Appendix 4 – Examples for Calculating the Renewable Hydrogen Contribution

To encourage the development of renewable hydrogen infrastructure, increased funding levels will be available for increased amounts of renewables. This appendix describes the steps for calculating the renewable percentages of the total energy inputs as well as renewable percentages for non-electricity feedstocks and electrical energy inputs (see Appendix 5 for complete definition of renewable resources). For the purpose of this RFP, production of hydrogen for transportation includes feedstock pretreatment, conversion, purification, liquefaction, and compression.

Bidders using renewable resources must also complete the Renewable Energy Information form in Attachment 9 to allow ARB to evaluate well-to-wheel and well-to-tank emissions.

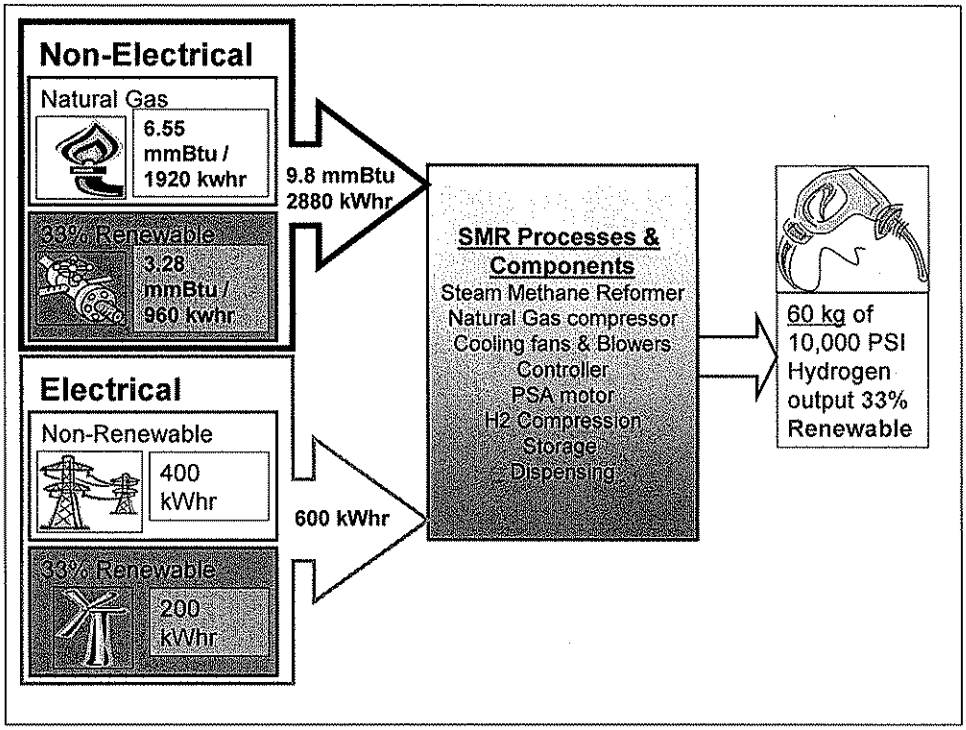
The following three examples illustrate how to determine percent renewables for different hydrogen production pathways. All examples assume a station capable of dispensing 60 kilograms per day at 10,000 psi (700bar, 70 MPa) with the electrical components for compression and auxiliary processes requiring 600 kilowatt hours (kWhr) per day or 10 kWhr per kilogram of hydrogen. These values were determined using data from the California Hydrogen Highway Blueprint Plan and estimates of production components (e.g. auxilary compressors, fans, controllers, PSA motors and hydrogen compressors).

Example 1: 33.3% renewable, Steam Methane Reformation - Biogas/natural gas blend[a]

In this first example, the station is producing 33.3 percent renewable hydrogen by using a blend of 33.3 percent renewable biogas and 66.7 percent natural gas in a steam reformer to create the hydrogen. Electricity demands are being met by a 33.3/66.7 percent blend of new renewable and grid electricity. Both the electrical and the non-electrical requirements of the station must incorporate a 33% renewable component on an energy equivalent basis for the station to be considered "33.3 percent renewable."

