Section R. Renewable Energy Sources for Hydrogen – Identifying Societal Benefits

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Introduction

There are many different types of renewable resources available in the state of California for the production of electricity and/or hydrogen. The characteristics of these resources and the manner in which they are purchased can vary widely. The purpose of this document is to provide background information on some of the ways in which renewable resources differ from one another, and what implications these differences might have for their potential use in either the electricity or transportation markets. Examples of these differences include the actual emissions associated with the renewable resource, both in terms of manufacturing energy and operating energy, the manner in which a resource is purchased, the intermittency and capacity factor characteristics of the resource, and any added benefits that may not be readily apparent when the resources are compared on an energy cost basis.

The primary focus of this paper is on the differences among renewable electricity options for producing hydrogen in order to understand their implications for the well-to-wheels analysis. Direct conversion of biomass to hydrogen through gasification is considered briefly as well. This does not suggest that more emphasis will be placed on electrolytic renewable hydrogen as part of the hydrogen highway. It is recognized that biomass gasification can present a compelling and attractive option for the production of hydrogen. This document provides a comparison of renewable electricity sources because there can be some wide disparities in the environmental benefits of renewable hydrogen depending on the source that is used.

There are four sections of this document, each dealing with separate issues regarding renewable resources. The sections are: Attribution of Renewable Power, Renewable Power Growth and the California Power Grid, Energy and Emissions Comparisons of Renewable Technologies, and Auxiliary Benefits of Renewable Energy Technologies. Section 1 looks at the differences in the ways renewable energy is purchased or consumed, whether it be in the form of Green Tags[a], or on-site generation, and a methodology for ranking these types of purchases in terms of their societal benefits to California. Section 2 deals with the prioritization of renewables for either offsetting electricity demand or transportation based on the characteristics of the fuels that the renewable energy sources would be offsetting. Section 3 examines the actual emissions that occur as a result of the use of various renewable energy technologies, including the emissions that occur during the manufacture of these technologies. Finally, Section 4 looks at some of the attributes of the renewable energy sources that are not typically considered when deciding which source makes the most sense for generating hydrogen or meeting grid electricity demand.

R.1 Attribution of Renewable Power

This section identifies the differences between renewable energy purchasing mechanisms in terms of their true benefit to California citizens. There are many different ways which renewable energy can be procured to produce hydrogen, some of which have multiple benefits and some of which are solely benefits on paper. A methodology is developed to allow a Well to Wheels analysis which will differentiate between various types of power purchases using a calculated vector to represent the relative "greenness" of that renewable purchase.

a. "Green Tags" or Renewable Energy Credits (REC's) refer to purchases of the renewable attributes, which have been separated from the power itself for the purpose of trading.

R.1.1 New vs. Existing Renewables

The first question to ask when looking at the use of renewable power for hydrogen production is whether the renewable electricity is from a "New Renewable" or an "Existing Renewable". The CEC's RPS Eligibility Guidebook defines "New Renewable" as being installed after January 1st, 2002[1], while the Center for Resource Solutions defines "New Renewable" as being installed after 1997[2]. Resources that were built before 1997 in California were typically financed by the utilities with the costs being added into the rate base. As a result, paying a little more for the attributes of those projects now would not result in any new capacity being built, and as new electricity demand came on-line, the end result would be a heavier reliance on fossil fuels in the electricity mix.

For the purpose of producing hydrogen, it is important to require that any "renewable hydrogen" be produced from new renewables rather than existing renewables. Production from existing renewables does not make sense because these sources are already a part of the existing grid supply. By adding a new demand source in the hydrogen electrolyzer, we add demand to the grid, above that which is already planned for based on load forecasts. The result of this additional load will likely be either increased reliance on marginal gas resources or new combined cycle gas plants as long as natural gas maintains an economic advantage over renewables. As a result, the environmental value of using existing renewables to produce hydrogen should be given the full emissions value associated with a marginal[b] California natural gas fueled electricity generation facility. A typical heat rate for such a facility is on the order of 8500 BTU/kWh[3], which results in approximately 450 kg CO_2/MWh being generated from direct combustion.

R.1.2 In-State Generation vs. Out of State Generation

The work done on the state RPS defines eligible resources as being located within California, or out of the state but bound by contract to deliver the energy to California, and being able to deliver that power to an Investor Owned Utility (IOU) designated in-state hub[4], as well as meeting a separate set of delivery requirements. For the purposes of generation of hydrogen, those out of state resources that meet this definition will be considered out of state power purchases. For purchases of resources that do not supply energy to the California market, we can effectively consider these to be equivalent to Green Tags.

The purchase of energy from a renewable resource that does not actually supply that energy to California results in additional natural gas generation occurring in California, as described before. Because of this, these renewable energy attributes that would be used to generate "renewable" hydrogen would be resulting in criteria pollutant emissions in California equivalent to a typical natural gas plant here. The greenhouse gas emissions from this sort of arrangement would net to zero if the resource was offsetting natural gas generation in the state it was occurring. Natural gas is the likely marginal source in most Western states due to the high fuel cost and wide range of operation possible with most natural gas electricity generation technologies. For green tags purchased from states where coal would be offset, we can see that there would actually be a GhG *reduction* as a result of the renewable generation and sale of the green tag. On the other hand, in the event that nuclear facilities were being curtailed to allow entry of the renewable resource, we can see that there could be an increase in greenhouse gas emissions as a result of the green tag purchase. These two scenarios would require extensive research to determine the feasibility of either case, and

b. "Marginal" refers to a generation resource that is brought on line or ramped up to meet electricity demand above baseload.

will not be addressed further as part of this effort. Rather, green tag, or attribute only purchases will be considered net-zero GhG energy, but will count for the full emissions value of a typical California natural gas fired generation facility. If the green tags are created from renewable power that is generated in California however, they would not be assigned the criteria pollutant penalty.

