H2A DELIVERY SCENARIO ANALYSIS MODEL VERSION 1.0*

USER'S MANUAL

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March 2006

Prepared for:
U.S. Department of Energy
Office of Hydrogen, Fuel Cells and Infrastructure Technologies

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1.0 OVERVIEW

Development of hydrogen production and delivery technologies, and their associated infrastructure, requires a robust suite of analytical tools to guide R&D decisions, provide transparency, and permit expert review. To this end, the US Department of Energy's (DOE's) Office of Fuel Cells, Hydrogen and Infrastructure Technologies initiated the H2A Project. This report documents one of the tools developed under that project, the Hydrogen Delivery Scenario Analysis Model (HDSAM), an Excel-based model that estimates the cost of delivering hydrogen from a centralized production facility to a hydrogen-fueled vehicle.

1.1 Approach

Like other H2A-developed tools, the HDSAM uses an engineering economics approach to cost estimation. For a given scenario (discussed below) a set of "components" (e.g., compressors, tanks, tube-trailers, etc.) are specified, sized and linked into a simulated delivery system or pathway. Financial, economic and technological assumptions are then used to compute the cost of those components and their overall contribution to the delivered cost of hydrogen.

HDSAM Version 1.0 contains many default values that represent currently available (2005) technology and costs. In many cases these parameters can be changed by the user to simulate advancements in technology and in future costs.

1.2 Scope of Hydrogen Delivery

For modeling purposes, hydrogen delivery is defined as the entire process of moving hydrogen from the gate of a central production plant onto a vehicle. Thus, delivery includes all transport, storage and conditioning activities from the outlet of a centralized hydrogen-production facility to and including a forecourt (i.e., refueling station) which stores, dispenses and, in some cases, further conditions the hydrogen fuel. Hydrogen delivery could also include compression, storage and dispensing of hydrogen produced on site at a forecourt (i.e., distributed production). The current version of HDSAM (Version 1.0) does not model distributed production scenarios. Future versions of the model will include this option.

1.3 Delivery Scenarios

In HDSAM, the user defines a scenario by selecting a market type (urban or rural interstate), specifying its size and the market penetration of hydrogen-fueled vehicles in the population of light-duty vehicles, and selecting a delivery mode. Market size can vary from an urbanized area of 50,000 persons to one of over 20 million, and from an interstate highway segment of 10 mi to 300 mi (1000 mi for pipeline delivery); market penetration can vary from 1 to 100 percent; and delivery can be via standard or high-pressure gaseous tube-trailer, liquid hydrogen truck or gaseous pipeline. The user can further define a scenario by changing a number of other default values, including the distance from a central production facility to the edge of the urban area, the fuel economy and annual utilization (i.e., miles driven per vehicle per year) of hydrogen-fueled light-duty vehicles, motorization rate (i.e., vehicles per person), financial assumptions, and the average number of light-duty vehicles served by each gasoline refueling station. Thus, delivery scenarios are combinations of (a) markets, (b) market penetration and (c) delivery mode with an associated set of assumptions about market demand and infrastructure. The user also must select the capacity of the hydrogen refueling stations (forecourts) that are to be considered in the scenario. HDSAM Version 1.0 allows the user to select stations of a design capacity of either 100kg/day or 1500 kg/day.

1.4 Delivery Pathways

In HDSAM, user selection of a delivery mode invokes an associated chain of delivery "components" or processes.[1] For example, if the user selects liquid hydrogen truck delivery for a given market and penetration rate, the model calculates not only the number and cost of the trucks required to deliver the fuel to refueling stations (or forecourts), but also the cost of appropriately-sized liquefiers, terminal storage, truck loading facilities, and forecourts. Collectively, these major steps or "components" are known as a pathway.

Figure 1 illustrates the three pathways contained in Version 1.0 of the Model. Note that because delivery is by a single mode, all loading, conditioning and storage activities normally associated with a terminal or depot are assumed to be located inside or immediately adjacent to the production plant gate. For illustrative purposes, these facilities are drawn as icons in the "black box" production facilities shown in Figure 1.

In Version 1.0 of HDSAM, a production plant need not be defined more specifically than as a centralized facility producing 300-psi hydrogen which then enters a delivery system composed of conditioning facilities (e.g., compressors, liquefiers), storage facilities (e.g., terminals geologic caverns), and various types of pipelines or trucks. Like petroleum product terminals, hydrogen terminals are modeled as transshipment locations where bulk hydrogen is stored, conditioned (as needed), and broken down for local delivery via a mix of modes that bring the hydrogen fuel to retail locations.

In subsequent versions of the model, the pathways shown in Fig. 1 will be "stretched out" to simulate terminal storage and loading at any location <u>outside</u> the plant gate (i.e., at any location between the production facility and the market).

[1] These steps or processes correspond to individual component spreadsheets or tabs within the HDSAM. These tabs, which were originally developed for a separate model (known as the H2A Delivery Components Model, see discussion in Section 2.2), are shown at the bottom of the HDSAM workbook so the user can view their contents. However, because some cells which are user defined in the H2A Delivery Components Model are now calculated within HDSAM, the color of these cells has been changed from tan (i.e., the color-code for input cells) to blue (i.e., the color-code for calculated cells) in the HDSAM. As noted in Section 4 of this Guide, while the user may no longer change default values within the respective components tab, such changes may still be made from the SCENARIO or INPUTS tab.

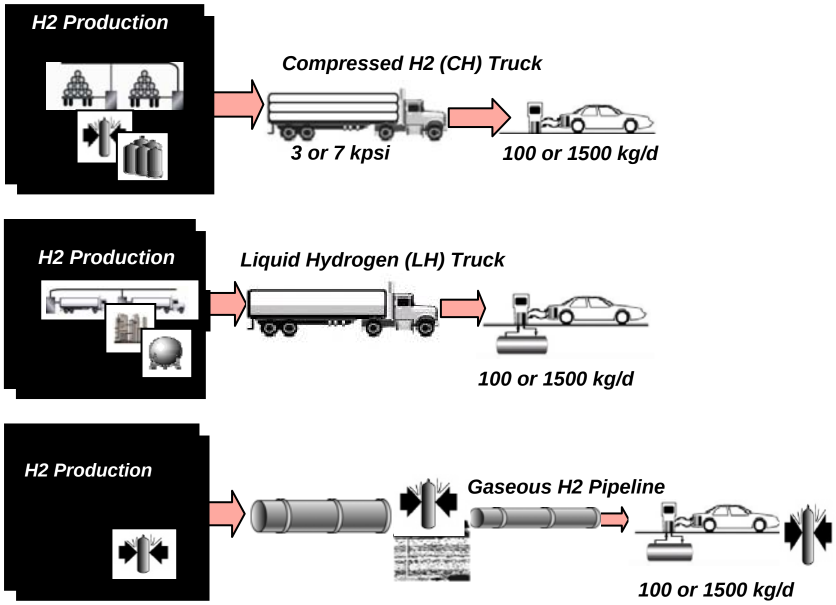

Figure 1. Delivery Pathways in HDSAM Version 1.0

1.5 Model Tab Structure

HDSAM includes the following individual tabs or spreadsheets:

- TITLE
- SCENARIO
- INPUTS
- RESULTS SUMMARY
- CF (CASH FLOW) RESULTS
- FORECOURT STATION – GASEOUS H2
- FORECOURT STATIONS – LIQUID H2
- COMPRESSED GAS H2 TERMINAL
- COMPRESSED H2 TRUCK_2700 PSI
- COMPRESSED H2 TRUCK_7000 PSI
- H2 LIQUEFIER
- LIQUID H2 TERMINAL
- TRUCK – LH2 DELIVERY
- H2 COMPRESSOR
- H2 PIPELINE
- GASEOUS H2 GEOLOGIC STORAGE
- SCENARIO PARAMETERS
- FINANCIAL INPUTS
- MACRS_DEPR. TABLE
- PHYSICAL PROPERTY DATA
- FEEDSTOCK & UTILITY PRICES

