H2A Model's cash flow analysis (see page 30). No user input is required within this worksheet.

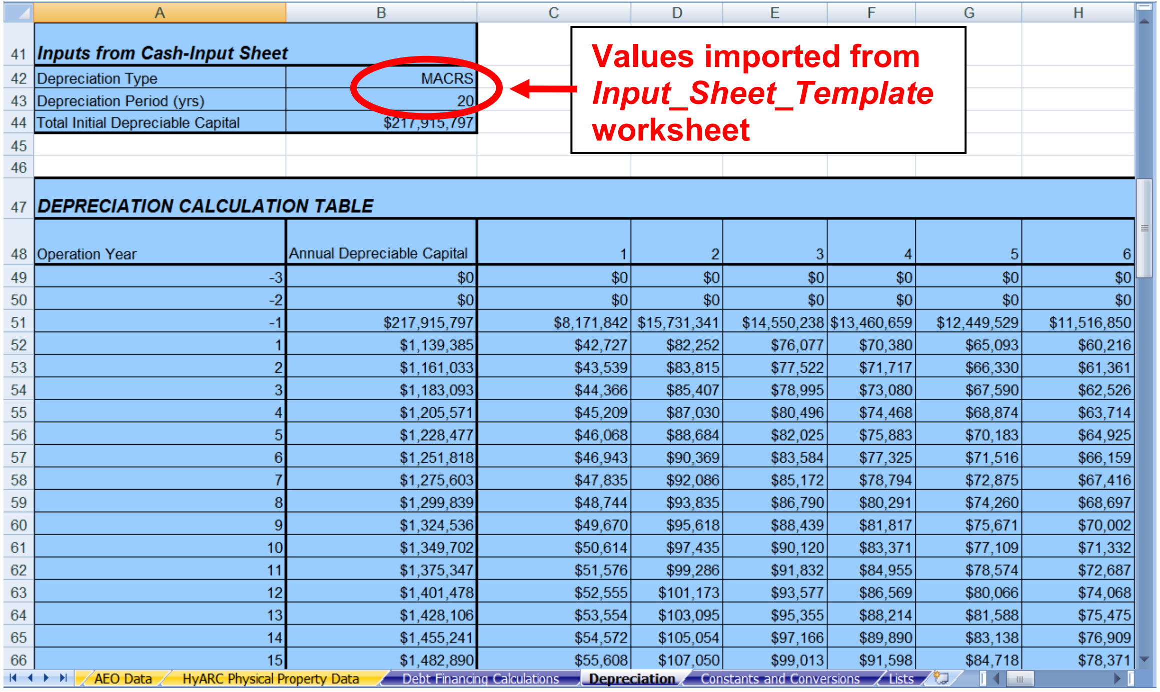
Input_Sheet_Template Worksheet



	B	C	D	E
25	**Financial Input Values**			**Notes 6/2/2011**
26	Reference year	2007	☑ H2a Default	Capital costs will be entered in Referen
27	Assumed start-up year	2010		
28	Basis year	2005		
29	Length of Construction Period (years)	3		
30	% of Capital Spent in 1st Year of Construction	8%	8%	These values were changed to match E
31	% of Capital Spent in 2nd Year of Construction	60%	60%	
32	% of Capital Spent in 3rd Year of Construction	32%	32%	
33	% of Capital Spent in 4th Year of Construction			
34	Start-up Time (years)	1		
35	Plant life (years)	40		
36	Analysis period (years)	40		
37	Depreciation Schedule Length (years)	20		
38	Depreciation Type	MACRS		
39	% Equity Financing	50%		
40	Interest rate on debt, if applicable (%)	6.00%		
41	Debt period (years)	20		
42	% of Fixed Operating Costs During Start-up (%)	75%		
43	% of Revenues During Start-up (%)	50%		
44	% of Variable Operating Costs During Start-up (%)	75%		
45	Decommissioning costs (% of depreciable capital investment)	10%	☑ **H2a Default**	
46	Salvage value (% of total capital investment)	10%	☑ **H2a Default**	
47	Inflation rate (%)	1.9%	☑ **H2a Default**	
48	After-tax Real IRR (%)	10.0%	☑ **H2a Default**	
49	State Taxes (%)	6.0%	☑ **H2a Default**	
50	Federal Taxes (%)	35.0%	☑ **H2a Default**	

Depreciation inputs

Depreciation Worksheet



	A	B
41	***Inputs from Cash-Input Sheet***	
42	Depreciation Type	MACRS
43	Depreciation Period (yrs)	20
44	Total Initial Depreciable Capital	$217,915,797