Figure 1 illustrates the energy requirements for a 60 kilogram per day Steam Methane Reformation (SMR) station. The total daily station energy inputs are 3,480 kWhr - 600 kWhr in electricity and 2,880 kWhr (9.83 million Btu [mmBtu]) non-electrical inputs. The energy inputs are further broken down into their renewable and non-renewable portions. The electrical component is using 400 kwhr non-renewable grid electricity and 200 kwhr renewable electricity. The non-electrical component includes renewable biogas (3.28 mmBtu) and non-renewable natural gas (6.55 mmBtu). Energy inputs are expressed on an energy equivalent basis converted to kWhr to simplify calculations. The output for the process would result in 60 kilograms of 33.3 percent renewable hydrogen dispensed at 10,000 psi.

Figure 1. SMR Station using 33.3% renewable inputs



An example breakdown for calculating percent renewable contributions is presented in Table 1.

Table 1. Renewable Calculations for SMR Station – 60 kg/day

Processes requiring electrical energy inputs	**List electrical energy sources**		**Daily energy requirement (in kWh per day) for station operating at 60 kg/day capacity**	
	Renewable	Non-renewable	Renewable	Non-renewable
1) Compression, etc.	Wind or solar	Grid	200 kWh	400 kWh
2) Other electrical	N/A	N/A	0	0
Total Electrical Energy Inputs			200 kWh	400 kWh
Percent Eligible Renewable Electricity (Renewable/Total)			33.3%	
Processes using non-electrical energy inputs	**List non-electricity feedstock or energy source**		**Daily feedstock or energy input for station operating at 60 kg/day capacity (convert to kWh)***	
	Renewable	Non-renewable	Renewable	Non-renewable
1) Reformation	Digester gas	Natural gas	960 kWh	1,920 kWh
Total Energy Feedstocks and Inputs			960 kWh	1,920 kWh
% renewable feedstocks & inputs (Renewables/total)			33.3%	
Total Energy Inputs (electricity and non-electricity)			1,160 kWh	2,320 kWh
Total Percent Renewable			**33.3%**	

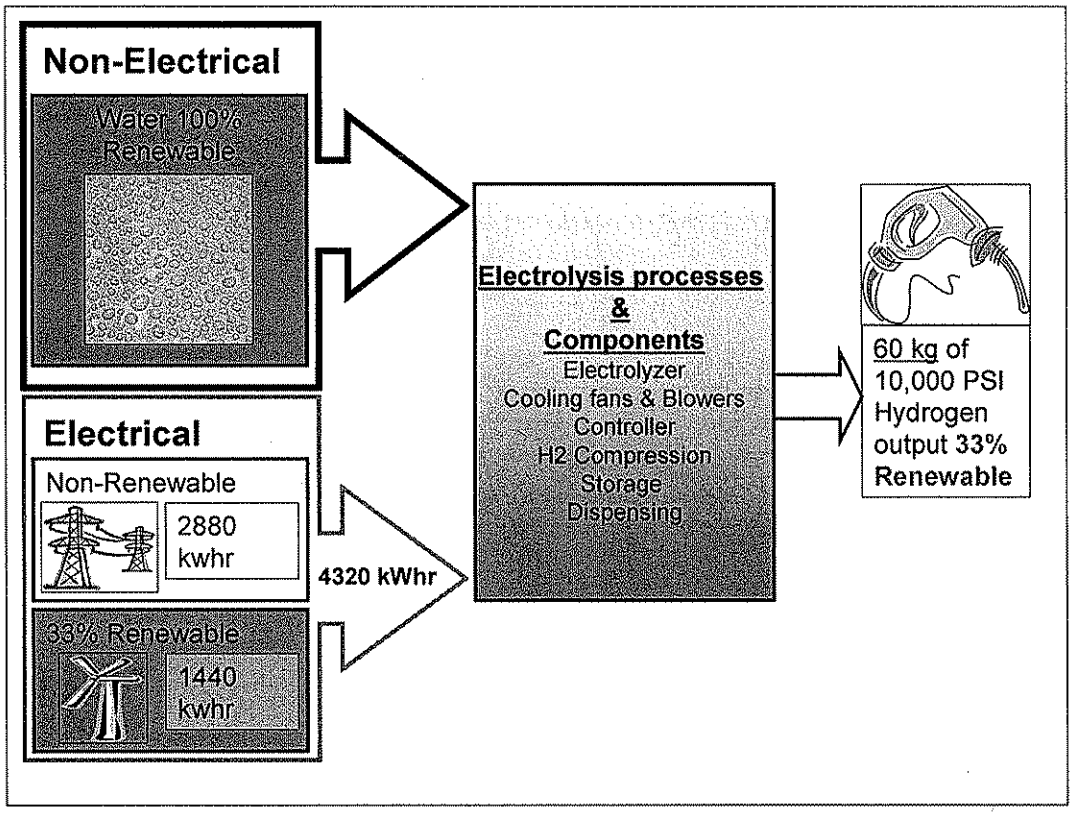
* Digester gas and natural gas expressed on an energy equivalent basis in kWh.