In addition to the negative environmental impacts, the purchase of out of state green tags may put California further at risk to natural gas price and supply fluctuations, which can have significant negative consequences on residential gas and electricity rates in California. Because risk and economics are not considered in the well to wheels analysis, no factor will be developed for this area. It is important however to recognize the danger of increased reliance on a single fuel for meeting California's energy needs, as is the case for transportation. It is also worth mentioning that should green tags be used, the resulting natural gas generation will consume more natural gas and produce more criteria pollutants than would natural gas reforming for hydrogen production, so this method makes very little sense except as a near term bridge to a renewable electrolysis future.

R.1.3 On-Site Generation vs. Distributed Generation

Because of issues of wind "curtailment", it may be necessary to consider collocating the hydrogen generation with the wind farm. Other renewable energy sources typically do not experience the intermittency associated with the wind resource, and therefore are not subject to the curtailment issues associated with wind farms. Because wind farms occasionally produce electricity at undesirable times for the grid, and can experience output swings at unpredictable rates, their output may be "curtailed", meaning their energy production is not accepted onto the grid. Additionally, utilities may accept wind electricity onto the grid when they do not need it to avoid paying curtailment charges, but the added wind may only end up raising the grid voltage, with no real benefit in terms of fossil fuel reduction. As a result, siting of the hydrogen generation at the wind farm may be a desirable way to capture wind energy that occurs during off-peak times. Because of the capture of power that would otherwise have been wasted, these on-site generators are effectively increasing the amount of renewable energy that can be captured, and when compared to a distributed generation scenario, are effectively decreasing the amount of natural gas generation required by the amount of wind energy that would otherwise be curtailed.

In order to estimate the amount of wind energy that could conceivably be curtailed, it is necessary to consider what the hours are in which California generating facilities are base-loaded. In California, the grid peak occurs in the late afternoon, and between the hours of midnight and 4 or 5 am most of the grid is base-loaded. Wind generated during this time would have the highest likelihood of being curtailed. In Solano County wind generation peaks at midnight[5], which means that there is a good amount of energy that falls during this time that could be curtailed. While these morning hours represent 21% of the day, the amount of energy that is generated during this time is roughly 25% of the average annual total for Solano. Curtailment might be a small portion of this 25%, depending on the utility, and the amount of wind penetration. For this case, we will assume that 20% of the energy that falls during these morning hours is curtailed, resulting in a 5% bonus for onsite generation over distributed generation in terms of criteria pollutants and greenhouse gases. Determining whether the on-site should receive a bonus, or the distributed generation should receive a penalty is the main difficulty here. It is anticipated in many regions that as the amount of installed wind power reaches 15-20% of the total grid capacity, the amount of curtailment may become quite significant.

R.1.4 Summary

Any hydrogen that is produced and results in increased electricity demand in California will be attributed the full criteria pollutant emissions value of an average marginal natural gas generation facility in California unless it clearly comes from a renewable resource. We take an average plant because a good deal of the required increased generation will come from existing marginal resources in California in addition to new natural gas plants that are built to meet steadily increasing demand. If the electricity demand is met through power purchase agreements with renewable energy producers in or bordering California, the hydrogen producer can legitimately call the hydrogen zero-emission. However, if the hydrogen is produced from grid electricity and out of state green tags are purchased to offset the emissions, the hydrogen will only be credited with the offset GhG's, not the offset criteria pollutants. In the event that the hydrogen is produced at the site of generation, (in particular at a wind or Hydro spill site), the emissions associated with the hydrogen should be considered negative, or some sort of credit should be given as a reward for utilizing an under-utilized renewable resource. The current estimate for this credit value for California is ~5%. Table 1.1 shows the emissions and energy savings ratings associated with various renewable energy purchases. The difficulty lies in determining whether this should be a credit, or whether the other purchasing methods should take a penalty.

Table 1.1: Renewable Energy Rating System for WtW analysis

Type of Renewable Energy Purchase	Types of Renewable Energy Benefits to California			
	Greenhouse Gas[2]	Criteria Pollutant[2]	Energy	Overall
Green Tags/Attribute Only Purchase	0.00	1	1	0.7
Renewable Power Purchase Agreement	0.00	0.00	0.00	0.00
On-Site Generation (Wind)[1]	-0.05	-0.05	-0.05	-0.05
Existing Renewable (Pre-2002)	1	1	1	1

Rating represents fraction of emissions from an 8500 BTU/kWh natural gas generation facility

1. The on-site generation has received a credit because it is harvesting power that would otherwise be lost if the production was located off-site.
2. Emissions will differ based on the type of renewable energy procured. Wind is effectively considered a zero emission source, however all other renewables have some small but quantifiable emissions value associated with them. See part 3.