Values imported from *Input_Sheet_Template* worksheet

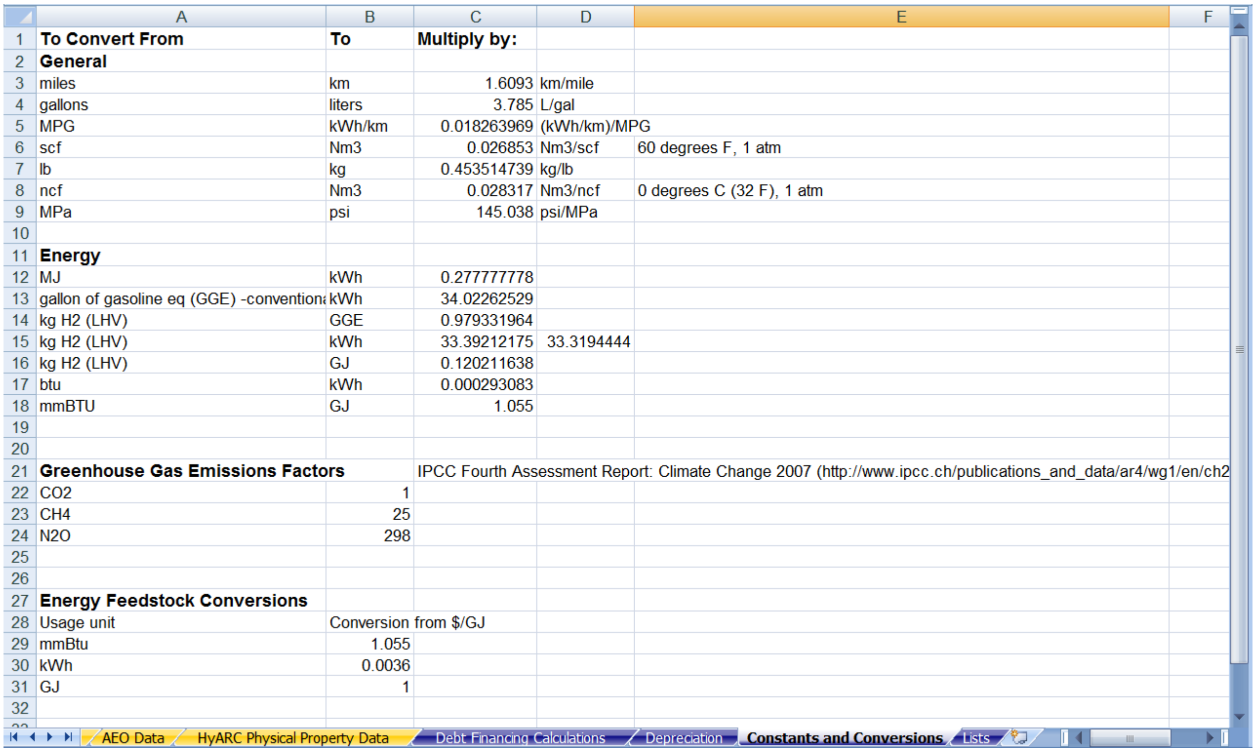
47 ***DEPRECIATION CALCULATION TABLE***

	Operation Year	Annual Depreciable Capital	1	2	3	4	5	6
49	-3	$0	$0	$0	$0	$0	$0	$0
50	-2	$0	$0	$0	$0	$0	$0	$0
51	-1	$217,915,797	$8,171,842	$15,731,341	$14,550,238	$13,460,659	$12,449,529	$11,516,850
52	1	$1,139,385	$42,727	$82,252	$76,077	$70,380	$65,093	$60,216
53	2	$1,161,033	$43,539	$83,815	$77,522	$71,717	$66,330	$61,361
54	3	$1,183,093	$44,366	$85,407	$78,995	$73,080	$67,590	$62,526
55	4	$1,205,571	$45,209	$87,030	$80,496	$74,468	$68,874	$63,714
56	5	$1,228,477	$46,068	$88,684	$82,025	$75,883	$70,183	$64,925
57	6	$1,251,818	$46,943	$90,369	$83,584	$77,325	$71,516	$66,159
58	7	$1,275,603	$47,835	$92,086	$85,172	$78,794	$72,875	$67,416
59	8	$1,299,839	$48,744	$93,835	$86,790	$80,291	$74,260	$68,697
60	9	$1,324,536	$49,670	$95,618	$88,439	$81,817	$75,671	$70,002
61	10	$1,349,702	$50,614	$97,435	$90,120	$83,371	$77,109	$71,332
62	11	$1,375,347	$51,576	$99,286	$91,832	$84,955	$78,574	$72,687
63	12	$1,401,478	$52,555	$101,173	$93,577	$86,569	$80,066	$74,068
64	13	$1,428,106	$53,554	$103,095	$95,355	$88,214	$81,588	$75,475
65	14	$1,455,241	$54,572	$105,054	$97,166	$89,890	$83,138	$76,909
66	15	$1,482,890	$55,608	$107,050	$99,013	$91,598	$84,718	$78,371

Constants and Conversions Worksheet

The constants and conversion factors listed on this worksheet are used in H2A calculations and included for users' reference. No user input is required within this worksheet.

Constants and Conversions Worksheet



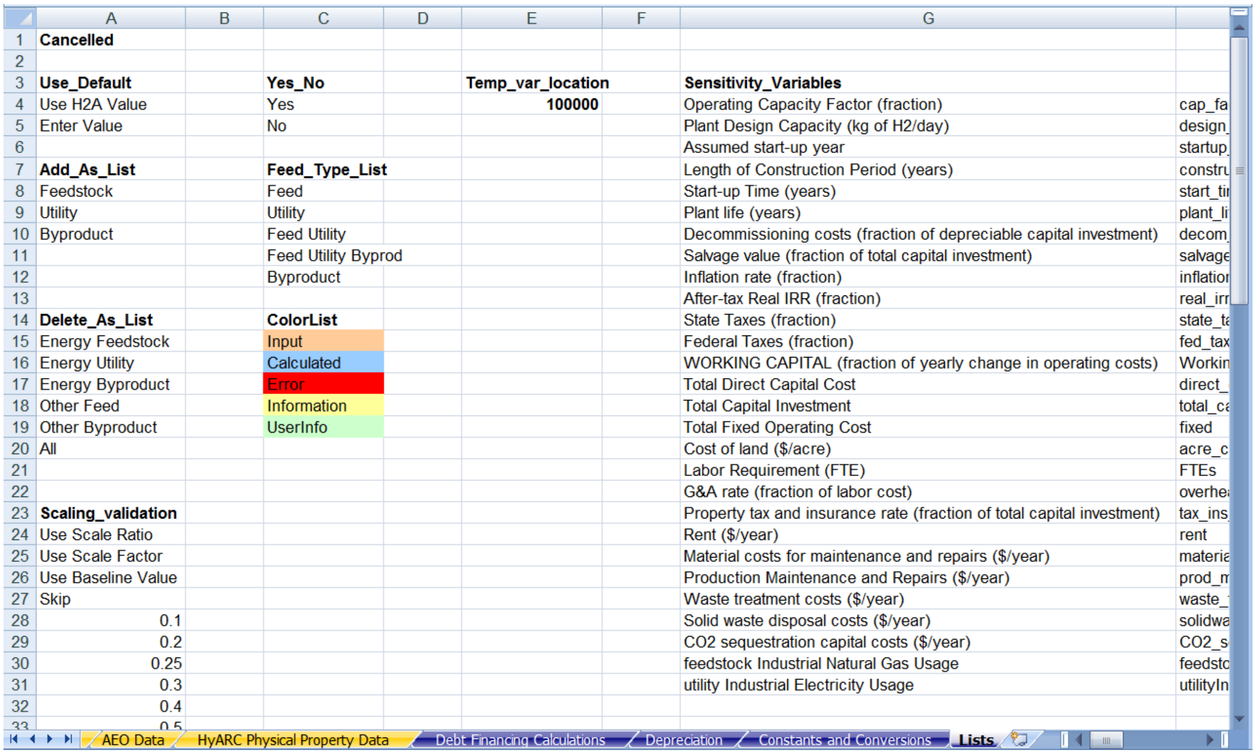
	A	B	C	D	E	F
1	**To Convert From**	**To**	**Multiply by:**			
2	**General**					
3	miles	km	1.6093	km/mile		
4	gallons	liters	3.785	L/gal		
5	MPG	kWh/km	0.018263969	(kWh/km)/MPG		
6	scf	Nm3	0.026853	Nm3/scf	60 degrees F, 1 atm	
7	lb	kg	0.453514739	kg/lb		
8	ncf	Nm3	0.028317	Nm3/ncf	0 degrees C (32 F), 1 atm	
9	MPa	psi	145.038	psi/MPa		
10						
11	**Energy**					
12	MJ	kWh	0.277777778			
13	gallon of gasoline eq (GGE) -conventiona	kWh	34.02262529			
14	kg H2 (LHV)	GGE	0.979331964			
15	kg H2 (LHV)	kWh	33.39212175	33.3194444		
16	kg H2 (LHV)	GJ	0.120211638			
17	btu	kWh	0.000293083			
18	mmBTU	GJ	1.055			
19						
20						
21	**Greenhouse Gas Emissions Factors**		IPCC Fourth Assessment Report: Climate Change 2007 (http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2			
22	CO2	1				
23	CH4	25				
24	N2O	298				
25						
26						
27	**Energy Feedstock Conversions**					
28	Usage unit	Conversion from $/GJ				
29	mmBtu	1.055				
30	kWh	0.0036				
31	GJ	1				
32						

Lists Worksheet

CAUTION

The *Lists* worksheet contains lists of variable labels that the H2A Production Model uses to perform all its calculations. Do not add, delete, or change anything on this worksheet. Modifying the lists could disable or introduce major errors into the model.

Lists Worksheet



	A	B	C	D	E	F	G	
1	**Cancelled**							
2								
3	**Use_Default**		**Yes_No**		**Temp_var_location**		**Sensitivity_Variables**	
4	Use H2A Value		Yes		**100000**		Operating Capacity Factor (fraction)	cap_fa
5	Enter Value		No				Plant Design Capacity (kg of H2/day)	design_
6							Assumed start-up year	startup_
7	**Add_As_List**		**Feed_Type_List**				Length of Construction Period (years)	constru
8	Feedstock		Feed				Start-up Time (years)	start_ti
9	Utility		Utility				Plant life (years)	plant_li
10	Byproduct		Feed Utility				Decommissioning costs (fraction of depreciable capital investment)	decom_
11			Feed Utility Byprod				Salvage value (fraction of total capital investment)	salvage
12			Byproduct				Inflation rate (fraction)	inflatio
13							After-tax Real IRR (fraction)	real_ir
14	**Delete_As_List**		**ColorList**				State Taxes (fraction)	state_t
15	Energy Feedstock		Input				Federal Taxes (fraction)	fed_tax
16	Energy Utility		Calculated				WORKING CAPITAL (fraction of yearly change in operating costs)	Workin
17	Energy Byproduct		Error				Total Direct Capital Cost	direct_
18	Other Feed		Information				Total Capital Investment	total_c
19	Other Byproduct		UserInfo				Total Fixed Operating Cost	fixed
20	All						Cost of land ($/acre)	acre_c
21							Labor Requirement (FTE)	FTEs
22							G&A rate (fraction of labor cost)	overhe
23	**Scaling_validation**						Property tax and insurance rate (fraction of total capital investment)	tax_ins
24	Use Scale Ratio						Rent ($/year)	rent
25	Use Scale Factor						Material costs for maintenance and repairs ($/year)	materia
26	Use Baseline Value						Production Maintenance and Repairs ($/year)	prod_m
27	Skip						Waste treatment costs ($/year)	waste_
28	0.1						Solid waste disposal costs ($/year)	solidwa
29	0.2						CO2 sequestration capital costs ($/year)	CO2_s
30	0.25						feedstock Industrial Natural Gas Usage	feedsto
31	0.3						utility Industrial Electricity Usage	utilityIn
32	0.4							
33	0.5							

Technical Support

Information related to the new H2A Production Model will be posted on the H2A Web site as it becomes publicly available: www.hydrogen.energy.gov/h2a_production.html. Visit the Web site to download copies of the model and technology cases.