Most users will be concerned with the TITLE, SCENARIO, INPUTS and RESULTS SUMMARY tabs. These are the tabs in which users can input assumptions and/or review results. The TITLE and SCENARIO tabs permit the user to name and broadly define a scenario in terms of market type and size, market penetration, delivery distance and mode by means of a series of option (radio) buttons, text boxes and drop-down menus. Once a scenario has been broadly defined, the model can be triggered using a command button to calculate delivery cost (in $/kg). Additional "default" inputs and calculated values, which further specify the delivery scenario, are displayed in color-coded cells on the SCENARIO and INPUTS tabs. The user can override the default values (in the tan-colored cells) but not the calculated values (in the blue-colored cells). Subsequently, whenever the user makes a selection or changes the default inputs, he/she must click the "Calculate" button in the SCENARIO tab to initiate a re-calculation. Upon completion of each calculation, the model displays summary results and intermediate calculations on the SCENARIO tab, and detailed results on the RESULTS SUMMARY and CF (cash flow) RESULTS tabs. Additional details on these tabs are presented in Section 4 of this Guide.

Most of the other tabs in the HDSAM are nearly identical to those in the H2A Delivery Components Model (www.hydrogen.energy.gov). The key difference between the two models occurs from the necessity to link relevant components within HDSAM so that they have the correct flow of input and output capacities among the components. These linkages are described in Section 4 of this Users Guide.

1.6 Financial Assumptions

All H2A-developed tools have a common set of default financial assumptions. In HDSAM, these are contained in the locked FINANCIAL INPUTS tab. In order to easily model alternative financial assumptions, key variables and their default values are also contained in the SCENARIO and INPUTS tabs where the user may override the H2A defaults. Financial assumptions contained on the INPUTS tab include:

- debt ratio (i.e., investment share financed with debt)
- debt interest rate (%) and period (yrs)
- construction period (yrs)
- salvage value ($)
- decommissioning value ($)
- start-up period (yrs)
- % revenue, fixed and variable costs during start-up period.

A nominal Internal Rate of Return (IRR) is calculated and displayed within the FINANCIAL INPUTS tab based on an assumed real after-tax discount rate (10% is the default H2A rate). The latter can be user-specified resulting in an alternative IRR.

On the INPUTS tab, these financial variables are listed for each component being modeled in the delivery pathway. Hence, although common financial assumptions are specified in the FINANCIAL INPUTS spreadsheet, scenarios can be specified in which market participants have different financial strategies.

Since capital cost accounts for a large fraction of the total cost of delivering hydrogen, the internal rate of return (IRR) strongly affects the calculated results. The default financial parameters in all H2A-developed tools result in an IRR of 10% real (12.1% nominal). This rate is linked to another H2A assumption – that 100% of capital is obtained through equity financing. The financial parameters are based on historical return on equity (ROE, adjusted for inflation) for large-capitalization companies,[2] as well as ROI and ROE statistics for major energy producers. For further discussion of financial assumptions in the H2A models, see http://www.hydrogen.energy.gov/h2a_production.html.

1.7 Other User Inputs

On the SCENARIO tab, the user can override default values for the distance between the hydrogen production facility and the edge of an urban market, the annual light-duty vehicle utilization, the fuel economy of hydrogen-fueled vehicles, the population and land area of an urban area, and the motorization rate (i.e., vehicles per person). These user inputs are in addition to the key parameters which define the scenario of interest. These latter parameters are: (a) market type (urban or rural interstate), (b) a measure of market size (either a specific urban area which the user selects from a drop-down menu, a user-entered population for a generic urbanized area, or the length of a single interstate highway segment to be served), (c) market penetration (i.e., the share of total light-duty vehicles operating on hydrogen fuel in the market of interest), and (d) delivery mode.

1.8 Discounted Cash Flow Analysis

Discounted cash flow (DCF) is computed on each of the component tabs and summed over all the components in the pathway to estimate the contribution of delivery to the cost of hydrogen. DCF includes capital, utilities, taxes, fixed operating expenses, and other cash flows. DCF is calculated for each analysis year to generate a table of annual cash flow which, with an after-tax nominal Internal Rate of Return (IRR), is used to calculate the Net Present Value (NPV) of the cash flows.

The cost contribution of each component is one that generates a Net Present Value of zero. In other words, HDSAM estimates the cost of hydrogen delivery such that the sum of the revenue cash flows, including the return on capital, and expense cash flows, results in a Net Present Value of zero. Note also that these costs represent only delivery and dispensing (i.e., production costs are excluded).

[2] Based on *Stocks, Bonds, Bills and Inflation 2003 Yearbook* (Ibbotson Associates 2003), the inflation-adjusted return on stocks of large capitalization companies, averaged 9% over the period 1926-2002.

1.9 Relationship to Hydrogen Delivery Components Model

HDSAM draws upon the engineering economics calculations in the H2A Delivery Components Model. In effect, the ‘component’ spreadsheets (or tabs) within the Delivery Components Model are embedded in HDSAM, which links them into appropriate combinations to define a delivery pathway, size the individual components consistent with a scenario’s demand estimate, and calculate the cost associated with delivering a given quantity of hydrogen via the specified pathway. For a more complete understanding of how the components within HDSAM are modeled, the user should consult the Delivery Components Model Users’ Guide which contains additional details on the tabs within the Delivery Components Model (see www.hydrogen.energy.gov).

1.10 User Interface

As noted above, HDSAM estimates the levelized cost to deliver hydrogen in quantities sufficient to meet a given level of market demand. Like other H2A-developed tools, HDSAM applies a common set of financial assumptions, runs in a Microsoft Excel environment and, to the extent possible, produces “transparent” results. Unlike other H2A tools, HDSAM incorporates a graphical user interface (GUI) to assist the user in selecting and analyzing alternative scenarios and estimating the cost of individual components within them. Details of the GUI are discussed in Sections 3.1.2 and 4.2.

2.0 BACKGROUND

2.1 Origins of HDSAM

Although a number of analyses of hydrogen production and delivery infrastructure have been conducted and have produced important insights into technical and cost barriers, most studies have failed to provide the guidance needed for Research and Development (R&D) decisions. In particular, findings have appeared inconsistent or conflicting because of differences in the analytical base (e.g., whether the analysis is based on current or advanced technologies, on targets or empirical results, on "real world' or simulated duty cycles, etc.), or in the many economic, financial and technological assumptions used in the analysis. As a result, analytical results have not always contributed the rigor desired for oversight and guidance of the hydrogen program.

The H2A (or Hydrogen Analysis) project was initiated to remedy this problem. Begun in 2003, H2A sought to improve transparency and consistency so researchers and program managers could better understand similarities and differences among efforts, and industry could better validate results. To that end, DOE leveraged the talents and capabilities of analysts from several national laboratories, universities and the private sector, forming two teams to develop a set of tools for production and delivery analyses. More information on H2A can be found at www.hydrogen.energy.gov.

The H2A Delivery team was charged with developing tools to model the cost contribution of all activities/components between the central production of hydrogen and its use on-board a vehicle. Two tools have been developed – the Delivery Components Model and the Delivery Scenarios Model. Version 1.1 of the **Delivery Components Model** and its documentation are available at the above web address. This report documents Version 1.0 of the **Delivery Scenarios Model**.