R.2 Renewable Power Growth and the California Power Grid

This section will look at how renewable power is expected to grow in California as a result of the RPS, and whether using renewables for hydrogen will be feasible considering resource projections. It will also discuss the question of offsetting electricity generation or transportation fuel in terms of societal benefits to California.

R.2.1 The Renewable Portfolio Standard vs. the Renewable Hydrogen Standard

As California looks at requiring the electric utility industry to move towards a 20% Renewable Portfolio Standard (RPS) by 2010, and a 33% RPS by 2020, it is important to consider the availability of renewable resources and their best use in terms of offsetting emissions and maximizing their societal benefit. In addition, when considering availability, a look at the overall state resource assessment is necessary to ensure that the state has adequate renewable resources to meet the rising demand in both the electricity and transportation sectors. According to the Renewable Resources Development Report put out by the CEC, the state has a total potential renewable generation capacity of 262,000 GWh per year[6]. This compares to the state's total electricity demand in 2003 of roughly 256,000 GWh[7]. The estimated potential done by the CEC does not include off-shore wind power or wave power, both of which could become feasible before California begins to exhaust its land-based renewable energy options, and both of which represent huge potential energy sources for California. In addition, the WECC technically has a significant surplus of renewable resources outside the state of California that could provide power to California's grid if there was a need for additional procurement of renewable power. Based on these assessments, it seems unlikely that a shortage of renewable power would force a choice between its use for either the electricity or transportation market.

As has been mentioned, the benefits of renewable energy sources range from reduction of greenhouse gases, criteria pollutants, and energy dependence, as well as the encouragement of supply diversity and economic development. These benefits apply regardless of whether the power is used to offset the electricity grid demand or the transportation demand in California. However, the magnitude of each of these categories of benefits differs depending on the market that they are being consumed in.

In looking at decisions for 2010, the question is of little significance considering the scale of the demand for hydrogen. For a very aggressive assumption of a 10,000 vehicle fleet in 2010, entirely fueled by electrolytic renewable hydrogen, this would represent three tenths of one percent of our current renewable electricity production in California. When looking further to the future, there are increased difficulties in projecting efficiency improvements in various technologies, although it is likely that newer technologies have the greatest room to improve in efficiency. These issues should be considered when examining this analysis.

In the electricity market, a new renewable will be offsetting natural gas fired generation in California. This is because the nuclear and hydroelectric resources will be fully utilized as a result of their price signals. The gas resource is the primary marginal resource in California, and for this analysis, an average assumed value of 8500 BTU/kWh for the marginal natural gas heat rate was used. On the transportation side, a 2:1 fuel economy improvement was assumed for a fuel cell vehicle over a gasoline vehicle. Emissions of NO_x were based on current emissions controls capabilities, using ARB and eGrid2002 numbers for California. The analysis considered the best use of 1 MWh of renewable energy, for each of the areas mentioned above. The results of the comparison are shown in Table 2.1

TABLE 2.1: Comparing Offset Options for 1 MWh of Renewable Electricity

Offset Market	Greenhouse Gases (kg CO_2)	Criteria Pollutants (g NO_x)	Fossil Fuel Offset	Market Diversity Impact
Transportation[1]	380	**37**	**Petroleum**	**High**
Electricity[2]	**530**	27	Natural Gas	Medium

1. For Transportation, assumptions included a 2X fuel efficiency improvement for FCV's over gasoline vehicles (60 mi/kg), an electrolysis efficiency of 60 kWh/kg. 1 MWh produces 16.7 kg of hydrogen or displaces 33.6 gal of gasoline. The displaced CO2 from the gasoline vehicle is 370 kg (WTW). This corresponds to 280 g CO_2/mile direct emissions or 370 g/mi WTW. (From WtW, 30 mpg, 11,100 g/gal GHG) and 0.037 g NO_x/mile (MY2010 vehicle over 150,000 miles EMFAC 2002)
2. For Electricity, the gas plant was assumed to have a heat rate of 8500 BTU/kWh (~40.1% efficiency) and a NO_x emissions rate of 0.027 kg NO_x/MWh (Both consistent with mid-90's Combined Cycle). Direct CO2 emissions are 460 kg CO2/MWh or 530 kg CO2/MWh on a "well to plug" basis.

Significant here is the fact that the transportation offsets are better for reducing NO_x and petroleum dependency, though not necessarily for GhG's. The GhG difference will likely close as older gas plants are retired, moving the gas heat rate towards 6000-7000 BTU/kWh and electrolysis efficiency improves towards the 50 kWh/kg range. The other categories offer some significant insights. In looking at criteria pollutants, offsetting transportation, even clean 2010 vehicles, is a better option than offsetting power-plants. In terms of offsetting fossil fuels, petroleum is clearly of greater significance given our near total dependence on it for transportation. Petroleum provides 94-96% of our transportation energy needs in California, while natural gas provides only 40-50% of our electricity needs.

If we examine the quantities of renewables that are consumed in each market, it becomes apparent that a significant disparity exists in both the fuel diversity and the overall size of each market in terms of energy. On an energy basis, the amount of gasoline consumed for transportation in California is 120% more than the amount of natural gas consumed for electrical generation, as shown in Figure 2.1. Further, natural gas consumed for electrical generation makes up just over a third of the total natural gas consumption in California, as shown in Figure 2.2. So in the short run, attempts to reduce the portion of natural gas used for electricity consumption through the use of renewables would have a relatively small impact on the overall total.