Example 2: 60 kg/day Electrolysis of Water[b]

In this example, an electrolyzer is used to convert water and electricity into hydrogen with electricity being the only energy input. In order for the hydrogen to be considered 33.3 percent renewable, 33.3 percent of the electricity must come from eligible renewable energy resources as defined in Appendix 5.

Figure 2 and Table 2 both illustrate how an electrolysis station producing 60 kilograms of hydrogen per day can be considered 33.3 percent renewable. In this example, a total of 4320 kWhr of electricity is needed to produce 60 kg of hydrogen, with 2880 kWhr from the grid and 1440 kWhr from eligible renewable energy resources. With this configuration, the dispensed hydrogen would be considered 33.3 percent renewable.

Figure 2. Electrolysis Station Using 33.3% Renewable Electricity



The following breakdown in Table 2 is another way of showing renewable and non-renewable electricity usage in terms of hydrogen production and support processes that prepare the hydrogen for use as a transportation fuel.

Table 2. Renewable Calculations for Electrolysis Station – 60 kg/day

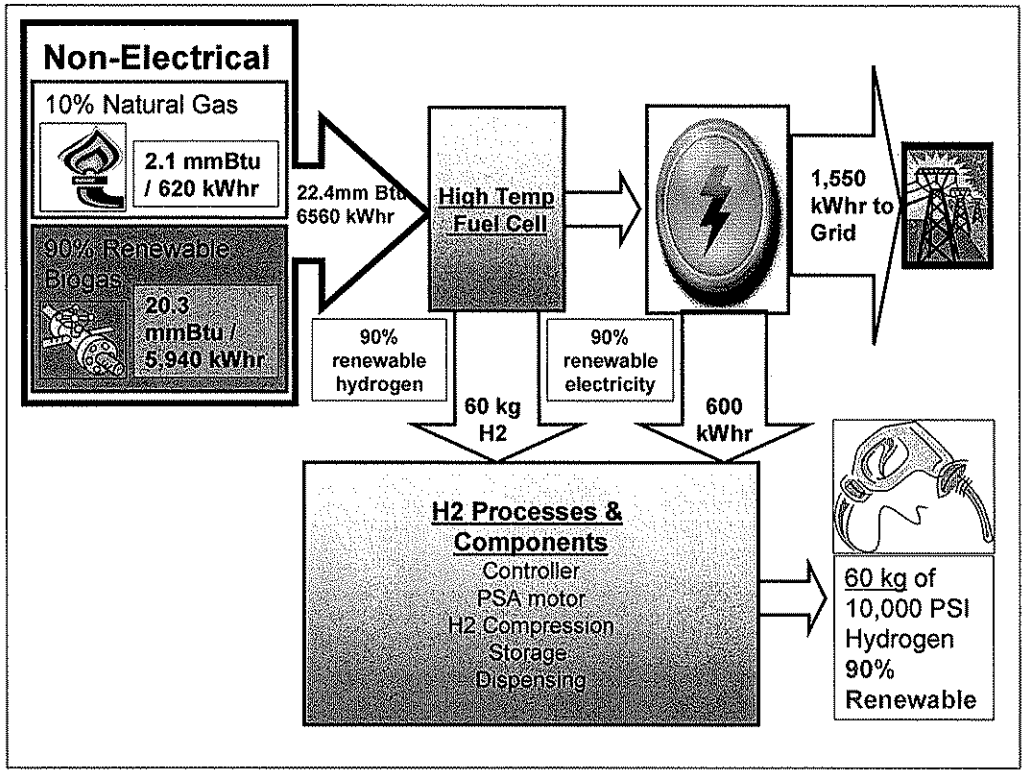
Processes requiring electrical energy inputs	List electrical energy sources		Daily energy requirement (in kWh per day) for station operating at 60 kg/day capacity	
	Renewable	Non-renewable	Renewable	Non-renewable
1) H2 Production	Wind or Solar	Grid	1,240 kWh	2,480 kWh
2) Compression, etc	Wind or Solar	Grid	200 kWh	400 kWh
3) Other electrical	N/A	N/A		
Total Electrical Energy Inputs			1,440 kWh	2,880 kWh
Percent Eligible Renewable Electricity (Renewable/Total)			33.3%	
Total Percent Renewable			**33.3%**	

