Renewable Natural Gas – Challenges & Opportunities

Center for Renewable Natural Gas
University of California Riverside
Contact: Arun Raju, arun@engr.ucr.edu
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Background

Renewable Natural Gas (RNG) is pipeline quality gas that is fully interchangeable with fossil natural gas but is produced from a renewable feedstock and can be used as a 100% substitute for, or blended with, conventional natural gas streams [1]. RNG is an important alternative fuel that can help the State of California meet several GHG and renewable energy targets. As a transportation fuel, RNG can result in approximately 90% reduction in GHG emissions [2, 3].

Despite considerable potential, current RNG contribution on national and state levels are very small. This document provides an overview of the potential, benefits, and barriers to RNG production in significant quantities. A concerted effort by all the stakeholders is needed to realize the potential of RNG. The University of California, Riverside (UCR) proposes to establish a research center dedicated to the development of technologies that will enable RNG production in substantial quantities in California and elsewhere. The new center, referred to as the Center for Renewable Natural Gas will leverage on-going research and collaborations at the Bourns College of Engineering – Center for Environmental Research & Technology (CE-CERT) to maximize the impact. As part of the effort, UCR will develop a *RNG testbed* in order to demonstrate key RNG related technologies so as to expedite commercial implementation.

RNG Potential

RNG potential is typically estimated in terms of the feedstock streams available or can be potentially produced. The potential biomass resources available for RNG production in the US has been estimated at 1,539 million dry tons/year [1]. The practical resource potential is estimated at 475 million dry tons/year. Using specific yield assumptions for different processes, the practical RNG potential for the US is estimated to be 4.8 TCF/year or 40 billion gge/year [1]. A 2015 report by the California Biomass Collaborative estimates the technical biogas potential in California from animal manure, landfill gas, MSW, and waste water treatment plants to be 93 billion cubic feet. The total RNG potential in California has been reported to be approximately 284 billion cubic feet/year or 2,187 gge/year. This is equivalent to 12 percent of the State's total annual NG consumption.

Existing studies evaluate the total estimated organic feedstock availability and calculate the practical potential using assumptions. While this is sufficient to understand the broad potential, *it is critical to identify potential high viability projects across the State*. This involves identifying concentrated resources, resource ownership and price information, logistic challenges, infrastructure availability (ex., access to pipelines), technology selection, commercial viability, and permitting barriers.

Power to Gas Potential

Power to Gas (P2G) is an innovative approach that can produce RNG while also addressing shortcomings related to renewable electricity production and storage. Converting excess renewable electricity into a gaseous fuel such as hydrogen or methane is very attractive since it offers a means to increase the renewable energy content of the pipeline infrastructure while addressing the well-known grid capacity and curtailment problems associated with electricity transportation. Since methane, and to some extent hydrogen, can be reliably stored for long periods using the *existing infrastructure*, Power to Gas can significantly 'decarbonize', i.e., reduce the GHG footprint of the natural gas supply while enabling increased *renewable energy use in all major sectors* including commercial, residential, and transportation.

Although water electrolysis was commercialized decades ago, it only accounts for approximately 4% of world hydrogen production [4]. This is primarily due to the higher cost of production through electrolysis and the fact that hydrogen consumption is dominated by large scale industrial processes that require centralized production in high volumes, something electrolysis is not capable of. Transportation costs and infrastructure availability/compatibility issues also pose a major challenge to projects where the hydrogen is not intended for 'captive use'. However, electrolysis using renewable electricity offers an important pathway towards carbon free energy production and usage.

The renewable hydrogen produced through electrolysis or other means can be converted into methane using the methanation reaction, provided that CO or CO_2 is available. Methanation will be a requirement for projects that generate large quantities of hydrogen since there are limits to the quantity of hydrogen that can be directly injected into the pipeline.

U.S. hydrogen production from *existing* nuclear and hydro power plants as of 2006 has been estimated to be 1.2 and 3.9 million tonnes/year respectively [5]. The assumptions include a relationship formula of 58.8 kWh per kg of hydrogen and only assumes 30% of the electricity (year 2006) is used for hydrogen production [5]. Geothermal energy sources, such as the Salton Sea, are an excellent choice for hydrogen production through electrolysis and the potential is yet to be evaluated.