The H2A teams were supplemented by a group of Key Industrial Collaborators (KIC) who attended H2A meetings, reviewed draft documents, provided "rules of thumb" for default assumptions, and reviewed "beta" or test versions of H2A-developed tools. In addition to contributing their own technical expertise, KIC members provided access to their organization's publicly available knowledge base. The resulting tools benefited greatly from this input.

2.2 Relationship to the Hydrogen Delivery Components Model

Once a delivery pathway has been defined, HDSAM links the applicable components so that each individual component is sized to permit the entire pathway to deliver enough hydrogen to satisfy market demand. It is in this feature that the HDSAM expands upon the Components Model (which is essentially embedded in HDSAM) to allow analysis of a completely integrated delivery pathway. HDSAM uses technical and operational efficiencies along with an endogenous estimate of hydrogen demand (determined in the SCENARIO PARAMETERS tab, see following discussion) as the basis for sizing each component. For example, the capacity required for a terminal/storage depot is first estimated from customer demand, and then increased from that quantity to account for seasonal demand variations and peak surges, for hydrogen losses in storage and handling, and for the availability of various sub-components. Similar adjustments in required capacity are made to other components throughout the pathway so that each component has a capacity appropriate to the selected demand and pathway. HDSAM automatically makes these capacity adjustments based on input provided in the SCENARIO and INPUTS tabs.

3.0 TABS AND OPERATIONS

3.1 Key Tabs

In addition to tabs for each of the delivery components which are described elsewhere (see http://www.hydrogen.energy.gov/h2a_production.html), HDSAM contains four key tabs where the user can input assumptions and review results. These are the TITLE, SCENARIO, INPUTS and RESULTS SUMMARY tabs. Note that all other tabs are available to the user only for viewing and information purposes. The user is cautioned that changes made to any of these tabs may result in inconsistent behavior of the model. The user can trace calculations by clicking on a particular cell in a component tab, but may not override the entry that appears in any cell from within that tab. Rather, the user must enter inputs on the SCENARIO or INPUTS tabs which are then passed to the input cells of the appropriate component tabs.

3.1.1 TITLE Tab

The first tab in HDSAM, the TITLE tab, is strictly for user convenience and consistency with other H2A-developed tools. It has no effect on calculations. The tab notes the color-coding convention used to distinguish different types of cells within the spreadsheet (see Section 4.). It also allows the user to identify him/herself, to describe the purpose of a particular run and to document when the inputs were specified or modified. This information can be very helpful if a large number of cases are to be evaluated.

3.1.2 SCENARIO Tab

The second tab in HDSAM is the SCENARIO tab. The following paragraphs describe some of the main features within the SCENARIO tab (Section 4.2 includes more detailed information). In the SCENARIO tab the user defines the basic parameters of the scenario to be evaluated, including market type and size, a market penetration rate, and a delivery mode.

<u>Market Selection</u>

Version 1.0 allows two market options – “Urban” or “Rural Interstate”. If the user selects “Urban” market, a scroll-down menu appears with an instruction to select either a particular urbanized area from those listed or to enter a population for a “generic” urbanized area. The “Rural Interstate” market assumes that hydrogen can be dispensed most cost-effectively from forecourts located along rural interstate highways which can serve both local and thru traffic.

The “Rural Interstate” option is further defined to consist of up to four interstate highway segments of equal, user-specified length. In cases where more than one segment is to be evaluated, it is assumed that the production facility and any necessary terminal are located at the intersection of the equal-length interstate segments.

Market Penetration

The other demand-related input on the SCENARIO tab is “H2 Vehicle Penetration”, expressed as a percent. This value represents the percentage of total light-duty vehicles operating within the particular market that are assumed to be hydrogen-fueled. As described later in this Guide, this information is passed to the SCENARIO PARAMETERS tab where a variety of parameters used throughout the model are calculated. Chief among these parameters is daily hydrogen demand (expressed in kg/day) which is used to size the individual components in the selected pathway. Other key parameters (also calculated in the SCENARIO PARAMETERS tab) are the number of refueling stations (forecourts) within the given “Urban” or “Rural Interstate” market and the average distance between these stations. Based on information from the PHYSICAL PROPERTY DATA tab, the SCENARIO PARAMETERS tab also determines the number of trucks and trailers that are needed to meet the daily demand. These calculations are fed, as appropriate, to the component tabs which estimate the cost of delivering hydrogen to the required number of refueling stations.

Delivery Mode

In this version of HDSAM, three delivery modes may be examined – (standard or high-pressure) gaseous tube-trailer trucks, cryogenic liquid-hydrogen tanker trucks, and gaseous pipelines sized to carry hydrogen with user-specified pressure losses in the system. As stated previously, it is assumed in this version of the HDSAM that a single mode is used to transport hydrogen from the production facility to the refueling stations.

Refueling Station Capacity

The last piece of basic input on the SCENARIO tab is refueling station capacity. HDSAM currently characterizes only 100 kg/day and 1500 kg/day stations. The user can select either of these options by depressing the associated option button. Note that user choice of these options is constrained by the physical implications of high vs. low station capacity. For example, in HDSAM Version 1.0 the user cannot select the 1500 kg/day option if it would result in hydrogen availability at fewer than 10% of all refueling stations in the market area. This insures a reasonable level of customer access to hydrogen refueling, even at relatively low market penetration. Similarly, for higher market-penetration scenarios the user cannot select the 100 kg/day option for gaseous truck delivery if the resulting scenario will require more than two tube-trailer deliveries per station per day. At both extremes, HDSAM will generate an error message requiring the user to make a different choice for station capacity. Note that although HDSAM permits 100 kg/day stations at higher market penetrations, it first cautions the user (via an error message) that the 1500 kg/day option will reduce the cost of hydrogen delivery.

Other Inputs

A summary of Key Delivery Inputs and Assumptions is also displayed on the SCENARIO tab. This summary allows the user to quickly review basic inputs to the selected scenario. Many of the displayed parameters are "default" or recommended values, which the user can change as he/she sees fit (see Section 4 for further discussion on color coding of spreadsheet cells).

Outputs

Selected results are also displayed on the SCENARIO tab. Delivery cost, as calculated within the model, is displayed in $/kg, where the denominator represents annual kilograms of hydrogen demand by the ultimate consumer. Other outputs displayed on this tab include daily hydrogen demand, infrastructure requirements of the selected delivery mode (e.g., number of trucks and tube-trailers, miles of transmission, trunk and service pipelines, etc.), and features of the delivery system (e.g., percent of all forecourts at which hydrogen fuel is dispensed).

As noted above, in Version 1.0 of HDSAM hydrogen transmission and distribution is accomplished by a single delivery mode. Thus, if the user selects pipeline delivery, the analysis considers only those components shown for the pipeline pathway in Figure 1. If truck delivery is selected, the analysis assumes that a truck terminal/storage depot will be built immediately adjacent to the hydrogen production facility. This terminal will include compression (if applicable), storage, and loading equipment. Future versions of HDSAM will lift this single-mode restriction and allow the user to select a transmission mode (e.g., from a production facility to a terminal or other transshipment point) different from the mode used to distribute hydrogen to individual forecourts. For example, a user could select pipeline transmission with liquid or gaseous truck distribution. Single-mode delivery (i.e., transmission and distribution via the same mode) will also be allowed as an option in future versions of HDSAM.