For technical questions not answered by this guide or the Web site, contact:

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National Renewable Energy Laboratory
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Appendix 1: Carbon Sequestration Calculations and Sources

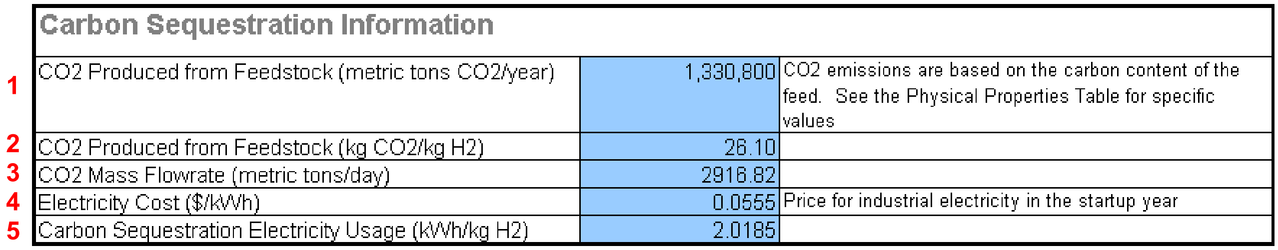
This appendix briefly describes the inputs and calculations used within the *Carbon Sequestration* worksheet (which is used for the H2A central model only, see page 22). See the sources listed in *References* at the end of this appendix for detailed descriptions and derivations of the calculations. Note that McCollum and Ogden (2006) include CO_2 pumps in their carbon sequestration calculations as well as compressors. Because super-critical CO_2 exhibits liquid-like density at the pressures and temperatures of carbon sequestration, pumps or compressors can be used in this application. The choice of using pumps, compressors, or both depends on the scale of the carbon sequestration process. At the high production capacities of most H2A central model cases, the higher efficiency of compressors offsets their higher initial capital cost; industry feedback supports this contention. Therefore, the H2A central model includes only CO_2 compressors, rather than pumps, in its carbon sequestration calculations.

The *Carbon Sequestration* worksheet is divided into four tables:

Table	Purpose	User Input Required
Carbon Sequestration Information	Source of values for carbon sequestration calculations	No
Carbon Sequestration Input Values	Source of values for carbon sequestration calculations	Yes
Carbon Sequestration Calculations	Calculate carbon sequestration results	No
Summary of Output Values	Display carbon sequestration results	No

See the screen captures of the tables below. The numbers on the left of each table correspond with the numbered descriptions of each field.

Carbon Sequestration Information



	Carbon Sequestration Information		
1	CO2 Produced from Feedstock (metric tons CO2/year)	1,330,800	CO2 emissions are based on the carbon content of the feed. See the Physical Properties Table for specific values
2	CO2 Produced from Feedstock (kg CO2/kg H2)	26.10	
3	CO2 Mass Flowrate (metric tons/day)	2916.82	
4	Electricity Cost ($/kWh)	0.0555	Price for industrial electricity in the startup year
5	Carbon Sequestration Electricity Usage (kWh/kg H2)	2.0185	

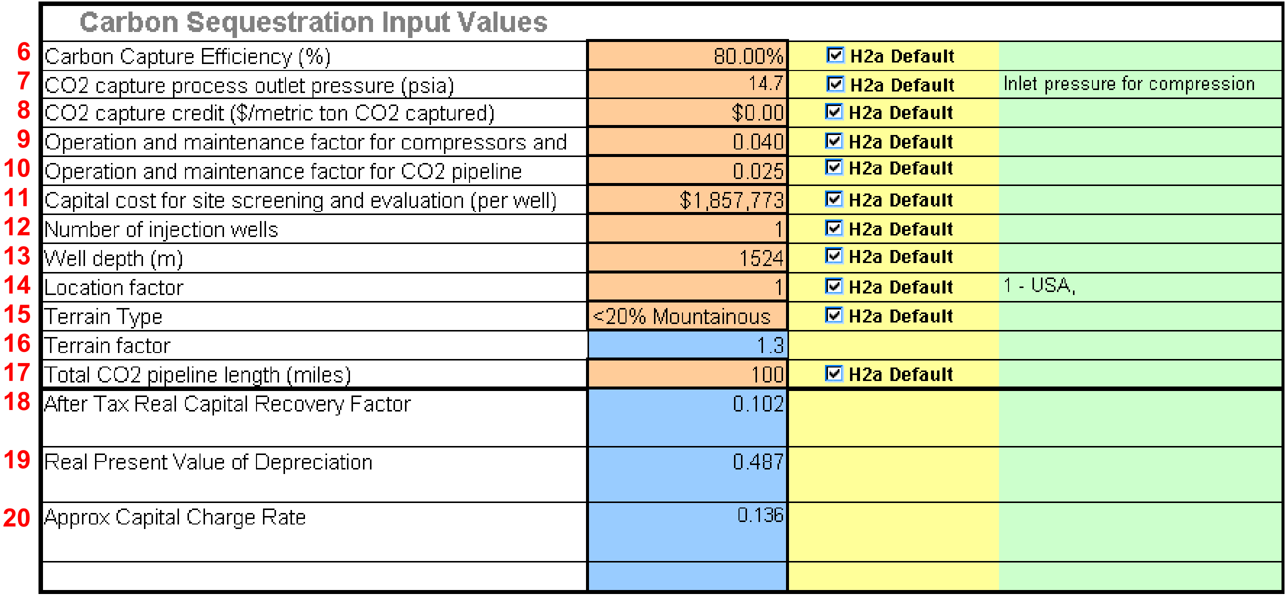
1, 2. *CO2 Produced from Feedstock*—CO_2 emissions produced from the feedstock are calculated based on the properties of the feedstock and the amount of feedstock used in hydrogen production. The feedstock type and use information comes from the *Input_Sheet_Template* worksheet. The properties come from the *HyARC Physical Property Data* worksheet.

3. *CO2 Mass Flowrate*—The CO_2 mass flow rate (the mass of CO_2 transported to the injection site each day) is calculated using the value for CO_2 produced from feedstock (**1**) and the carbon capture efficiency (**6**).

4. *Electricity Cost*—The industrial electricity cost is drawn from the *Energy Feed & Utility Prices* worksheet for each year of the calculations. The startup year cost is shown here.

5. *Carbon Sequestration Electricity Usage*—This value is calculated using the power requirement (**21**) from the *Carbon Sequestration Calculations* table (in the *Carbon Sequestration* worksheet) and the capacity factor and plant output from the *Input_Sheet_Template* worksheet.

Carbon Sequestration Input Values



	Carbon Sequestration Input Values			
6	Carbon Capture Efficiency (%)	80.00%	☑ H2a Default	
7	CO2 capture process outlet pressure (psia)	14.7	☑ H2a Default	Inlet pressure for compression
8	CO2 capture credit ($/metric ton CO2 captured)	$0.00	☑ H2a Default	
9	Operation and maintenance factor for compressors and	0.040	☑ H2a Default	
10	Operation and maintenance factor for CO2 pipeline	0.025	☑ H2a Default	
11	Capital cost for site screening and evaluation (per well)	$1,857,773	☑ H2a Default	
12	Number of injection wells	1	☑ H2a Default	
13	Well depth (m)	1524	☑ H2a Default	
14	Location factor	1	☑ H2a Default	1 - USA,
15	Terrain Type	<20% Mountainous	☑ H2a Default	
16	Terrain factor	1.3		
17	Total CO2 pipeline length (miles)	100	☑ H2a Default	
18	After Tax Real Capital Recovery Factor	0.102		
19	Real Present Value of Depreciation	0.487		
20	Approx Capital Charge Rate	0.136		

6. *Carbon Capture Efficiency*—Input the percentage of CO_2 emissions captured here (note: only CO_2 emissions from feedstock processing can be captured). This value is used in the calculation of CO_2 mass flow rate (**3**). The default value is 80%.