A comprehensive evaluation of existing U.S. hydrogen potential from solar and wind power plants is not available in the literature. An NREL technical report has evaluated the U.S. hydrogen potential from available land and wind resources while accommodating for land-use, environmental and other exclusions. The study estimates that the U.S. can potentially generate 717 and 273 million metric tonnes/year of hydrogen from solar and wind resources respectively [6-8]. The estimated potential for California are 30 and 2.3 million metric tonnes/year of hydrogen from solar and wind resources respectively [6]. However, this estimate does not include the many practical challenges associated and can only be used to identify regions with high potential. *<u>There is a clear need to evaluate existing, practical renewable hydrogen potential via electrolysis in California and the U.S. as a whole</u>*. Factors that must be accounted for besides the production cost include excess electricity availability, water resources, and substations, pipelines and other infrastructure availability.

Benefits

The benefits of replacing fossil fuels with RNG are broad and multifaceted. A key advantage of RNG compared to other renewable fuels is its potential to make significant contributions in the transportation sector. *<u>RNG has the unique advantage of a mature, and extensive storage and</u>*

distribution infrastructure and the availability of NG vehicle technologies. By comparison, building up a hydrogen infrastructure in the U.S. is expected to take decades and cost $70 billion [9]. Fungible liquids fuels (ex. Fischer-Tropsch diesel) from biomass are the only renewable alternative with a better infrastructure/vehicle technology compatibility than RNG but the technological maturity and commercial viability of these fuels are poor.

The following sections provide an overview of some of the benefits listed below.

- Renewable fuels production
- GHG emissions reduction
- Reduce landfilling of waste
- Reduce wildfire risks
- Reduce criteria pollutant emissions
- Improve short-lived climate pollutant impacts
- Increased energy storage capacity and supply reliability

GHG Emissions Reduction

RNG pathways, in general, have very low carbon intensities and under California's Low Carbon Fuel Standards, biomethane is the transportation fuel with the lowest carbon intensity[1]. RNG use in the transportation sector can result in significant net GHG emission reductions. This includes heavy duty, long haul trucks as well. The Table below provides the Carbon Intensity values for fossil and alternative transportation fuels.

Table 1 Carbon Intensity of Transportation Fuels
(grams CO_2e per megajoule energy)[2]

Transportation Fuel	Carbon Intensity
Gasoline	98.47
Diesel	102.01
Biodiesel from Midwest soy beans	19.11 to 54.05
Corn ethanol	77.52
Natural Gas	78.36
Sugarcane ethanol	40.47 to 51.33
Hydrogen Fuel Cell Vehicles	35.33 to 60.40
Electric vehicles	30.95
Renewable Diesel	17.29 to 49.88
Landfill gas	**18.11**
Wastewater biogas	**7.75**
Biogas from food and green waste	**- 22.93**
Dairy Biogas (*Prospective*)	**-276.24**

[1] http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf

[2] Sources: California Low Carbon Fuel Standard: 17 CCR 95488 - Table 6; California Air Resources Board, "LCFS Illustrative Fuel Pathway Carbon Intensity - Determined using CA-GREET 2.0", presented September 17, 2015

Currently, California accounts for less than 1% of U.S. natural gas production and imports more than 90% of its natural gas, supplied by interstate pipelines from Arizona, Nevada, and Oregon. The Bioenergy Association of California estimates that replacing 10% of California's natural gas with RNG would result in annual GHG emissions reduction of 12.6 metric tons or more [10].

Criteria Pollutant Emissions

Natural gas, due to its simpler structure, is a cleaner burning fuel compared to gasoline and diesel and has the potential to reduce NO_x and Particulate Matter (PM). While GHG emissions have received increased attention over the past two decades due to climate change, criteria pollutant emissions are still the cause of most immediate and serious health hazards and environmental damage related to combustion. The South Coast Air Quality Management District (SCAQMD) will significantly rely on a NO_x heavy reduction strategy in order to achieve the 2023 and 2031 federal ozone standard deadlines in the South Coast Air basin[3]. Reducing NO_x emissions also lead to reductions in PM2.5 levels.