3.1.3 INPUTS Tab

Once the user has selected a delivery option, HDSAM prepares a scenario-specific INPUTS tab. This tab contains all inputs required for each of the components that make up the selected delivery pathway. For the three delivery modes allowed in this version of HDSAM, the components in each delivery pathway are:

Gaseous Truck Delivery
Compressed Gas Forecourt
Compressed Gas H2 Truck (standard pressure)
Compressed Gas H2 Truck (high pressure)
Gaseous Terminal

Liquid Truck Delivery
Liquid H2 Forecourt
Truck-LH2 Delivery
Liquid Terminal
Liquefier

Pipeline Delivery
Compressed Gas Forecourt
H2 Pipeline
H2 Compressor
Geologic Storage

HDSAM automatically “populates” the INPUTS tab with a set of input tables containing all inputs required to run each individual tab in the selected pathway. The default or reference values in these tables represent typical operating or design conditions for the facilities in question, or conditions defined within the H2A Program to be reference case conditions. The user can change any value in a tan (light brown) colored cell. However, blue cells represent calculated values and should not be changed by the user. Note that not only might values on HDSAM’s INPUTS tab differ from values on the corresponding tab of the Hydrogen Delivery Components Model, but the fill color of the two cells may also differ. This occurs because many of the inputs in the Components Model must be calculated within HDSAM to ensure that the components of a given scenario are consistently linked. Such linkages are described in greater detail elsewhere in this Guide.

A table of “General Economic Assumptions” is also included in the INPUTS tab. This table provides H2A default values for tax rates, discount rate, startup year, and length of analysis period. These values are applied to all components within the delivery pathway.

Section 4.3 of this Guide describes additional features of the INPUTS tab.

3.1.4 RESULTS SUMMARY Tab

This tab provides more detailed results than those on the SCENARIO tab, while excluding results of intermediate calculations. Tables and figures show the contribution of each component to the delivery cost of hydrogen (in $/kg), permitting the user to identify major cost contributors across a range of scenarios or for a particular scenario of interest.

In the RESULTS SUMMARY tab, delivery costs are summarized in several ways. First, results are presented for each component in the pathway. Thus, for example, for pipeline delivery to an urban area, cost is broken down into contributions from pipelines, main or central compressors, geologic storage caverns, and forecourts. Pipeline cost is further broken down into contributions from transmission pipelines (the lines connecting production facilities with trunk or “main” pipelines) and from distribution pipelines (the trunk or “main” lines as well as smaller-diameter service lines leading directly to a forecourt). Within each of these components, costs are further broken down into Capital, Energy/Fuel, and non-fuel O&M categories. A pie chart of this last breakdown is provided.

The second set of results on the RESULTS SUMMARY tab is a breakdown of delivery cost by function. Functions include compression or liquefaction, storage, other terminal costs (if applicable), transport, and forecourt. Within each of these categories, additional breakdowns are provided for Capital, Energy/Fuel, and non-fuel O&M costs. A pie chart of delivery cost by function is provided on this tab.

Additional details of the RESULTS SUMMARY tab are provided in Section 4.4 of this Guide.

3.1.5 SCENARIO PARAMETERS Tab

The SCENARIO PARAMETERS tab provides the linkage between the scenario-defining variables of the SCENARIO and INPUTS tabs and the appropriate component tabs. Note that this tab is available to the user only for viewing and information purposes. The user is cautioned that any changes made to this tab may result in inconsistent behavior of the model. All inputs by the user should be made in the SCENARIO and INPUTS tabs. The user can view several tables on the SCENARIO PARAMETERS tab. One table summarizes forecourt design parameters such as daily capacity, capacity factor, and service ratio (i.e., number of vehicles per station), while a second table displays energy densities of gasoline and hydrogen fuel. A third provides key features of hydrogen-fueled light-duty vehicles (e.g., annual utilization and fuel economy) and a fourth displays characteristics of trucks used to carry liquid or compressed hydrogen to forecourts. Information in this latter table includes average truck speed, fuel economy, diesel fuel cost, driver cost, tank volume and carrying capacity, capital costs for cab and trailer, loading and unloading times, and (for liquid hydrogen delivery) boil-off rates during various activities.

Table 6 on the SCENARIO PARAMETERS tab provides information on production facilities, liquefaction, compression, and storage. This table is not "live", but is included in Version 1.0 as a placeholder for ultimately linking the delivery model (HDSAM) with production cost models, thereby permitting a full "Cost of Hydrogen" analysis on a consistent basis. Information required for compression, liquefaction, etc. for a scenario of interest is provided on the SCENARIO or INPUTS tab.

The most important part of the SCENARIO PARAMETERS tab is the section titled "Delivery Scenario Assumptions and Demand Calculations". Here, values from the SCENARIO and INPUTS tabs are used to calculate and display information on hydrogen demand. For example, population and hydrogen light-duty vehicle (LDV) penetration from the SCENARIO tab are used to calculate the number of hydrogen vehicles, which in turn is used to determine average demand (in kg of hydrogen per day), the number of hydrogen refueling stations (forecourts) required, and the average quantity of hydrogen dispensed from each station. The latter parameter is based on user selection (on the SCENARIO tab) of a forecourt design capacity (1500 or 100 kg/day are currently allowed) and an assumed average-to-peak demand ratio of 0.7. Thus, a 1500 kg/day forecourt will dispense an average of 1050 kg/day. It should be noted that the model will adjust the capacity factor so that a whole number of forecourts is realized. This adjustment is typically quite small and usually rounds to 0.7. Other information summarized in this table includes truck speed, availability, and distance from the production facility to the market. As stated previously, users should not change the values contained in this table from within the SCENARIO PARAMETERS tab. Users must make all desired changes on the SCENARIO and/or INPUTS tabs which are linked to this tab.

The next set of tables on the SCENARIO PARAMETERS tab summarizes demand – in terms of values specified by the user in the SCENARIO tab and those calculated within the model. Peak and average daily demand are calculated based on user inputs and data sets internal to the model. The number of forecourts is estimated and displayed in this table, as is the average distance between forecourts throughout the market area. For truck delivery scenarios, average round-trip time is estimated and used to determine the number of truck tractors (cabs) and trailers needed to meet the estimated hydrogen demand. For urban pipeline scenarios, the model determines whether a single or double configuration of trunk "rings" is less costly, positions the trunk ring(s) at the appropriate distance(s) from the demand center, and calculates pipe diameters based on user-supplied pressure drops. Similar parameters are calculated for rural interstate scenarios. Depending on the scenario and the descriptive parameters entered by the user on the SCENARIO tab, the model sets the appropriate parameters in the SCENARIO PARAMETERS tab. This information is then provided to the appropriate components tabs to properly size all components and subcomponents, and to develop cost estimates for each component.

Section 4.5 of this Guide includes additional information regarding the SCENARIO PARAMETERS tab.

3.1.6 Other Tabs

The remaining tabs in HDSAM are very similar to those in the H2A Delivery Components Model. As noted earlier, a major difference between the two is that in HDSAM design capacities are calculated within the model rather than input by the user. Within HDSAM, design capacities are initially computed to accommodate demand, but capacities are then increased to allow for hydrogen losses within the pathway, for the availability of the individual components, and for peak surges. For example, the amount of hydrogen the system must be able to deliver to forecourts must equal peak consumer demand plus all losses that may occur within the delivery pathway. The number of trucks needed to deliver the proper amount of hydrogen to forecourts must include a sufficient number of spare trucks to account for break downs or scheduled maintenance, as well as losses within the forecourt. A liquefier must be sized to meet customer demand, account for forecourt losses, losses during truck loading and unloading and losses in storage at the terminal, as well as liquefier availability. Nevertheless, the proper quantity of hydrogen must be liquefied over the course of a year. Similar capacity determinations are made in pipeline scenarios where, for example, the pipeline must be designed to deliver hydrogen in quantities to meet peak daily demand.

3.2 Analytical Methodology

Once all inputs have been defined on the SCENARIO and INPUTS tabs and the user clicks the "Calculate" button, the model calculates demand and links the appropriate component tabs to define the delivery pathway. As noted elsewhere in this Users Guide, the principal linkages among tabs in a given scenario are established by determining the appropriate capacities. Simplified descriptions of these linkages are presented for each of the following three basic delivery pathways allowed in Version 1.0.