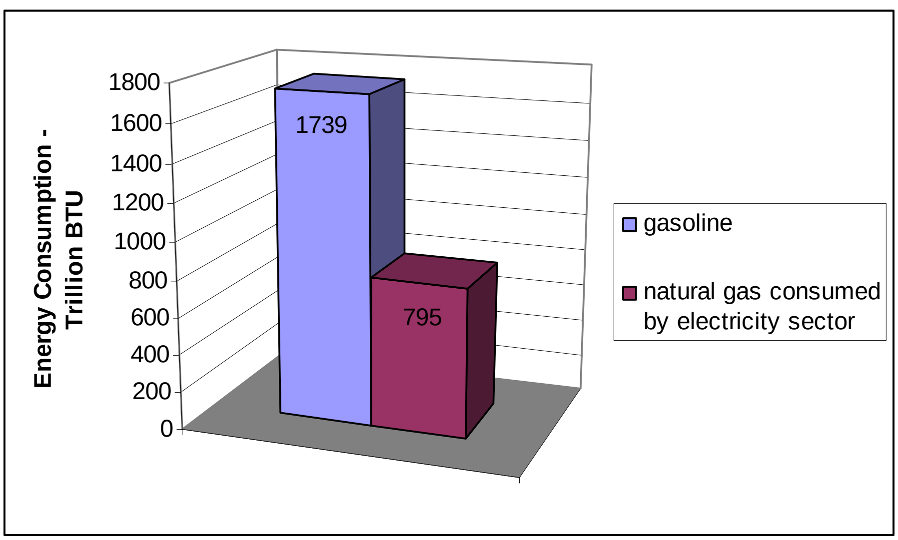

FIGURE 2.1: Gasoline and Natural Gas Consumption in California in 2002
(Source: EIA and CEC)

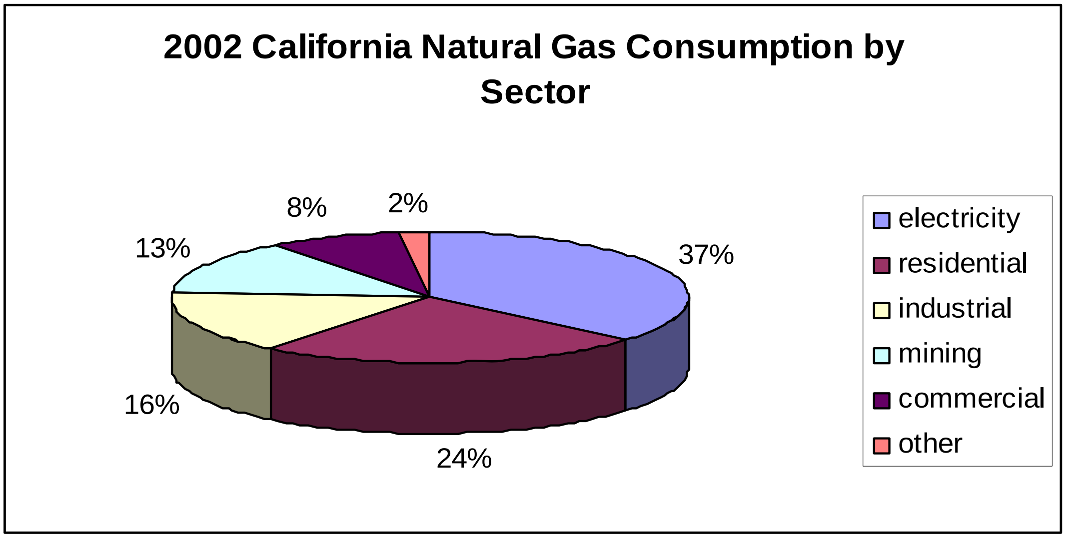

Figure 2.2: Breakdown of Natural Gas Consumption in California **(Source: CEC)**

When considering whether renewables would have a larger impact on the electricity or transportation market, it is useful to examine the diversity of fuel supplies in each of these markets. In the transportation market, gasoline makes up 94% of the fuel used for passenger vehicles in California[8]. On the other hand, in the electricity market, natural gas generation made up roughly 50% of the in-state electricity in 2000(eGrid 2002)

Considering the significant improvements being made in both the hydrogen production areas and the natural gas generation areas, it appears that the maximum societal benefit could be achieved by encouraging the use of renewables in the transportation market as a first priority and the electricity market second. While this may not be true for other states, the fact that California's grid mix is as clean as it is, and that natural gas is its marginal resource, point towards gasoline and the transportation market as the primary area for cleanup of emissions.