Example 3: 60 kg/day Stationary Fuel Cell – biogas/natural gas blend[c]

In this last example, a stationary fuel cell is used to convert a methane-based feedstock (a blend of 90% biogas and 10% natural gas) into electricity, with heat and hydrogen as by-products. In general, the resulting electricity, heat and hydrogen are all considered renewable to the extent that the feedstock is renewable. For example, a stationary fuel cell using 90 percent renewable feedstock (defined in Appendix 5) will produce 90 percent renewable electricity and hydrogen. If that same electricity is used to process the hydrogen for transportation purposes, then the hydrogen itself is 90% renewable.

Figure 3 illustrates how a high temperature fuel cell could be used to reform and convert a biogas/natural gas feedstock into hydrogen and electricity. In this example, a blend of renewable biogas (20.3 Btu) and natural gas (2.1 Btu) are injected into a high temperature fuel cell to produce 60 kg of hydrogen and 2,150 kWhr of electricity. Only a fraction of the resultant electricity (600 kwhr) is needed to support hydrogen production for transportation while the remainder (1,550 kWhr) could be used for other purposes, including exporting to the grid. Energy inputs are expressed on an energy equivalent basis and converted to kWhr to simplify calculations. The resulting output in this example is 60 kg of 90 percent renewable hydrogen dispensed at 10,000 psi, and 1,550 kWhr of 90 percent renewable electricity.

Figure 3. Fuel Cell Energy Station Using 90% Renewable Feedstock



In addition, a facility producing electricity from a blend of natural gas and renewable biogas has the option to choose how they credit the renewable attributes of their electricity, provided they do not credit the same renewable attributes to another purpose or program (i.e., no double-counting).

Table 3 provides an example of percent renewable calculations for a stationary fuel cell energy/hydrogen station using 90% digester gas and 10% natural gas to produce electricity and hydrogen. The excess 1,550 kWhr/day of electricity produced at this station could be used for other on-site purposes or exported to the grid and credited towards a utility's Renewable Portfolio Standard obligation.

Table 3. Renewable Calculations for Fuel Cell Energy/Hydrogen Station – 1,550 kWhr/day and 60 kg/day

Processes requiring electrical energy inputs	**List electrical energy sources**		**Daily energy requirement (in kWh per day) for station operating at capacity***	
	Renewable	Non-renewable	Renewable	Non-renewable
1) Compression, etc	Fuel cell with biogas	Fuel Cell with natural gas	540 kWh	60 kWh
2) Other electrical	N/A	N/A	0	0
Total Electrical Energy Inputs			540 kWh	60 kWh
Percent Eligible Renewable Electricity (Renewable/Total)			90%	
Processes using non-electrical energy inputs	**List non-electricity feedstock or energy source**		**Daily feedstock or energy input for station operating at capacity (convert to kWh)**	
	Renewable	Non-renewable	Renewable	Non-renewable
1) Reformation	Digester gas	Natural gas	5940 kWh	620 kWh
Total Energy Feedstocks and Inputs			5940 kWh	620 kWh
% renewable feedstocks & inputs (Renewables/total)			90%	
Total Energy Inputs (electricity and non-electricity)			6480 kWh	680 kWh
Total Percent Renewable			**90%**	

* Excess 1,550 kWhr per day electricity produced in fuel cell available for on-site use or export to the grid.

---

[a] Values derived from California Hydrogen Blueprint Plan "Societal Benefits Topic Team Report," March 2005 (http://www.hydrogenhighway.ca.gov/plan/reports/sbreport.pdf)

[b] Values derived from California Hydrogen Blueprint Plan "Societal Benefits Topic Team Report,", March 2005 (http://www.hydrogenhighway.ca.gov/plan/reports/sbreport.pdf)

[c] Tyndall, D., "Validation of an Integrated Hydrogen Energy Station," DOE Hydrogen Program, Annual Progress Report, 2007. (http://www.hydrogen.energy.gov/pdfs/progress07/vi_b_1_tyndall.pdf)