3.2.1 Compressed Gas Tube-Trailer Delivery Pathway

Urban Market Scenarios

In all scenarios, average annual demand (in kg/day of hydrogen) is calculated in the SCENARIO PARAMETERS tab using a combination of model defaults and user inputs in the SCENARIO and INPUTS tabs. Using this value and a 70% capacity factor, peak daily demand and the number of refueling stations (of a selected capacity) are calculated. These forecourts are assumed to be located uniformly throughout the service area. Distances between forecourts are calculated and the average time required for truck travel between the forecourt and the truck loading terminal is estimated. The numbers of tractors and trailers required to meet peak hydrogen demand are also determined in this tab.

In Compressed Gas Tube-trailer Delivery scenarios, station size (as specified by the user in the SCENARIO tab) is passed to the FORECOURT STATION –GASEOUS H2 tab which determines the number of dispensers required at each station. In the current version of HDSAM, the tube-trailer provides primary on-site storage and a small storage/cascade system at the forecourt provides secondary storage. Capital and operating costs for dispensers and ancillary equipment, the storage/cascade charging system, and forecourt compressors are estimated within the FORECOURT STATION –GASEOUS H2 tab.

The number of trucks and trailers, and distances traveled are also calculated in the SCENARIO PARAMETERS tab. This information is passed to the COMPRESSED H2 TRUCK_2700 PSI tab where it is used to compute capital and operating costs of the delivery trucks, including the amount of diesel fuel required.

Peak demand, as calculated in the SCENARIO PARAMETERS tab (adjusted for peak surges and storage losses) is also passed to the COMPRESSED GAS H2 TERMINAL tab to determine the design capacity of the terminal or depot where hydrogen is stored, compressed and loaded onto trailers for delivery to forecourts. The terminal's storage requirement is determined by peak daily demand and a user-input number of storage days. This tab then determines the number of truck-filling bays required at the terminal, the capacities of storage tanks and compressors (consistent with other input and calculated information), and the resulting capital and operating costs associated with the terminal.

The total cost associated with this pathway is the sum of the costs estimated in the FORECOURT STATION-GASEOUS H2 tab, the COMPRESSED H2 TRUCK_2700

PSI tab, and the COMPRESSED GAS H2 TERMINAL tab. If the user selects the high-pressure (7000 psi) tube delivery on the SCENARIO tab, calculations proceed in the same manner as for standard-pressure tube delivery but the required number of trucks and trailers is significantly reduced. The user should note however, that such high-pressure tube delivery is not currently available in the marketplace and is only available in HDSAM as an option for delivery to the large refueling stations (1500 kg/day).

Rural Interstate Scenarios

In HDSAM "Rural Interstate" scenarios are modeled much like "Urban" scenarios. In these cases, the user specifies the number of interstate segments and the length of the segments. These selections are made on the SCENARIO tab. The user can select up to four interstate segments and a segment length (all segments are assumed to be of the same length) of up to 300 miles. This upper limit on segment length is based on the assumption that a single driver is assigned to each truck tractor and thus the maximum round-trip distance must be completed in one work day (14-hours driving time). The costs within the corresponding tab of the Delivery Components Model are estimated on this same premise.

If a user selects a single interstate segment, it is assumed that the hydrogen production facility and an on-site truck terminal are located at one end of the segment and that refueling stations (forecourts) are distributed evenly along the segment so as to meet the specified hydrogen demand. Each refueling station is assumed to be at a user-specified distance off the interstate. Truck travel times are estimated on the basis of these assumptions and are, in turn, used to determine the number of truck tractors (or cabs) and trailers needed to meet demand.

If a user selects multiple interstate segments, the model assumes that all segments meet at one end-point (i.e., that the intersection of two segments forms an "I", three segments form a "T" and four segments form an "X"). Further, it is assumed that each segment is of the specified length, and the production facility and terminal are located at this intersection. All other assumptions and methods of analysis are the same as for a single segment.

Standard vs. High-Pressure Tube-trailers

Conventional-technology hydrogen tube-trailers typically operate at roughly 2700 psi with capacities of 300-400 kg of hydrogen. It is not practical to make more than about one delivery to a refueling station (forecourt) per day. As a result, this technology is limited to relatively small forecourts. HDSAM currently characterizes two forecourt sizes -- 100 kg/day and 1500 kg/day. In Version 1.0, the user selects forecourt size on the SCENARIO tab (see Sec. 3.1.2). The model then computes the number of stations required to dispense sufficient hydrogen to satisfy consumer demand and the percentage of total stations in the market dispensing hydrogen. If the resulting percentage is less than 10% of total gasoline refueling stations in the service area (as might occur with 1500 kg/day hydrogen stations), the model will return an error message prompting the user to switch to the 100 kg/day option, thereby increasing the number of refueling stations in the service area. If the user fails to select the 100 kg/day option the simulation will be terminated. This assures a minimum level of customer convenience. Further, in order to limit the number of tube-trailer deliveries to no more than two per day, Version 1.0 of HDSAM does not permit the user to specify a scenario with delivery to large forecourts via low-pressure tube-trailers.

HDSAM also includes a high-pressure tube-trailer tab which characterizes tubes that can operate at about 7000 psi and deliver around 600-800 kg of hydrogen. The user can select this option from the drop-down menu located in cell E1 of the SCENARIO tab. However, the user is cautioned that this technology is NOT yet commercially available and, hence, its characterization in the respective components tab is less certain than the conventional-technology tube-trailer.

3.2.2 Liquid Delivery Pathway Hydrogen Truck

Urban Scenarios

Linkages for liquid hydrogen truck delivery scenarios are conceptually similar to those discussed above for compressed gas tube-trailer delivery. Tabs specific to the handling of cryogenic liquids are used instead of those associated with compressed gas but the analytical methodology is similar. An additional tab used in liquid delivery scenarios is the H2 LIQUEFIER tab which estimates the cost associated with liquefying hydrogen at the terminal. An inherent assumption in Version 1.0 of HDSAM is that the liquefier and the terminal are located immediately adjacent to the hydrogen production facility.

As with most components tabs in HDSAM, liquefier design capacity is linked to the peak hydrogen demand as determined in the SCENARIO PARAMETERS tab. Since the liquefier must also liquefy any hydrogen subsequently lost during storage, handling, transportation, and dispensing, its capacity is increased above the peak demand to account for these additional loads.

Rural Interstate Scenarios

Liquid hydrogen truck delivery in “Rural Interstate” scenarios is evaluated in the same manner as described above for compressed gas tube-trailer delivery. The liquefier is assumed to be immediately adjacent to the production facility and the terminal.

3.2.3 Pipeline Delivery Pathway

In pipeline delivery scenarios, average and peak hydrogen demand (and the number and relative location of forecourts) are determined in the same manner as in gaseous truck delivery scenarios. However, there are key differences in how hydrogen is delivered to each forecourt.

Urban Scenarios

For urban scenarios the pipeline pathway consists of three types of pipeline. The largest diameter pipe, referred to as transmission pipeline, extends from the production facility through the geologic storage site to the city gate. The diameter of this pipeline is a function of its length, peak hydrogen demand, and the pressure differential between the pipeline inlet at the production end and the pipeline outlet at the city gate. These parameters are entered on the INPUTS tab.

An intermediate diameter pipeline is referred to as a "trunk" or "main" line. In effect, trunk lines create a ring or circle within an urban area where they are used to carry hydrogen from the transmission line, which terminates at the city gate, to the individual service pipelines which connect to each refueling station. Depending on the size of the urban area, there may be either one or two trunk lines. The model finds the least-cost combination of trunk and service lines and in doing so determines the number of trunk lines, their location (i.e., the radius of the trunk line(s) from the center of the urban area), length(s) and diameter(s); and the total length and diameter of service lines. These service lines are the third type of pipeline within a pipeline delivery scenario.