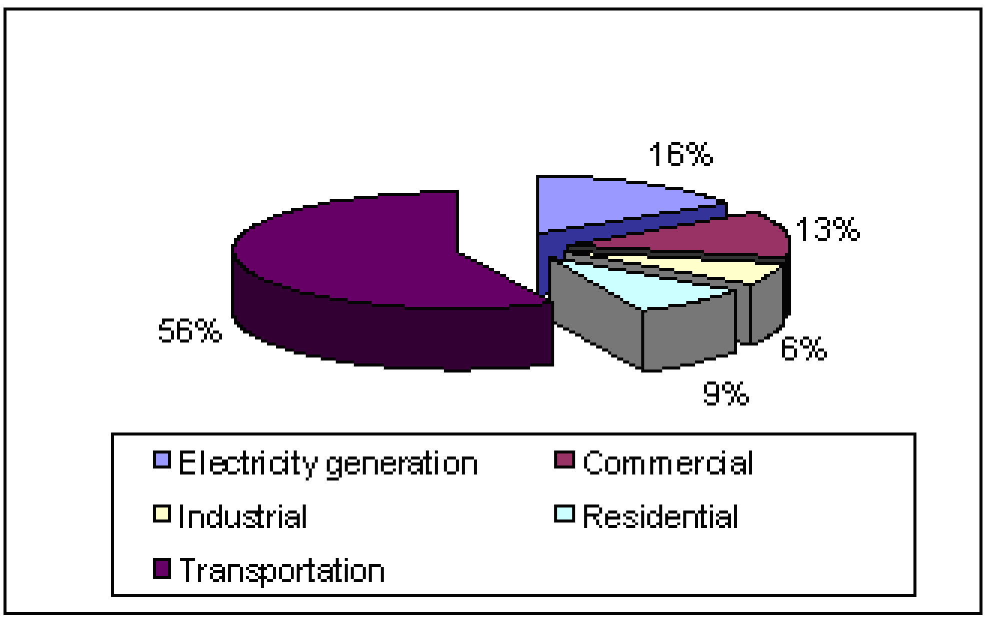

Figure 2.3: CO2 Emissions in California by Sector (1999) **(Source CEC)**

Figure 2.3 shows the transportation sector being responsible for more than 50% of the CO_2 emissions in California. This suggests the use of renewable energy sources might best be targeted at this sector in order to minimize our state's greenhouse gas emissions. In addition to CO_2, mobile sources account for as much as 70% of Ozone precursor emissions in the Sacramento Metropolitan AQMD[9]. The use of renewable hydrogen to offset CO_2 and NO_x emissions in the transportation market would have the maximum benefit for those renewable resources.

R.2.2 Existing grid constraints and impacts on peak demand vs. hydrogen availability

One of the challenges of simply connecting electrolyzers to the electricity grid for the production of hydrogen is the question of existing grid generation and transmission capacity. The electricity grid in California has experienced several Stage 1 alerts in recent years in which we have come within 7% of our upper limits for grid demand. The addition of significant amounts of electrolysis onto the grid must be done with full consideration of its impacts on grid reliability to ensure that its presence adds to grid stability rather than worsening our current situation.

Renewables can add stability to the grid, however they can also cause difficulty for schedulers because of their intermittency. For example, a wind resource that was scheduled to deliver power could fail to do so during a peak demand time. For this reason, wind is often looked at as an undesirable addition to the grid from the perspective of a power scheduler. On the other hand, load following of a wind resource with an electrolyzer may not necessarily be much easier. Depending on the size and design of the electrolyzer, ramp up and ramp down rates may prevent the electrolyzer from load following in an optimal manner.

One way in which renewable hydrogen can add benefit to the grid reliability is to utilize the energy storage characteristic of hydrogen. For instance, electrolyzers could plan to shut down during the grid peak demand or to utilize "spill" power in the late night hours to make hydrogen for the following day's business. By designing this capability into the stations, the renewable power plants that are dedicated to supplying power to these electrolysis units effectively become peaking units when the electrolysis load shuts off on a hot summer afternoon, but probide stabilizing load during the off-peak hours. In this manner, the grid scheduler is no longer forced to accept power when they don't want it, but have load on the system when nature makes power available.

R.2.3 Summary

Renewable electricity sources that are dedicated to the production of hydrogen can bring significant societal benefits to California. This can be done in addition to using renewables to supply electricity demand in California. There are potentially more than enough regional renewable sources to provide California's entire electricity and transportation markets for the foreseeable future. While the question is frequently asked as to whether renewables are better used to offset electricity emissions in California, the question should be how can we most fully utilize our renewable resources to offset as much of our energy needs as possible. Renewables used to produce hydrogen for fuel cell vehicles offer a huge benefit in terms of NO_x emissions. They can also offer the most significant CO_2 emissions reductions for California's largest source of Greenhouse Gases, transportation. Finally, by using renewable electrolysis in cooperation with the grid schedulers, renewables can be used to stabilize the electricity grid by providing a renewable peak power source.

R.3 Renewable Technology and Energy Inputs

This section compares the different renewable resources, the state of the technology, and likely future public benefits to choosing one or another. The differences in emissions of the various renewable technologies are also examined in order to understand whether or not they can be considered equivalent or whether they must be considered separately. Life cycle energy use, or manufacturing energy necessary for manufacturing will also be examined.

R.3.1. Attributes of Renewable Sources

The Renewable Portfolio Standard and the Western Renewable Energy Generation Information System both currently consider energy sources that meet the definition of “renewable” to be equivalent to one another. Qualifying renewable energy sources include:

- Biomass
- Biodiesel
- Fuel cells using renewable fuels
- Digester gas
- Geothermal
- Landfill gas
- Qualifying Municipal solid waste
- Ocean wave, ocean thermal, and tidal current
- Photovoltaic
- Small hydroelectric (30 megawatts or less)
- Solar thermal
- Wind

Looking at the list, there are several areas that renewable energy sources differ from one another. These include criteria pollutants, greenhouse gas offsets, intermittency and capacity factor issues, and life cycle energy use for the renewable technologies themselves.