7. *CO2 Capture Process Outlet Pressure*—Input the value for the pressure of CO_2 exiting the capture phase and entering the compression phase here. This value becomes $P_{initial}$ in the CO_2 compression calculations (**23**). The default value is 14.7 psia (atmospheric pressure).

8. *CO2 Capture Credit*—Input the value for CO_2 capture credits here. If a value is entered, the credits offset operation and maintenance costs (**29**). The default value is zero.

9. *Operation and Maintenance Factor for Compressors*—Input the compressor operation and maintenance factor here. The model multiplies this value times the compressor capital cost to determine annual compressor operation and maintenance cost (**24**). The default value is 0.04.

10. *Operation and Maintenance Factor for CO2 Pipeline*—Input the pipeline operation and maintenance factor here. The model multiplies this value times the pipeline capital cost to determine annual pipeline operation and maintenance cost (**28**). The default value is 0.025.

11. *Capital Cost for Site Screening and Evaluation (per well)*—Input the per-well capital cost for site screening and evaluation here. This value is multiplied times the number of wells to become C_{site} in the CO_2 compression calculations (**25**). The default value is $1,857,773.

12. *Number of Injection Wells*—Input the number of injection wells here. This value is used in the calculations for drilling and injection equipment capital costs as well as injection operation and maintenance costs (**25**, **26**). The default value is 1 well, which is the typical number needed for injecting 10,000 metric tons/day or less using a 0.15-m-diameter injection pipe. For an iterative process for calculating number of wells needed, see McCollum and Ogden (2006), page 15.

13. *Well Depth*—Input well depth here. This value is used in the calculations for drilling capital cost as well as injection operation and maintenance costs (**25**, **26**). The default value is 1,524 m, which is the base case for gas reservoirs in McCollum and Ogden (2006), page 15 (Table 3). Benson (2000) describes California oil and gas reservoirs as no deeper than 1,500 m.

14. *Location Factor*—Select a location factor from the drop-down menu. A location factor of 1 corresponds to location in the United States, Canada, Europe, Japan, or Australia. A location factor of 1.2 corresponds to location in the United Kingdom. This value is used in the calculation for pipeline capital cost; a higher location factor increases the cost (**27**). The default value is 1.

15, 16. *Terrain Type/Terrain Factor*—Select a terrain type from the drop-down menu. Each terrain type corresponds to a specific terrain factor, which is automatically entered into the *Terrain Factor* field as follows:

- cultivated land = 1.1
- grassland = 1
- wooded = 1.05
- jungle = 1.1
- stony desert = 1.1
- <20% mountainous = 1.3
- >50% mountainous = 1.5

This value is used in the calculation for pipeline capital cost; a higher terrain factor increases the cost (**27**). The default value is 1.3 (<20% mountainous).

17. *Total CO2 Pipeline Length*—Input total pipeline length here. This value is used in the calculation for pipeline capital cost (**27**). The default value is 100 miles. Required CO_2 transportation distances (i.e., required pipeline lengths) vary by location.

18–20. These factors (after tax real capital recovery factor, real present value of depreciation, and approximate capital charge rate) are automatically calculated using values from the *Input_Sheet_Template* worksheet and financial calculations. They are used in the carbon sequestration calculations for capital, electrical, and O&M cost per metric ton of CO_2

sequestered. The capital and operating costs for carbon sequestration are also included in the model's discounted cash flow calculations—see the *Cash Flow Analysis* (page 30) and *Results* (page 27) sections. The results shown on the *Results* worksheet are for the entire plant.

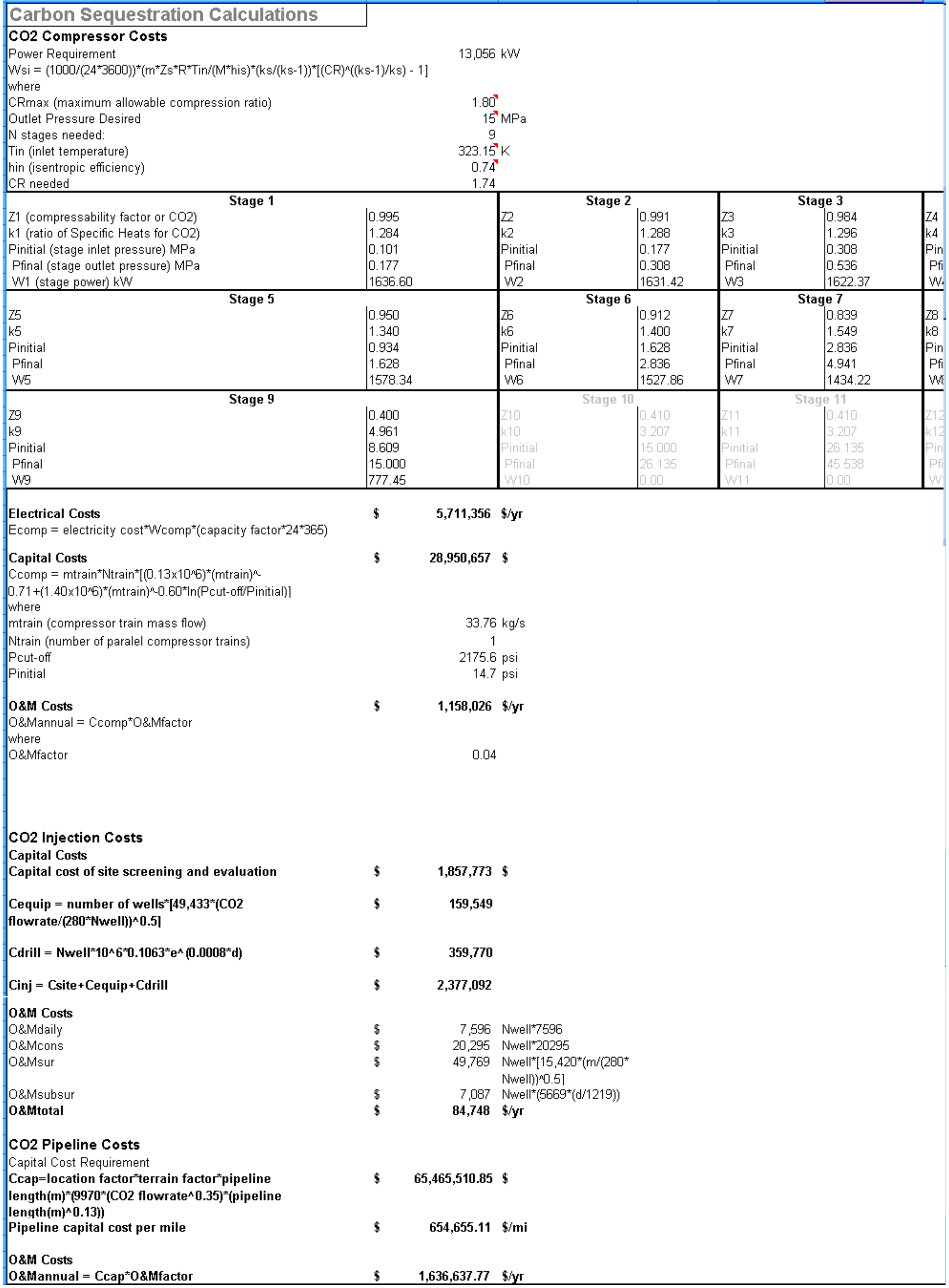
21–28. The *Carbon Sequestration Calculations* table shows calculations based on the input and calculation tables described above as well as default values and constants. The upper half of the table (**21–24**) calculates compressor costs, including a power requirement calculation for multi-stage compression (**21**). The lower half of the table (**25–28**) calculates injection and pipeline costs. See McCollum and Ogden (2006) for details about the calculations. Do not change any of the cells in this table directly.

29. The *Summary of Outputs* table summarizes the major results of the carbon sequestration calculations. The costs are for CO_2 compression, transportation to the sequestration site, and injection. Costs for CO_2 capture are assumed to be included in the production facility's capital and operating costs and are not included here. Costs are shown in reference year dollars. Do not change any of the cells in this table directly.