Mobile sources are responsible for 88% of NO_x emissions in the Basin with gasoline and diesel resulting in the highest NO_x emissions. According to the SCAQMD, "The most significant air quality challenge in the Basin is to reduce oxides of Nitrogen (NOx) emissions sufficiently to meet the upcoming ozone standard deadlines. Based on preliminary analyses, the current 580 tons per day (TPD) of total Basin NOx emissions are expected to drop to 300 TPD and 250 TPD by 2023 and 2031 respectively, due to continued implementation of already adopted control measures"[4]. However, the AQMD estimates that the total Basin NO_x emissions must be reduced to approximately 150 TPD by 2023 and 100 TPD by 2031 in order to attain the federal ozone standards. This represents a significant challenge and will require deployment of new vehicles that can meet the stringent emissions standards but also commercialization and deployment of technologies and resources that can make a significant positive contribution.

An important scenario in reducing NO_x emissions is to deploy heavy-duty trucks that can reduce NO_x emissions to 0.02 g/bhp-hr, a 90% reduction from the 2010 NO_x exhaust emissions standard. *Natural gas engines can play a key role in the AQMD's transportation based emissions reduction strategy* - Cummins Westport midrange natural gas engines were certified last year to meet these standards. Increased NG use in transportation will help the Basin attain criteria pollutant standards that are most challenging. RNG, unlike fossil NG, not only contributes to criteria pollutant emissions reduction but also GHG emission and fossil fuel use reduction and will lead to benefits in multiple fronts.

Short-Lived Climate Pollutants

Short-Lived Climate Pollutants (SLCPs) such as methane, fluorinated gases, black carbon and tropospheric ozone have relatively shorter atmospheric lifetimes but play an outsized role in their warming impacts, estimated to be responsible for approximately 40% or more of warming to date. Rate of net CO_2 emissions reduction across the world are significantly slower than the rates needed to avoid an average 2 °C warming. SLCP emission reduction has evolved as a key

[3] http://www.aqmd.gov/home/about/groups-committees/aqmp-advisory-group/2016-aqmp-white-papers/EnergyOutlook

[4] http://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2016-air-quality-management-plan/factsheet-2016-aqmp.pdf?sfvrsn=4

strategy that can potentially reduce global average climate warming by approximately 0.6 °C by 2050. Short atmospheric lifetimes of SLCPs enable SLCP concentration reductions in the atmosphere that are equivalent to corresponding SLCP emission reductions, resulting in immediate climate warming and health related impacts.

California must achieve deep SLCP emissions reduction by 2030 in order to meet the State's GHG emission and air quality targets [11]. An important part the SLCP reduction strategy proposed by the California Air Resources Board is to utilize organic wastes to produce energy. RNG production is an excellent way to convert a significant portion of the State's organic waste streams, especially if thermochemical processes are applied in large scales. Methane emission reduction from diverse sources is another important approach that can benefit from increased RNG production and use [11].

Energy Storage

Unlike fossil fuels, most renewable energy sources perform poorly in providing a continued, 'baseline' output and increased renewable energy generation targets create an unavoidable need for efficient, reliable energy storage methods. The Power To Gas pathway can help address many of these challenges while increasing the renewable energy utilization levels. Converting excess renewable electricity into hydrogen or methane essentially allows this energy to be stored safely and efficiently with little loss over long periods.

Storage is an important aspect of California's heavily import-dependent natural gas market as it enables supply reliability and load balancing. According to the CEC, California had 13 underground natural gas storage facilities with a total working gas inventory of 349.3 billion cubic feet as of 2011, and storage expansions are planned[5]. Approximately half of California's total storage capacity is owned and operated by investor owned utilities (IOUs) and the rest is owned by independent providers that connect into the Pacific Gas and Electric Company gas system. With such broad storage capabilities, Power To Gas can play an important role in helping the State achieve many of its renewable energy and GHG reduction targets.