In terms of criteria pollutants, biomass sources including landfill gas, MSW, and agricultural residues all produce NO_x emissions. Several of these biomass sources also result in some non-biogenic CO_2 emissions as a result of fossil content and fuel transportation. Figure 3.1 gives a comparison of several of the technologies in terms of the CO_2 emissions associated with their manufacture and operations. The emissions from the transportation of the biomass materials is not quantified however, as it varies widely depending on the resource. Figure 3.2 below it shows the NO_x emissions associated with the manufacture and operations of each of the technologies. From the plots, it is clear that the best renewable electricity sources to use for hydrogen production would be geothermal, wind and solar, while biomass and biogas options would be better suited for direct conversion to hydrogen through gasification and steam methane reforming in order to minimize emissions.

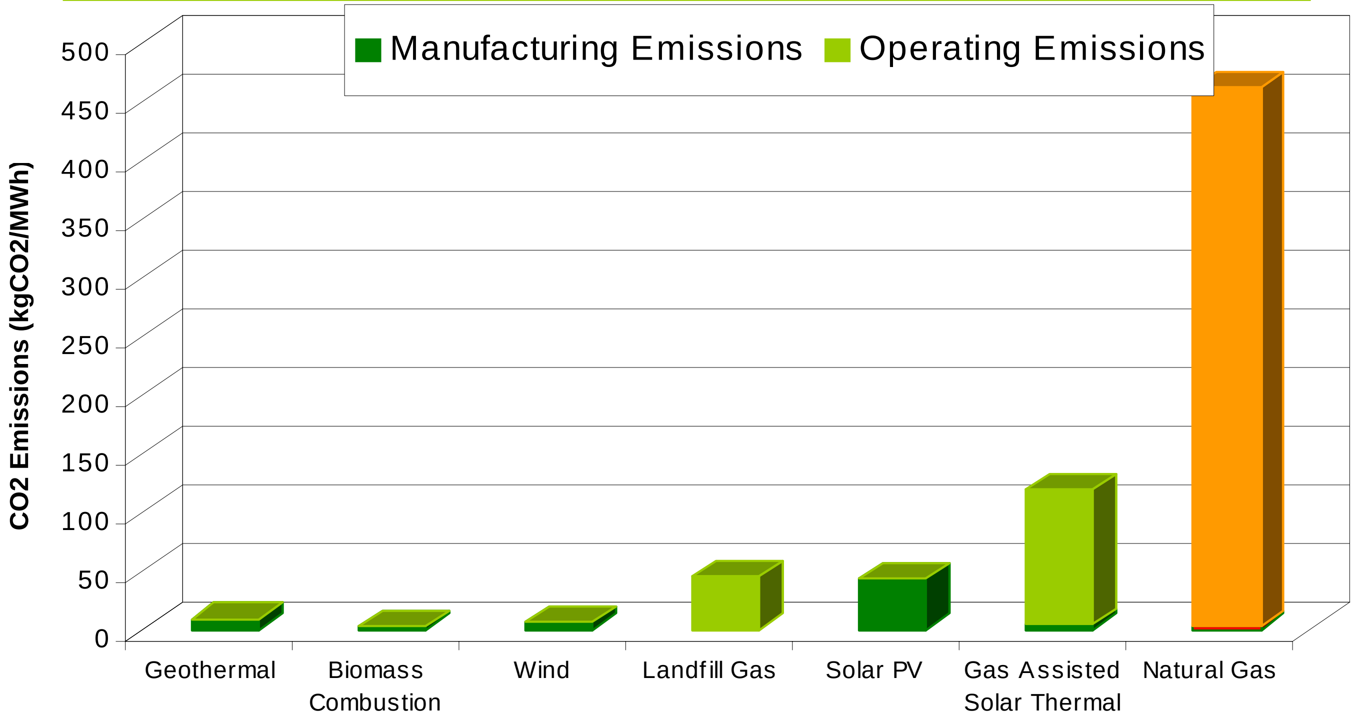

Figure 3.1: Manufacturing and Operating CO_2 Emissions for Various Renewable Energy Sources, Compared to Natural Gas Based Electricity (Sources: European Commission's ATLAS Program, ARB 2007 DG Standards, SEGS 2000 Operating Data)