The calculations for the cost of sequestration per metric ton of CO_2 are based on the capital recovery factor (CRF) method rather than a rigorous discounted cash flow method, which is used for the H2A Model's hydrogen production calculations. Although the CRF method is not quite as rigorous, the results are comparable when the same economic parameters are used.

30. The approximate indirect capital costs due to carbon sequestration are calculated by multiplying the total indirect capital costs by the ratio of carbon sequestration direct capital costs to total direct capital costs. This approximation (like the approximation of uninstalled capital cost in the preceding cell) is for information only; it does not participate in the model's calculations.

Carbon Sequestration Calculations



Carbon Sequestration Calculations

CO2 Compressor Costs

21 Power Requirement	13,056	kW
Wsi = (1000/(24*3600))*(m*Zs*R*Tin/(M*his)*(ks/(ks-1))*[(CR)^((ks-1)/ks) - 1]		
where		
CRmax (maximum allowable compression ratio)	1.80	
Outlet Pressure Desired	15	MPa
N stages needed:	9	
Tin (inlet temperature)	323.15	K
hin (isentropic efficiency)	0.74	
CR needed	1.74	

Stage 1		Stage 2		Stage 3		
Z1 (compressability factor or CO2)	0.995	Z2	0.991	Z3	0.984	Z4
k1 (ratio of Specific Heats for CO2)	1.284	k2	1.288	k3	1.296	k4
Pinitial (stage inlet pressure) MPa	0.101	Pinitial	0.177	Pinitial	0.308	Pin
Pfinal (stage outlet pressure) MPa	0.177	Pfinal	0.308	Pfinal	0.536	Pfi
W1 (stage power) kW	1636.60	W2	1631.42	W3	1622.37	W
Stage 5		**Stage 6**		**Stage 7**		
Z5	0.950	Z6	0.912	Z7	0.839	Z8
k5	1.340	k6	1.400	k7	1.549	k8
Pinitial	0.934	Pinitial	1.628	Pinitial	2.836	Pin
Pfinal	1.628	Pfinal	2.836	Pfinal	4.941	Pfi
W5	1578.34	W6	1527.86	W7	1434.22	W
Stage 9		**Stage 10**		**Stage 11**		
Z9	0.400	Z10	0.410	Z11	0.410	Z12
k9	4.961	k10	3.207	k11	3.207	k12
Pinitial	8.609	Pinitial	15.000	Pinitial	26.135	Pin
Pfinal	15.000	Pfinal	26.135	Pfinal	45.538	Pfi
W9	777.45	W10	0.00	W11	0.00	W

22 **Electrical Costs**	$	**5,711,356**	**$/yr**
Ecomp = electricity cost*Wcomp*(capacity factor*24*365)			
23 **Capital Costs**	$	**28,950,657**	**$**
Ccomp = mtrain*Ntrain*[(0.13x10^6)*(mtrain)^-0.71+(1.40x10^6)*(mtrain)^-0.60*ln(Pcut-off/Pinitial)]			
where			
mtrain (compressor train mass flow)		33.76	kg/s
Ntrain (number of paralel compressor trains)		1	
Pcut-off		2175.6	psi
Pinitial		14.7	psi
24 **O&M Costs**	$	**1,158,026**	**$/yr**
O&Mannual = Ccomp*O&Mfactor			
where			
O&Mfactor		0.04	

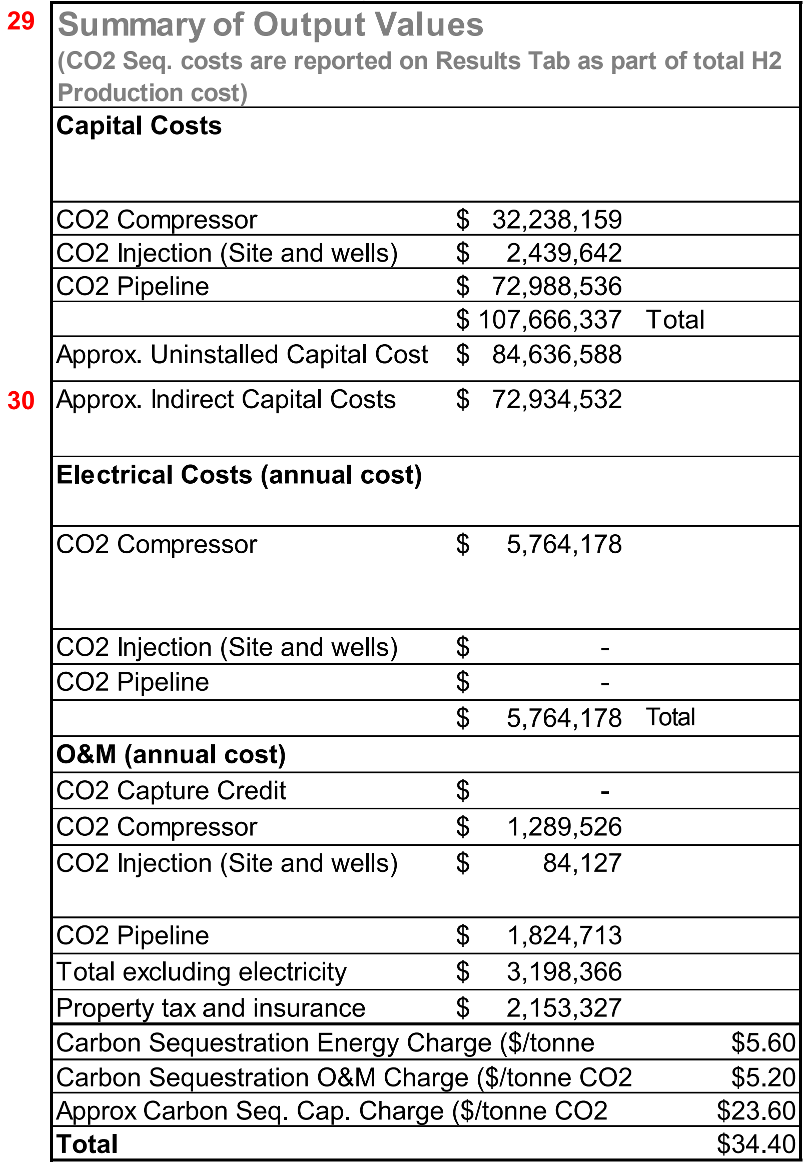
CO2 Injection Costs

Capital Costs			
25 **Capital cost of site screening and evaluation**	$	**1,857,773**	**$**
Cequip = number of wells*[49,433*(CO2 flowrate/(280*Nwell))^0.5]	$	**159,549**	
Cdrill = Nwell*10^6*0.1063*e^(0.0008*d)	$	**359,770**	
Cinj = Csite+Cequip+Cdrill	$	**2,377,092**	
26 **O&M Costs**			
O&Mdaily	$	7,596	Nwell*7596
O&Mcons	$	20,295	Nwell*20295
O&Msur	$	49,769	Nwell*[15,420*(m/(280*Nwell))^0.5]
O&Msubsur	$	7,087	Nwell*(5669*(d/1219))
O&Mtotal	**$**	**84,748**	**$/yr**

CO2 Pipeline Costs

27 Capital Cost Requirement			
Ccap=location factor*terrain factor*pipeline length(m)*(9970*(CO2 flowrate^0.35)*(pipeline length(m)^0.13))	$	**65,465,510.85**	**$**
Pipeline capital cost per mile	$	**654,655.11**	**$/mi**
28 **O&M Costs**			
O&Mannual = Ccap*O&Mfactor	$	**1,636,637.77**	**$/yr**

Summary of Output Values



29	Summary of Output Values (CO2 Seq. costs are reported on Results Tab as part of total H2 Production cost)		
	Capital Costs		
	CO2 Compressor	$ 32,238,159	
	CO2 Injection (Site and wells)	$ 2,439,642	
	CO2 Pipeline	$ 72,988,536	
		$ 107,666,337	Total
	Approx. Uninstalled Capital Cost	$ 84,636,588	
30	Approx. Indirect Capital Costs	$ 72,934,532	
	Electrical Costs (annual cost)		
	CO2 Compressor	$ 5,764,178	
	CO2 Injection (Site and wells)	$ -	
	CO2 Pipeline	$ -	
		$ 5,764,178	Total
	O&M (annual cost)		
	CO2 Capture Credit	$ -	
	CO2 Compressor	$ 1,289,526	
	CO2 Injection (Site and wells)	$ 84,127	
	CO2 Pipeline	$ 1,824,713	
	Total excluding electricity	$ 3,198,366	
	Property tax and insurance	$ 2,153,327	
	Carbon Sequestration Energy Charge ($/tonne		$5.60
	Carbon Sequestration O&M Charge ($/tonne CO2		$5.20
	Approx Carbon Seq. Cap. Charge ($/tonne CO2		$23.60
	Total		$34.40

References

The calculations used in the *Carbon Sequestration* worksheet were developed by Directed Technologies, Inc. and the National Renewable Energy Laboratory based on information from compressor/turbine manufacturer MAN Turbo and the following publications:

Benson, S.M. (2000). *Comparison of Three Options for Geologic Sequestration of CO2—A Case Study for California*. LBNL-46365. Berkeley, CA: Lawrence Berkeley National Laboratory. http://repositories.cdlib.org/lbnl/LBNL-46365.