The pipeline system requires a compressor to increase hydrogen pressure from its production level (assumed to be 300 psi but the user can change this default value) to the pressure at the terminus of the transmission line. The user can input this maximum pressure at the inlet of the transmission pipeline (the default value in Version 1.0 of HDSAM is 1000 psia). Design requirements for the pipeline central (main) compressor are then calculated as a function of the change in pressure and the incremented peak hydrogen demand (to allow for losses in the pathway).

Rural Interstate Scenarios

In "Rural Interstate" scenarios only two types of pipeline are used -- a transmission pipeline to transport hydrogen from the production facility and along the interstate segment(s), and service lines connecting the transmission pipeline to each individual forecourt. As in the truck delivery scenarios, the production facility and the terminus of the transmission pipeline(s) are assumed to be at the end of a single segment or at the intersection of two or more segments. An implicit assumption in "Rural Interstate" scenarios is that geologic storage is at this same location.

Note that in "Rural Interstate" scenarios, pipelines can serve a larger market (defined by segment length) than trucks. Truck segment lengths are constrained by DOT rules which limit drivers to a maximum of 14 driving hours/day. Hence, segment lengths are constrained to 300 miles (600 miles round trip). Longer segments are permitted for pipeline delivery since the limiting factor is the potential requirement for compressor booster stations. Given other default inputs, an upper limit of 1000 miles has been established in HDSAM.

Geologic Storage

The remaining component in a pipeline delivery scenario is geologic storage. In Version 1.0 of HDSAM, geologic storage is intended solely to provide capacity for sustained demand surges as might occur during the summer driving season. On the INPUTS tab, the requirement for geologic storage is a function of the percent by which the average demand surge exceeds average annual demand, and the duration (number of days) of that surge. Multiplying these parameters by average daily system demand (increased by hydrogen losses and equipment availabilities) yields the total quantity of hydrogen that must be provided to meet that surge. This value is used to determine the size of the geologic cavern. A compressor is required at the geologic storage facility to charge hydrogen into the cavern. The same compressor is used to extract hydrogen from the cavern and push it into the pipeline. The GASEOUS H2 GEOLOGIC STORAGE tab determines the required capacities of the cavern and compressor, and their associated capital and operating costs. These costs are added to the costs of all other components in the delivery pathway to determine the total cost of pipeline delivery.

4.0 DETAILED INSTRUCTIONS AND INFORMATION

Earlier sections of this Users Guide described the objectives of HDSAM and the basic methodologies used in estimating the cost of hydrogen delivery. Included in these descriptions are explanations of various inputs and outputs. The following sections (Sections 4.2-4.5) provide additional detail on the four principal tabs users will work with in the model. This detail is intended to enhance users' understanding of the range of applications and limitations of Version 1.0 of HDSAM, as well as aid the analyst in effectively and efficiently changing basic inputs to conduct a variety of analyses.

4.1 Color Coding

The cells in each tab of HDSAM are color coded to show the user which values are inputs to the model and which are not. The color-coding convention is the same as that used in other H2A-developed tools. Figure 2 is a screen capture showing the color-coding convention.

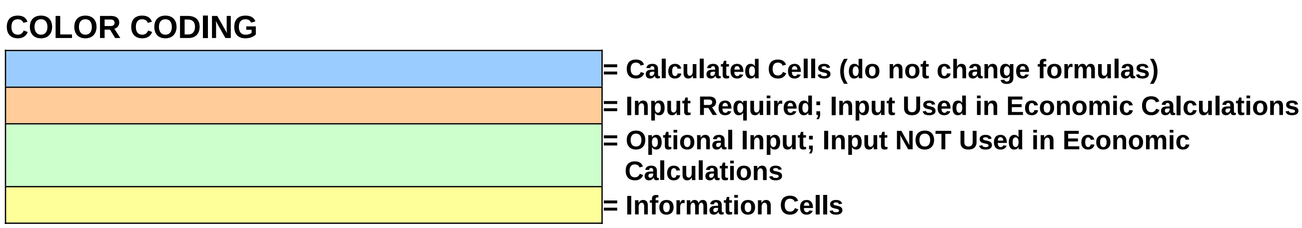

Figure 2. Color-Coding Convention in H2A Models

The blue cells in the model are calculated cells and should not be changed by the user. When scrolling through the various tabs, a blue cell may be opened to see how a particular calculation is completed, but the formula may not be changed. Note that the tabs at the bottom of the screen corresponding to the RESULTS SUMMARY and CASH FLOW RESULTS spreadsheets are also colored blue to correspond to the color-coding convention.

As in all other H2A-developed models, the tan (light brown) cells require user input. However, unlike those models where the user must enter a value (if the cell is blank) or use the default supplied in the spreadsheet, HDSAM's graphical user interface (GUI) automatically enters input values consistent with all other scenario parameters selected by the user on most of the tabs. The key exceptions are the SCENARIO and INPUTS tabs which function more like the tan cells in the other models. On these two tabs, the user can enter values corresponding to the specific scenario being modeled. The model's internal error-detection system will return an error message if these user-specified inputs are beyond a reasonable range pre-programmed into the model. Note that the tab at the bottom of the screen for the INPUTS spreadsheet is also colored tan to correspond with the above-discussed color-coding convention.

The light green cells are typically used for comments and references. The information entered in these cells is beneficial to future users of the model, as it can assist in tracking assumptions and identifying the rationale for particular inputs.

The yellow cells, always on the right-hand side of the tables, provide miscellaneous information like empirical ranges for input values, references, and data sources.
In addition to these color-coding conventions, HDSAM also color-codes tabs appearing at the bottom of the screen so that the user can quickly and easily see which components are linked into particular delivery pathways. Thus, all tabs involved in gaseous truck delivery are colored aqua, while those for liquid delivery are red and those for pipeline delivery are gold. General information tabs (FINANCIAL INPUTS, PHYSICAL PROPERTIES, MACRS, FEEDSTOCK & UTILITY PRICES) are yellow, the SCENARIO tab is green, the SCENARIO PARAMETERS tab is orange, and the TITLE tab is purple. The GH2 and LH2 FORECOURT tabs are gray, which is consistent with the color-coding used for the refueling station capacity options on the SCENARIO tab.

4.2 SCENARIO Tab

4.2.1 User Inputs Prior to Calculation

As described earlier, it is in the SCENARIO tab that the user specifies the principal parameters that define a scenario. Upon opening the tab, the user sees five major input blocks across the top of the screen. In the first block, titled “H2 Market”, the user selects either an “Urban” or “Rural Interstate” market. In the second, “Market Penetration”, block the user specifies the percentage of light-duty vehicles in the market that are hydrogen-fueled. This value can range from 1 to 100 percent and can be entered either by typing the value in the indicated cell or by using the slide bar located below the indicated value. The third and fourth blocks allow the user to select a delivery mode. As noted throughout this Guide, Version 1.0 of HDSAM requires that a single delivery mode be assumed for both transmission and distribution. Therefore, when a user selects a delivery mode in the “Transmission Mode” block, the model automatically selects the same option for the “Distribution Mode” block. Future versions of HDSAM will eliminate the requirement that both transmission and distribution be via the same mode.