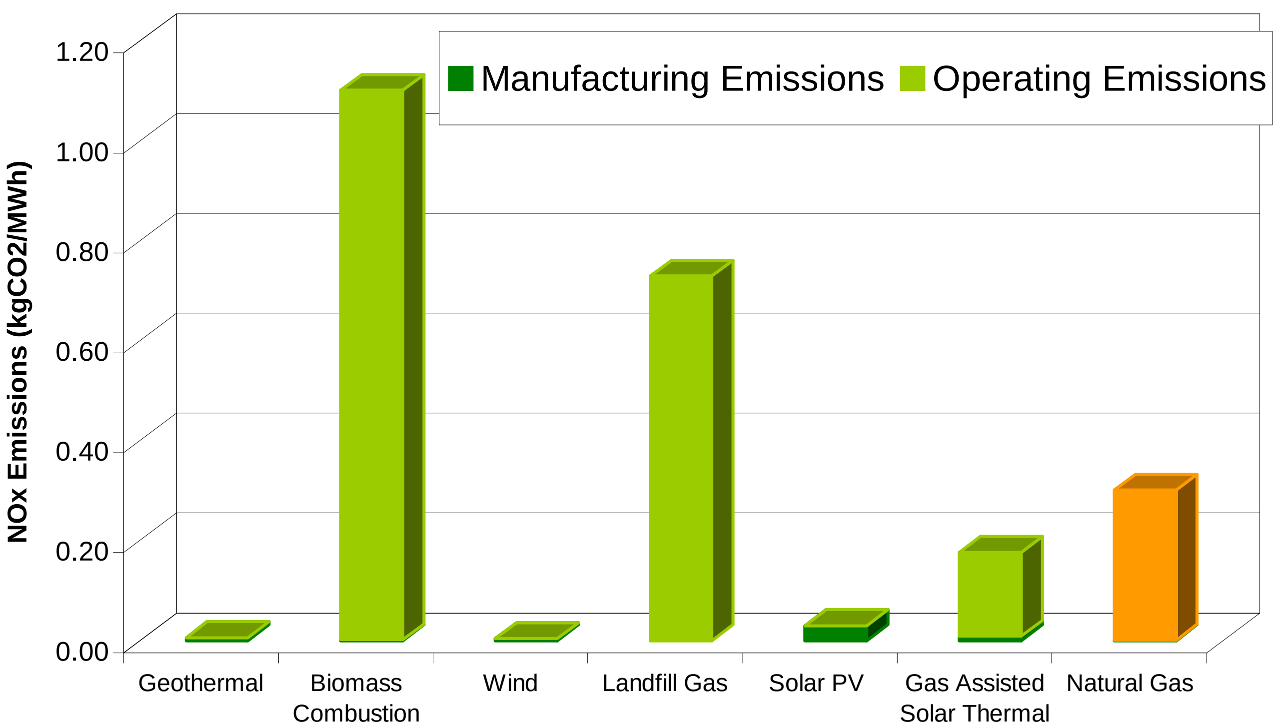

Figure 3.2: Manufacturing and Operating CO_2 Emissions for Various Renewable Energy Sources, Compared to Natural Gas Based Electricity (Source: E.C.'s ATLAS Program)

While it is possible to compare these technologies as they exist today, the truth is that many of them are emerging technologies and their emissions values and energy intensiveness will likely improve in the future. Because of this, it is difficult to look very far into the future to compare each of these technologies to one-another, as the differences will likely be even smaller. However, at the same time, it is important to realize that these "renewable" resources do not all have the same characteristics, and by using some of them to produce hydrogen, we may very well be creating a fuel which actually increases NO_x emissions, depending on the feedstock and way that it was made. It is important to identify these emissions, and ensure that they are minimized and that the hydrogen is produced from the cleanest possible feedstocks.

R.3.2. Intermittency and Capacity Factor Issues with Renewable Sources

Another issue that frequently separates renewable energy technologies is their intermittency and annual capacity factor. The capacity factor of a resource refers to the percentage of the year that a resource is operating at its rated capacity. The intermittency of a resource is more of a measure of the predictability of a resource for scheduling generation. Typically, solar facilities, unless coupled with storage or with a natural gas assist, have the lowest capacity factors, while wind resources have the highest intermittency.

Intermittency and capacity factor typically impact the cost of integrating these resources onto the grid, but can also play a large role in the availability of hydrogen, if production is tied to the output of a facility. In particular, swings between seasonal capacity factors could result in hydrogen shortages in the winter months if the output is tied to solar or to certain wind resources. This would limit the size of a hydrogen production facility to the average output for the smallest month, or week, or even 2-3 days, depending on the storage available. In the case of Solano Wind, this would result in a hydrogen production facility being sized for 5% of rated wind capacity or less, as opposed to the annual wind capacity factor of approximately 30%. These sizing issues would need to be considered in any situation where the hydrogen production is tied directly to the output of a single renewable resource. Attempts to assess both Capacity Factor and Intermittency have lead to the concept of the Relative Capacity Credit that is being developed at the CEC. Table 3.2. Shows the average capacity credit assigned to various resources as part of California's RPS integration costs analysis[11].

TABLE 3.3: Relative Capacity Credit of Various Renewable Technologies and Natural Gas

Resource:	**Medium Gas**	**Biomass**	**Geothermal**	**Solar Thermal w/ gas assist**	**Wind (Altamont)**	**Wind (Tehachapi)**	**Wind (San Georgino)**
Relative Capacity Credit	100%	97.8%	88%	56.6%	26%	23.9%	22%

Source: California RPS Cost Analysis Phase 1: One Year Analysis of Existing Resources
* Note that the Solar resource in this case is from the SEGS plants, which utilize a natural gas assist for as much as 25% of the overall energy.

While these numbers look very difficult for the wind resources from either the perspective of producing hydrogen or electricity, the integration of the electrolysis control with the grid scheduler might allow increased installation of wind turbines in California. This integration would allow the scheduler to control the load of the electrolyzers based on the output from the wind resource and the grid demand.