> This study examines the distribution of carbon emissions from fossil fuel power plants in California and their proximity to active or depleted oil and gas fields and brine formations—reservoirs that might be suitable for carbon sequestration. It also assesses the feasibility of sequestering CO_2 from California fossil fuel plants in these reservoirs.

Chen, S.G.; Lu, Y.; Rostam-Abadi, M.; Nyman, D.J.; Dracos, J.S.; Varagani, Rajani. (2004). *Carbon Dioxide Capture and Transportation Options in the Illinois Basin*. Champaign, IL: Illinois State Geological Survey. http://sequestration.org/publish/MGSC_year1report.pdf.

This report describes CO_2 capture options from large stationary emission sources in the Illinois Basin, focusing on coal-fired power plants. It includes information on pipeline costs.

McCollum, D.L.; Ogden, J.M. (2006). *Techno-Economic Models for Carbon Dioxide Compression, Transport, and Storage & Correlations for Estimating Carbon Dioxide Density and Viscosity*. UCD—ITS—RR—06-14. Davis, CA: Institute of Transportation Studies, University of California, Davis. http://hydrogen.its.ucdavis.edu/publications/2006pubs/resolveuid/7c6a2993156155db8d3209af679b4cdb.

This report is divided into three sections:

- *Techno-Economic Models for Carbon Dioxide Compression, Transport, and Storage* contains models for estimating the engineering requirements and costs of carbon capture and storage (CCS) infrastructure.
- *Simple Correlations for Estimating Carbon Dioxide Density and Viscosity as a Function of Temperature and Pressure* describes simple correlations—which are functions of only temperature and pressure—for estimating the density and viscosity of CO_2 within the range of operating temperatures and pressures that might be encountered in CCS applications.
- *Comparing Techno-Economic Models for Pipeline Transport of Carbon Dioxide* illustrates an approach used to compare several recent techno-economic models for estimating CO_2 pipeline sizes and costs, resulting in a new CO_2 pipeline capital cost model that is a function only of flow rate and pipeline length.

Appendix 2: Default Values and Assumptions

The following default values and assumptions apply to the H2A central model, unless a specific technology case specifies otherwise:

Analysis Methodology	Discounted cash flow (DCF) model that calculates a levelized hydrogen cost yielding a prescribed IRR
Analysis Period	40 years
Average Burdened Labor Rate for Staff	$50/hour
Capacity Factor	90% with case exceptions
Central Storage	Optional buffer only as required for efficient operations
CO_2 Capture Credit	Not included in base cases (default value = 0)
CO_2 Production Taxes	Not included in base cases (default value = 0)
Construction Period and Cash Flow	Varies per case
Co-produced and Cogenerated Electricity Price	$30/MWh
Decommissioning	10% of initial capital, with case exceptions
Depreciation Type and Schedule for Initial Depreciable Capital Cost	MACRS: 20 years with case exceptions
Facility Life	40 years with case exceptions
G&A Rate	20% of the staff labor costs above
Hydrogen Pressure at Central Gate	300 psig; if higher pressure is inherent to the process, apply pumping power credit for pressure > 300 psig
Hydrogen Purity	98% minimum; CO < 10 ppm, sulfur < 10 ppm
Income Taxes	35% federal; 6% state; 38.9% effective
Inflation Rate	1.9%, but with resultant price of hydrogen in reference year constant dollars
Land Cost	$50,000/acre purchased
O_2 Credit	Not included in base cases
Process Contingency	% adjustment to the total initial capital cost such that the result incorporates the mean or expected overall performance

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
Property Taxes and Business Insurance	2%/year of the total initial capital cost
Reference Financial Structure	100% equity with 10% IRR; includes levelized hydrogen price plot for 0%–25% IRR[2]; model allows debt financing
Reference Year Dollars	2007 (can be adjusted 2005–2010)
Sales Tax	Not included on basis that facilities and related purchases are wholesale and through a general contractor entity
Salvage Value	10% of initial capital, with case exceptions
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
Technology Development Stage	All cost estimates are based on mature, commercial facilities
Working Capital Rate[3]	15% of the annual change in total operating costs

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[2] The default 10% real IRR value was derived from return-on-equity statistics (adjusted for inflation) for large-company stocks during the period 1926–2002, which show a return of approximately 9% (Source: Ibbotson Associates, 2003, *Stocks, Bonds, Bills and Inflation 2003 Yearbook*). 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. NREL has explored the feasibility of other IRR values, ranging from a few percent up to 25%, which users might choose based on their assumptions about the maturity of hydrogen technology and hydrogen investment risk (Source: NREL, 2004, *An Approach to Handling Internal Rate of Return for the H2A Analysis* [Internal Memo Report]).

[3] Working capital is defined as a measure of a business' daily operating liquidity, calculated by subtracting current liabilities from current assets. Working capital is considered a part of operating capital, along with fixed assets such as facilities and equipment. It is also known as net working capital.

Appendix 3: Central Model Version 3 Updates

Introduction

Version 2 of the H2A Production Model was released in 2008. Since then, multiple improvements have been made, culminating in the release of version 3 in 2011. This appendix lists the major assumptions behind version 3 and details the rationale for the changes made since version 2. Although the changes discussed specifically apply to the current timeframe central steam methane reformer (SMR) without CO_2 sequestration production case, they are broadly applicable to the other central production cases. Where SMR-specific values (e.g., costs) are shown, these can be seen as examples of the adjustments made to central production cases in general. Table 1 summarizes version 3 improvements, which are detailed in the subsequent sections of this appendix.

Table 1. Summary of changes from H2A central model version 2 to version 3 (specific example is current SMR without CO_2 sequestration)

	Version 2	Version 3
Financial Input Values		
Reference year	2005	2007
Assumed start-up year	2005	2010
Length of construction period (years)	2	3
Percent of capital spent in years 1–2 (version 2), 1–3 (version 3)*	60%, 40%	8%, 60%, 32%
Direct Capital Costs		
All direct capital costs	$2005	Escalated to $2007
Indirect Capital and Other Costs		
Site preparation	2% of uninstalled capital costs	2% of installed capital costs
Up-front permitting costs	15% of uninstalled capital costs	15% of installed capital costs
Cost of land ($/acre)	$5,000	$50,000
Fixed and Variable Operating Costs		
Burdened labor cost ($/man-hr)	$50 ($2005)	$49.69 ($2007)
Material costs for maintenance and repair ($/year)	$810,097 ($2005)	$860,492 ($2007)
Other variable operating costs ($/year)	$2,123,000 ($2005)	$2,304,356 ($2007)
Feedstock and Utility Prices		
Feedstock/utility price source	EIA (2005), $2003	EIA (2009), $2007; constant-price biomethane (Saur 2011)
Feedstock/utility price reference year	2005	Conversion to reference year dollars for 2005–2010

Financial Input Values

Version 3 has several differences in financial input values compared with version 2: reference year (i.e., base-year dollars), assumed start-up year, length of construction period, and the percent of capital spent during each year of construction. These are shown in Table 2 and discussed in the subsections below.