Distribution mode options are “Compressed H2 Truck”, “Liquid H2 Truck”, and “Pipeline”. As noted earlier, there are two options for “Compressed H2 Truck”. The first is based on commercially available technology and involves delivery of 2700-psi hydrogen in quantities of 300-400 kg. The second option is based on advanced technology which suggests hydrogen can be pressurized to approximately 7000 psi and delivered in loads of approximately 600-800 kg. The user can choose whether or not to consider the (currently unavailable) high-pressure tube-trailer option by using a toggle switch located in Cell E1 above the “Transmission Mode” box. As noted in Section 3.2.1, the model will permit higher pressure tube-trailers only if the user has specified higher-capacity (1500 kg/day) forecourts.

The fifth major block on the SCENARIO tab is the choice of refueling station (forecourt) capacity. In Version 1.0, the user may select either 100 kg/day or 1500 kg/day stations. However, as noted elsewhere in this Guide, the model restricts the user from selecting certain combinations of forecourt capacity, market size, penetration rate, and delivery mode. For example, the low-pressure gaseous tube-trailer delivery mode cannot be used in combination with 1500 kg/day stations. Also, the model will automatically use 100 kg/day stations if the number of larger-capacity stations required to serve market demand would constitute less than 10 percent of the gasoline stations in the market area. The rationale for these restrictions has been discussed earlier in this Guide.

If the user selects the “Urban” market option, a box titled “City Selection” appears on the SCENARIO tab. This box enables the user to select either a specific urbanized area from a drop-down menu or to enter a population for an unspecified, generic urbanized area. When using this option, the input population must be between 50,000 and 20,000,000. In selecting specific cities to be examined, the user should be aware that the only city-specific data contained in the model are population, land area, motorization (i.e., the number of LDVs per person) and utilization rate (i.e., annual miles/vehicle). No location-specific cost data are contained in HDSAM or its component parts.

Once the user has made his/her selections, he/she must click the “Calculate” button on the SCENARIO tab for the model to accept these inputs and calculate. If all necessary information has been provided, an estimated delivery cost will appear in Cell C11. This value, expressed in $/kg of hydrogen delivered to the customer, is a levelized cost of delivery as defined in the H2A Program.

4.2.2 Additional Inputs and Outputs

Following user selection of the above inputs, three additional blocks appear on the SCENARIO tab. The first block, titled “Key Delivery Inputs and Assumptions”, includes both input and output data. Cell C15 displays the population of the urban area of interest. This value is the same as that contained in the “City Selection” box unless the user chooses to change it. If the user changes the population in this manner, the city area remains that of the chosen city but the user-input population is used in subsequent calculations. Cells C16, C18, andC19 allow the user to alter land area, vehicles per capita, and vehicle utilization, respectively. Cell C20 contains the distance between the hydrogen production facility and the urban area. It should be noted here that there are modeling limitations that necessitate some user discretion in choosing a value. For example, the pipeline delivery mode is based on the premise that a compressor is located at the pipeline inlet (at the production facility) but that no booster compressors are required on transmission or distribution lines. The model determines pipe diameters based on hydrogen flow rate, distance, and a user-specified pressure drop. Therefore, for hydrogen demands of realistic interest, calculated pipe diameters are within typical manufacturing capabilities for distances of up to 1000 miles. Truck delivery modes, however, pose a more stringent limitation on this parameter. Cost models within the appropriate Component tabs assume that a single driver delivers each load and that a round trip must be completed within one working day. Thus, a realistic limit to the parameter in Cell C20 is on the order of 300 miles for truck delivery scenarios.

Cell C23 represents average fuel economy of hydrogen-fueled vehicles and is used to determine daily H2 demand. The user can vary this parameter to determine the impact of improved fuel economy on delivery costs.

The remaining cells in this block (C17, C21, and C22) are calculated values and cannot be changed by the user. Cell C17 is a simple determination of population density. Cell C21 represents the average capacity of the refueling stations (forecourts). The model assumes an average-to-peak daily hydrogen demand ratio of 70 percent so the forecourt capacity factor should be almost the same value. The model adjusts forecourt capacity to allow for a whole number of forecourts, but this factor is typically very close to 70 percent.

Cell C22 displays the average daily quantity of hydrogen dispensed from each forecourt. As noted elsewhere in this Guide, Version 1.0 of HDSAM permits two forecourt capacities, 100 and 1500 kg/day. Applying the capacity factor from Cell 21 to the appropriate forecourt yields the value displayed in Cell C22. In Version 1.0, the user can select between these two forecourt options, which are displayed on the SCENARIO tab. If 10 percent or more of the existing gasoline refueling stations can be made hydrogen-capable with 1500 kg/day hydrogen capacity, then 1500 kg/day forecourts are recommended for the simulation. However, if the 10-percent threshold cannot be met with 1500 kg/day forecourts, then 100 kg/day units must be selected or the simulation will be terminated.

"Demand Calculations" are summarized in Cells F15-F21 of the SCENARIO tab. Since these are calculated values (blue color-coded cells), the user cannot change them. Parameters displayed in this block include: average daily and annual hydrogen demand per vehicle, the number of hydrogen-fueled light-duty vehicles (in the market), average daily hydrogen demand (for the entire market), the number of hydrogen stations or forecourts, the average distance between them, and the ratio of hydrogen-capable stations to total gasoline stations. As noted throughout this Guide, the latter two parameters are particularly important for estimating infrastructure and equipment requirements for hydrogen delivery and, consequently, its cost.

The final output block on this tab, "Delivery Mode Calculations", summarizes various details of the selected delivery mode. For pipeline delivery, this block contains lengths and diameters for each type of pipeline – transmission, ring (or trunk), and service – as well as the results of calculations to determine if a "one-ring" or "two-ring" configuration is less costly. For truck delivery, the block includes round-trip travel time, annual deliveries, the maximum number of daily round-trips per truck, and the number of tractors (cabs) and trailers required to meet demand.

4.2.3 Rural Interstate Scenarios

If the user selects a "Rural Interstate" market, inputs and outputs on the SCENARIO tab are somewhat different from those for "Urban" scenarios. Initially, an "Interstate Selection" box appears and the user must enter the length of interstate segment to be examined. Segment lengths can vary from 10 to 300 miles for truck-delivery scenarios but can be up to1000 miles for pipeline delivery. Following user-selection of segment length, the "Key Delivery Inputs and Assumptions" box displays this input, as well as the number of intersecting segments (the user may select up to four such segments), the average number of vehicle-miles traveled per highway-mile, the distance from the forecourt to the interstate highway, and the fuel economy of conventional light-duty vehicles. The user may change any of these inputs. Output information in this block includes the forecourt capacity factor (Cell C19) and the average amount of hydrogen dispensed per forecourt (Cell C20).

For "Rural Interstate" scenarios, the "Demand Calculations" box contains much the same information as for "Urban" scenarios. For the former, however, information on gasoline refueling stations along the interstate is also provided. Gasoline station information is calculated within the SCENARIO PARAMETERS tab (see Section 4.5). These values are significant in determining the number of gasoline stations on the interstate segments and thus the percentage of such stations that are hydrogen capable. Other information in this box includes peak and average hydrogen demand along the interstate, number of hydrogen-capable refueling stations and the percentage of total gasoline stations that are hydrogen-capable.

As with "Urban" scenarios, outputs in the "Delivery Mode Calculations" box depend on the delivery mode. For pipeline delivery, outputs include length of transmission and service pipelines.[3] For truck delivery, outputs include average round-trip time and distance, and the number of tractors and trailers required.

4.3 INPUTS Tab

In the INPUTS tab the user can modify the basic description and cost parameters of the various delivery components. Three types of inputs are displayed on the INPUTS tab. The first type is displayed in a block titled "General Economic Assumptions" (found in Cells B2 through B7) which contains startup year, reference-year dollars, real after-tax discount rate, analysis period, and state and federal tax rates. The user can modify any of these parameters. Based on this input, the model calculates the total tax rate which is noted in the blue color-coded Cell B8.