R.3.3 Summary

While there are many different types of renewable electricity that can be used to produce hydrogen, some types are far better than others in terms of the environmental benefits to Californians. In particular, development of new wind, geothermal and solar resources for the production of electricity and hydrogen should be encouraged. Combustion of biomass and landfill gas should be encouraged to shift to cleaner technologies to minimize NO_x emissions for electricity production. For hydrogen production though, biomass and landfill gas resources are better used through a direct gasification and steam methane reforming process to minimize emissions and maximize efficiency. While manufacturing and operating emissions were considered here, other factors such as emissions offset from avoided forest-fires or ag-residue burning or methane escape should be considered and applied when considering the benefits of biomass resources.

In terms of intermittency, solar and wind are the most difficult to deal with from the perspective of hydrogen production while wind is the most difficult to deal with from the perspective of electricity production. By allowing the option of hydrogen production integrated with grid scheduler control, intermittency could be sufficiently mitigated to allow an increase in the amount of renewable allowed on the grid.

R.4 Auxiliary Benefits of Renewable Energy Technologies

Finally, we examine the benefits to the existing electricity grid that various renewable resources could provide, as well as the possible benefits they might provide if coupled with hydrogen production. These benefits may be difficult to quantify, particularly when we are looking at reliability, however it is important to identify which resources have added value and which should just be taken at face value.

R.4.1 Wind Auxiliary Benefits

While it is clear that the intermittency effects of wind resources are not desirable for a utility grid operator, it should be noted that for the most part, both the wind and solar resources are desirable from a seasonal availability perspective. Both of these resources peak in the summer, which coincides with the peak electricity demand in California. Looking at both resources on a diurnal basis, depending on the wind resource, the output of a wind resource may peak as late as midnight, while solar output peaks in the middle of the day. As a result, the solar resource is more desirable in order to meet peak demand, while wind must be accommodated as demand for power is dropping. This coincidence with peak electricity demand is an auxiliary benefit of the solar resource, and points towards using this resource primarily to meet electricity demand rather than using it for hydrogen production. Wind resources that peak at midnight however, have very little auxiliary benefit to a grid operator, and might be better suited for off-peak hydrogen production.

R.4.2 Biomass Auxiliary Benefits

Biomass resources provide an added benefit of being the most dispatchable of any of the resources. Depending on fuel availability, biomass facilities can be operated at near a 100% capacity factor[12], or may be operated solely to meet peak demand for electricity. This allows a built in diurnal and seasonal storage capability that none of the other resources have, and enhances biomass benefits both for producing electricity and for producing hydrogen. This is dependent however, on having a variety of feedstocks available for the biomass generation facility, or on having a consistent feedstock that does not vary in seasonal availability.

Biomass resources also provide auxiliary benefits in terms of enhanced utilization of the waste product that they typically are generated from. In the cases of dairy waste and landfill gas, eliminating methane emissions by combustion or conversion to hydrogen greatly reduces GhG emissions. When looking at forest trimmings, utilization for electricity and hydrogen production provide an enhanced revenue stream as part of otherwise required forest fire prevention activities.

R.4.3 Geothermal Auxiliary Benefits

Geothermal resources provide a level of consistency that is typical of a base-loaded electricity generation facility, which is also desirable both for grid electricity and hydrogen production. The use of geothermal energy of course would be limited to new installations, or re-powering of old installations.

R.4.4 Solar PV Auxiliary Benefits

Solar photovoltaics (PV) provides added value in several ways. Primarily, PV can be deployed in a distributed fashion on the grid, providing clean generation sources where they are needed. This can be of benefit to both electricity and hydrogen production, as no transmission of the energy is required for either case, eliminating problems of grid congestion and fuel transportation. In addition, PV can offset the embodied energy and cooling demands of the structures it is attached to through the use of insulated, or enhanced roofing building integrated PV (BIPV). Another use of PV that has added benefit is integration into shade structures for covered parking. This can reduce the heat buildup of the cars that park under the structures, which can in turn reduce the startup emissions resulting from intensive air conditioning use as the vehicles leave the parking facility. These factors provide some offset to the energy requirements for producing the PV modules, which as shown in Section 3, are not trivial. These are also factors that may not show up in the technical analysis of using PV to create hydrogen from a public benefit perspective, however they should be considered as potential attributes of PV systems.

R.5 Conclusions

There are many differences between renewable resources that should be taken into account when planning to use them for hydrogen generation. Some important things to note include:

- The use of Green Tags as opposed to Renewable Power Purchase Contracts can actually increase emissions and natural gas dependence in California if the Renewable Energy does not get imported into California with the Green Tags,
- The differences in intermittency and capacity factor of renewable resources can affect daily and seasonal availability of fuel,
- There can be significant differences in operating and manufacturing emissions associated with various renewable energy sources, specifically NO_x emissions associated with biomass and waste resources, as well as CO_2 emissions associated with natural gas co-firing of solar thermal facilities,
- Renewables should be used to offset both electricity and transportation, but we should recognize that transportation in California faces big problems given its complete dependency on petroleum, and also is a cause of many of our environmental problems considering it accounts for a majority of both CO_2 and NO_x emissions in California,
- While analysis of quantitative differences may point to the use of certain renewables for the production of hydrogen, the inclusion of auxiliary benefits could lead to a much wider scope of renewable hydrogen production options.

All of these areas deserve attention in developing a robust plan for utilizing renewable resources to meet California’s hydrogen demand.

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