Table 2. H2A central model version 3 differences in general and financial input values (specific example is current SMR without CO_2 sequestration)

Central Model Financial Input Values	Version 2	Version 3
Reference year	2005	2007
Assumed start-up year	2005	2010
Length of construction period (years)	2	3
Percent of capital spent in years 1–2 (v2), 1–3 (v3)	60%, 40%	8%, 60%, 32%

Reference Year

The reference year determines the base-year dollars used in the model, i.e., the nominal-year currency in which hydrogen costs are reported. Version 2 reported hydrogen costs in 2005 dollars; version 3 reports them in 2007 dollars.

The way capital costs are adjusted for inflation affects the projected hydrogen cost. For version 3, capital costs are updated to 2010 dollars using the composite index of the *Chemical Engineering Magazine* Plant Cost Index (CEPCI). The composite index charts actual inflation in a basket of chemical plant cost categories (heat exchangers, piping, construction, labor, compressors, etc.) and thus narrowly calculates the annual increase in plant equipment and preparation costs. Once plant cost is determined in 2010 dollars, the value is deflated to 2007 dollars using the Consumer Price Index (CPI). The CPI (also called the GDP Implicit Price Deflator Index) is a broad measure of U.S. inflation and thus is appropriate for adjusting the generic buying power of money over time. Using the two indexes (CEPCI and CPI) together results in a current (2010) estimate of hydrogen costs stated in 2007 dollars. Table 3 shows indexes used to escalate the costs to 2007 dollars.

Table 3. General inflation, plant cost, and labor indexes used to escalate costs to 2007 dollars (tables are included in the H2A *HyARC Physical Properties Data* worksheet)

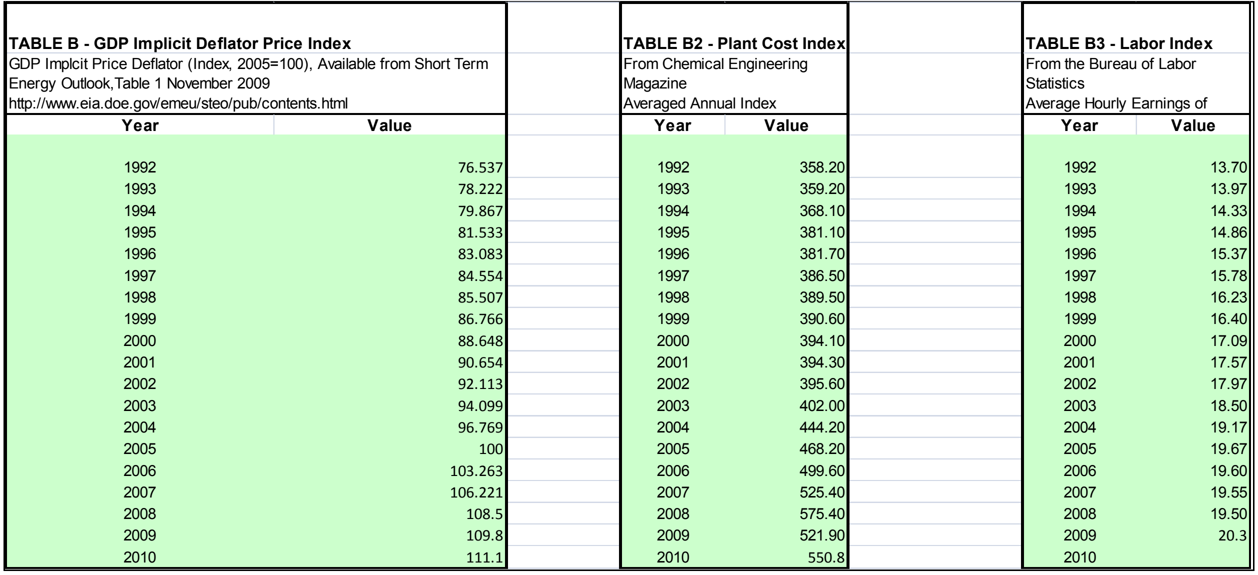


TABLE B - GDP Implicit Deflator Price Index
GDP Implcit Price Deflator (Index, 2005=100), Available from Short Term Energy Outlook,Table 1 November 2009
http://www.eia.doe.gov/emeu/steo/pub/contents.html

Year	Value
1992	76.537
1993	78.222
1994	79.867
1995	81.533
1996	83.083
1997	84.554
1998	85.507
1999	86.766
2000	88.648
2001	90.654
2002	92.113
2003	94.099
2004	96.769
2005	100
2006	103.263
2007	106.221
2008	108.5
2009	109.8
2010	111.1

TABLE B2 - Plant Cost Index
From Chemical Engineering Magazine
Averaged Annual Index

Year	Value
1992	358.20
1993	359.20
1994	368.10
1995	381.10
1996	381.70
1997	386.50
1998	389.50
1999	390.60
2000	394.10
2001	394.30
2002	395.60
2003	402.00
2004	444.20
2005	468.20
2006	499.60
2007	525.40
2008	575.40
2009	521.90
2010	550.8

TABLE B3 - Labor Index
From the Bureau of Labor Statistics
Average Hourly Earnings of

Year	Value
1992	13.70
1993	13.97
1994	14.33
1995	14.86
1996	15.37
1997	15.78
1998	16.23
1999	16.40
2000	17.09
2001	17.57
2002	17.97
2003	18.50
2004	19.17
2005	19.67
2006	19.60
2007	19.55
2008	19.50
2009	20.3
2010	

Assumed Start-up Year

The assumed version 3 current/near-term plant start-up year is 2010 (compared with a version 2 start-up year of 2005). Although this assumption may not be feasible, it is made so that the H2A cost estimates reflect a mature-system hydrogen price in the first year the technology could be fielded.

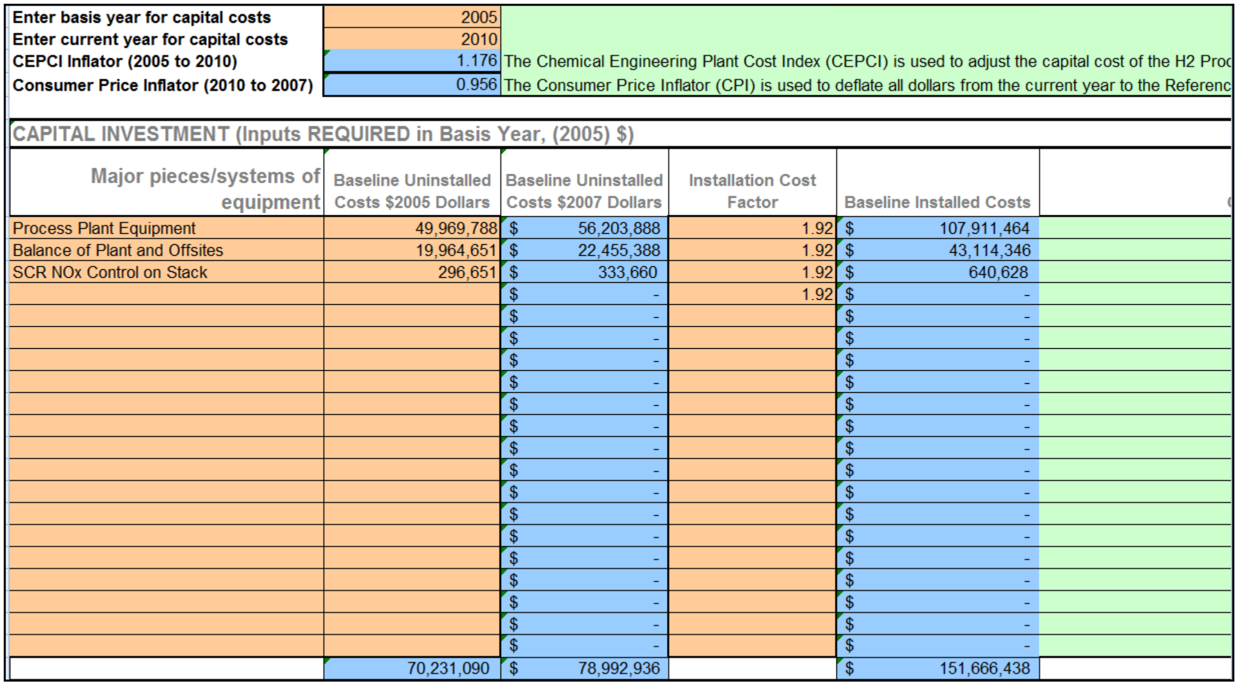
Length of Construction Period/Spending Schedule

The length of the construction period in version 2 of the H2A central model is 2 years, with 60% of capital spent in the first year of construction and 40% in the second year. In version 3, the construction period is 3 years, with 8% of capital spent in the first year of construction, 60% in the second year, and 32% in the third year. Version 3 was revised to match assumptions used in other DOE modeling efforts.