The second type of input, contained in cell E5, is the average number of light-duty vehicles that are serviced by a single gasoline station. The default value in Version 1.0 of HDSAM is 2,000. A refueling station serving this many customers would pump on the

[3] In Version 1.0, the former is the same as the user-specified segment length; the latter is the calculated number of stations times the user-specified service pipeline length (Cell C18).

order of 100,000 gals of gasoline per month. The sole objective of this parameter is to determine the number of gasoline refueling stations within an urban market area.
The third type of input on this tab is a series of blocks summarizing key features of the individual components in a pathway. As noted in Section 3.1.3 of this Guide, selection of a delivery mode causes the relevant contents of the corresponding component tabs to be displayed. If a user wishes, he/she can change any input parameter associated with these components in the same manner as described in the Delivery Components Model Users Guide (see www.hydrogen.energy.gov). However, because some inputs to the Components Model are calculated in HDSAM or are linked to other components in the pathway, **the user may only change component inputs from within the INPUTS tab**. Parameters that are now calculated or linked in the components' tabs will not be included in the INPUTS tab (because they are no longer inputs in scenario applications). Examples of inputs to the Components Model that are calculated in HDSAM include:

Pipeline Delivery Mode:

Cell E25: Pipeline pressure in feeder to cavern
Cell K23: Forecourt Station Capacity
Cell K24: Pressure of Hydrogen Delivered to Forecourt Station

The user will note similar blue color-coded cells (i.e., calculated cells) for compressed gas and liquid truck delivery modes.

4.4 RESULTS SUMMARY Tab

An overview of the RESULTS SUMMARY tab is provided in Section 3.1.4 of this Guide. As noted there, total delivery cost for the scenario being examined is summarized in two pie charts. The first shows the distribution by cost type - energy/fuel, capital, and other operating and maintenance (i.e., non-fuel O&M). Figure 3 shows a typical breakdown of cost by type for a compressed gas truck delivery scenario.

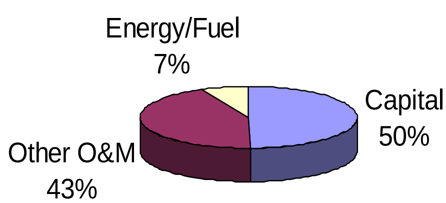

Figure 3. Breakdown of Delivery Cost by Type (Illustrative)

The second pie chart in the RESULTS SUMMARY tab shows a breakdown of cost by function. Figure 4 shows that breakdown for the same scenario described in Figure 3.

Note that in addition to these pie charts, the user can also use the normal display functions available within EXCEL to display cost breakdowns for each component in the pathway, e.g., for the terminal, for trucks/trailers, or for the forecourt.

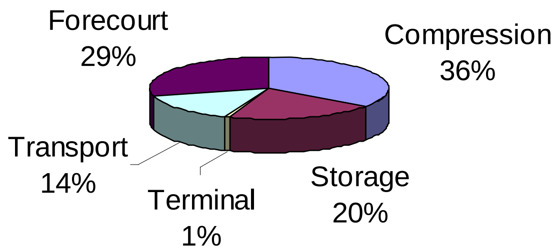

Figure 4. Breakdown of Delivery Cost by Function (Illustrative)

Whereas most cost results are displayed in terms of $/kg of hydrogen delivered to the customer, the SUMMARY RESULTS tab contains additional details and units. These appear on lines 35 and 36 of the tab and consist of:

- Total Initial Capital Investment
- Annual Standard O&M cost (not including energy or fuel)
- Annual Electrical Energy Consumption
- Annual Truck Fuel Consumption (if applicable)

4.5 SCENARIO PARAMETERS Tab

An overview of the SCENARIO PARAMETERS tab is provided in Section 3.1.5 of this Guide. As noted there, this tab determines average and peak hydrogen demand and thus drives the capacity requirement for each component in the delivery pathway. This tab is also used to determine the required number of forecourts, the distance between them, the required number of tractors and trailers, round-trip time and distance, and a variety of other parameters necessary to define the delivery pathway and estimate delivery costs.

The SCENARIO PARAMETERS tab consists of a series of blocks that contain information developed within the H2A Program. As the development of HDSAM evolved, some of the information contained in these blocks was replaced by other assumptions or analytical methodologies. Other blocks in this tab contain information that is not used in Version 1.0 of HDSAM but which could be relevant in future versions. Therefore, the various information blocks described below have been retained in Version 1.0 of HDSAM.

4.5.1 "Active" Cells

Tables 2 and 4 remain "active" in Version 1.0 of HDSAM. Table 2 presents data on the energy content of gasoline and hydrogen. This is used to estimate hydrogen demand. Table 4 contains data on trucks used for hydrogen delivery. This is used within the SCENARIO PARAMETERS tab to estimate the number of trucks required, their travel time, and other relevant parameters. Some of this information is also fed to the appropriate component tabs to estimate costs. The information in this table was developed primarily from industry experts (typically KIC members) and represents the best available collective knowledge. While the user can vary the assumptions in this table, it is highly recommended that the default values contained within HDSAM Version 1.0 be used.

Scenario-independent delivery and demand information is contained in cells B106 through B120. This information is generally linked to corresponding data on other tabs within HDSAM. It is also used within this tab for delivery-specific calculations ultimately used to estimate delivery costs. Scenario-specific information is contained in cells B125-B129. These data describe baseline conditions for determining hydrogen demand and duplicate information contained in the SCENARIO tab.

Rows 147-159 present input (repeated from previous rows in this tab) for the Compressed-Gas Delivery mode. Columns A and B correspond to low-pressure tubes (2700 psi) and columns E and F are for high-pressure tubes (7000 psi). Rows 161-172 present demand-specific results for compressed gas delivery. These results are obtained by combining the demand calculations (rows 132-145) with the compressed gas delivery information in rows 147-159. Appropriate information from this block is linked to the corresponding component tab for purposes of estimating delivery costs. Rows 176-187 provide the same information for liquid delivery applications. Column B shows basic input parameters and column F displays calculated results.

Cells B191-B202 display input information for pipeline delivery in urban applications. Calculated values are contained in cells F190-F202. These values are linked to the PIPELINE component tab.

“Rural Interstate” Scenarios

The above descriptions of calculated parameters are for “Urban” scenarios. Comparable information for “Rural Interstate” scenarios are presented in rows 207-235. Demand parameters are repeated in cells B209-215 and corresponding results for the various delivery modes are displayed in the remaining blocks. As with “Urban” scenarios, appropriate results from this tab are linked to the corresponding component tab for use in estimating delivery costs.

4.5.2 “Inactive” Cells

Tables 5 and 6, as well as a number of other cell ranges are not linked to other parts of the model and the user is cautioned against attempting to enlist them in the process of defining a particular scenario.

Table 5 contains information on “Large” and “Small” cities. These two city sizes were the market sizes considered in the early development of HDSAM but have since been replaced by specific urbanized areas or generic urban areas with populations between 50,000 and 20,000,000 persons as described in Section 4.2. Table 5 is included in this tab for historical purposes.

Table 6 provides information on centralized hydrogen production. As with Table 5, this information was used in the early development of HDSAM but is not used in Version 1.0 of the model. However, future versions of HDSAM may link hydrogen production with delivery. Therefore Table 6 is included in this tab both for historical reasons and as a placeholder for potential application in future versions of HDSAM.

Hydrogen demand in an urban area is described in cells B133-B145. These cells also display the estimated number of hydrogen-capable refueling stations and the percent of total gasoline stations that are hydrogen-capable. Cells B144 and B145 show demand as a percentage of an assumed hydrogen production facility (cells F25 and F26) but these values have no real impact on the simulation results in the Version 1.0 framework.

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