Direct Capital Costs

Direct capital costs were changed in version 3 based on escalating to 2007 dollars. Table 4 shows the direct capital cost changes made in version 3.

Table 4. H2A current central SMR model version 3 differences in direct capital costs ($2005 uninstalled costs from version 2, $2007 uninstalled costs and installed costs from version 3)



Enter basis year for capital costs	2005	
Enter current year for capital costs	2010	
CEPCI Inflator (2005 to 2010)	1.176	The Chemical Engineering Plant Cost Index (CEPCI) is used to adjust the capital cost of the H2 Proc
Consumer Price Inflator (2010 to 2007)	0.956	The Consumer Price Inflator (CPI) is used to deflate all dollars from the current year to the Referenc

CAPITAL INVESTMENT (Inputs REQUIRED in Basis Year, (2005) $)

Major pieces/systems of equipment	Baseline Uninstalled Costs $2005 Dollars	Baseline Uninstalled Costs $2007 Dollars	Installation Cost Factor	Baseline Installed Costs
Process Plant Equipment	49,969,788	$ 56,203,888	1.92	$ 107,911,464
Balance of Plant and Offsites	19,964,651	$ 22,455,388	1.92	$ 43,114,346
SCR NOx Control on Stack	296,651	$ 333,660	1.92	$ 640,628
		$ -	1.92	$ -
		$ -		$ -
		$ -		$ -
		$ -		$ -
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		$ -		$ -
		$ -		$ -
	70,231,090	$ 78,992,936		$ 151,666,438

Indirect Capital and Other Costs

The version 3 changes to indirect capital and other costs are summarized in Table 5. Installed capital costs were made the basis for site preparation and up-front permitting costs in all version 3 cases. Land cost was increased from $5,000/acre to $50,000/acre to reflect more realistic assumptions about the value of land in areas where a central hydrogen production plant might be located.

Table 5. H2A central model version 3 differences in indirect capital and other costs

Field	Version 2	Version 3
Site preparation	2% of uninstalled capital costs	2% of installed capital costs
Up-front permitting costs	15% of uninstalled capital costs	15% of installed capital costs
Cost of land ($/acre)	$5,000	$50,000

Fixed and Variable Operating Costs

The version 3 changes to fixed and variable operating costs are summarized in Table 6. The labor cost was updated to 2007 dollars using a Bureau of Labor Statistics labor index, the material costs were updated using the CPI, and the other variable operating costs were updated using the SRI Inorganic Price Index. See the *HyARC Physical Property Data* worksheet in the H2A model for details about the indexes.

Table 6. H2A central model version 3 differences in fixed and variable operating costs (specific example is current SMR without CO_2 sequestration)

Field	Version 2	Version 3
Burdened labor cost ($/man-hr)	$50 ($2005)	$49.69 ($2007)
Material costs for maintenance and repair ($/year)	$810,097 ($2005)	$860,492 ($2007)
Other variable operating costs ($/year)	$2,123,000 ($2005)	$2,304,356 ($2007)

Feedstock and Utility Prices

The H2A model requires current and projected future feedstock/utility prices. The default set of projected feedstock/utility prices for version 3 is from the Energy Information Agency (EIA) Annual Energy Outlook (AEO) 2009 Reference Case (EIA 2009). AEO 2009 price projections are presented in 2007 dollars, so no escalation of the prices is required. In addition, the AEO 2009 High Price Case (EIA 2009) and the AEO 2010 Reference Case (EIA 2010) are available in version 3 as pull-down menu options. Biomass is not included in the AEO projections, so biomass projections created by DOE’s Biomass Program are used. Table 7 shows the sources for feedstock/utility prices and properties for version 2 and version 3.

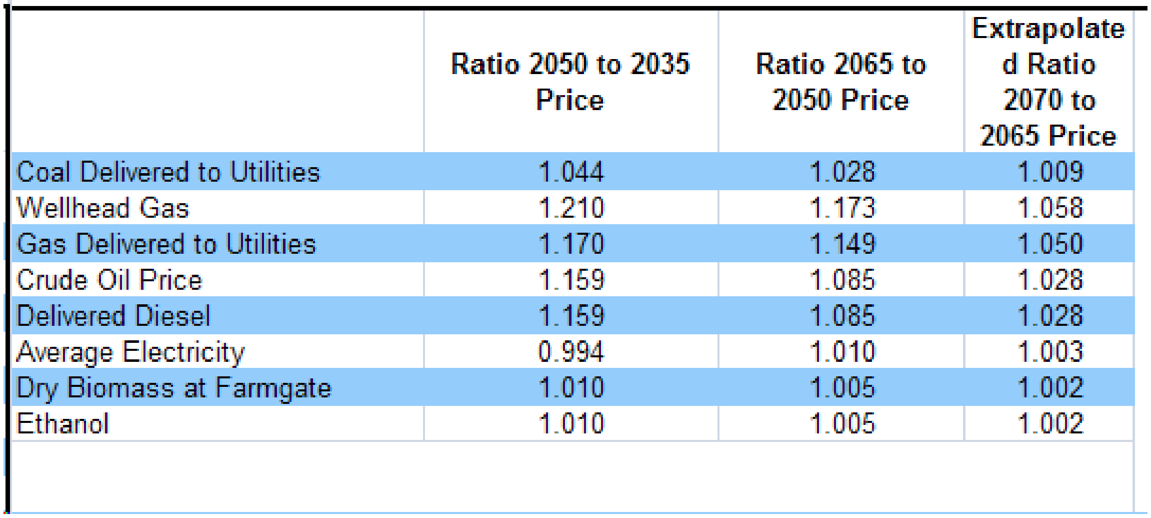
To accommodate lifecycle modeling of hydrogen production facilities, the AEO price projections were extrapolated beyond the 2030 end date for the AEO data. The GCAM (formerly MiniCAM) model (Joint Global Change Research Institute 2011) was used to extrapolate out-year feedstock prices (Table 8).

Table 7. H2A central model version 3 differences in feedstock/utility prices

Field	Description/Data Source for Version 2	Description/Data Source for Version 3
All feedstock prices except biomass and biomethane	EIA (2005): High A Case, Appendix C, Table 3 (Energy Prices by Sector and Source), 2003 dollars	EIA (2009): Reference Case (Stimulus Scenario), Table 3 (Energy Prices by Sector and Source), 2007 dollars
Biomass (farmed trees) prices	DOE (2011b), feedstock and utility price projections for 2001–2070, EIA units, 2005 dollars	DOE (2011c)
Biomethane prices	Not included in version 2	Saur (2011): $13.11/mmBtu, assumed constant through 2070, 2007 dollars
Price projections, 2031–2070	GCAM projections (Table 8)	GCAM projections except for biomethane, which is assumed constant
Conversion to reference year dollars, all feedstocks	2005 reference year	Conversion to reference year dollars automatically included in price tables for any reference year between 2005 and 2010
Conversion from HHV to LHV, all feedstocks	DOE (2011a)	Same as version 2

HHV—higher heating value; LHV—lower heating value.

Table 8. Price ratios from the GCAM model



	Ratio 2050 to 2035 Price	Ratio 2065 to 2050 Price	Extrapolated Ratio 2070 to 2065 Price
Coal Delivered to Utilities	1.044	1.028	1.009
Wellhead Gas	1.210	1.173	1.058
Gas Delivered to Utilities	1.170	1.149	1.050
Crude Oil Price	1.159	1.085	1.028
Delivered Diesel	1.159	1.085	1.028
Average Electricity	0.994	1.010	1.003
Dry Biomass at Farmgate	1.010	1.005	1.002
Ethanol	1.010	1.005	1.002

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