Waste Reduction

Converting carbonaceous wastes into high value fuels results in diverse economic, environmental and land use benefits. These wastes are often landfilled or incinerated in undesirable ways, often resulting negative environmental and financial consequences. Forest residues cause serious wildfire hazards and the ongoing drought in California has led to a tree mortality rates epidemic, prompting an executive order by the Governor to expedite the removal of dead and dying hazardous trees[6]. RNG production will address these dangers while creating a fuel with very low carbon intensities.

Technological Challenges

Current RNG production relies heavily on biological pathways such as anaerobic digestion that are well understood and are commercially mature but have serious limitations including limited feedstock acceptability, low conversion efficiency, and poor product quality. Two technology options that can enable RNG production in significant enough quantities to be meaningfully

[5] http://www.energy.ca.gov/2014publications/CEC-200-2014-001/CEC-200-2014-001-SF.pdf

[6] https://www.gov.ca.gov/news.php?id=19180

beneficial: thermochemical conversion and water electrolysis. Both technologies are available, with electrolysis being a commercially mature technology while thermochemical biomass conversion is still undergoing commercialization. However, important technology, logistic, and process economy issues must be addressed to expedite widespread commercial implementation. Carbonaceous renewable feedstocks such as biomass, biosolids, and waste matter can be directly converted into Renewable Natural Gas (RNG) or hydrogen through thermochemical processes such as gasification and pyrolysis. Direct thermochemical conversion can enable the use of significant quantities of sustainable carbonaceous resources including waste streams such as Municipal Solid Waste (MSW), agricultural residue, etc. and energy crops. Gasification is the best-known pathway for direct RNG production, and a number of gasification technologies are currently available, although commercial success has not been achieved. Besides issues related to gasification technology itself, there are significant additional barriers such as feedstock availability, collection and transportation costs, feedstock pretreatment, tar formation, gas cleanup, and high capital costs.

Electrolyzers are essentially reverse fuel cells and split water into hydrogen and oxygen using DC electricity. The oxygen is typically vented while the hydrogen is captured and stored. The major components of an electrolyzer are an anode, cathode, and the electrolyte. Electrolyzers can be classified into two categories based on the electrolyte pH: acidic and basic. Alkaline electrolyzers have been developed much more rapidly due to the advantage of not requiring noble metal electrodes to prevent corrosion. Acid water electrolysis technology is feasible through the use of Solid Polymer Electrolytes (SPE) instead of liquid acids [12, 13]. A well-known example is the Nafion® membrane developed by DuPont. Proton Exchange Membrane (PEM) electrolyzers use a highly acidic polymer membrane as the electrolyte and are commercially available. Both types are operated under low to moderate temperature, primarily due to material limitations.

High temperature water electrolysis yields higher efficiencies and is a major area of research focus. High temperature water electrolysis is particularly attractive when a heat source is readily available such as in the case of geothermal resources or concentrated solar power. If commercialized, this technology can provide an option to build centralized, large scale renewable hydrogen production plants. High temperature electrolyzers also do not require precious metal catalysts and are typically not sensitive to feed water impurities. However, challenges related to material degradation, system cost, and design complexity must be addressed [4] [12-16].

Policy Barriers

Policy related issues pose some of the biggest challenges to RNG project developers, even in California, a pioneer state in climate benefitting regulations. Several policy measures have been adapted by the State that encourage renewable energy generation, including RNG. Examples are the LCFS program, Bioenergy Action Plan (2012), SB 1122, AB1900, EPIC program, and the ARFVTP program. However, the direct impact of these measures on RNG production have been extremely limited. This demonstrates a clear need for programs that directly address the technological and commercial issues discussed above while encouraging commercial ventures. The Bioenergy Association of California has proposed establishing a Renewable Gas Standard similar to the RPS [10].

Some of the key policy issues that must be resolved include:

- RNG is not approved in the Renewable Portfolio Standard (RPS)
- Current LCFS does not include several important RNG pathways
- RNG (or hydrogen production) through water electrolysis is not an approved option in the 1.3 GW by 2020 energy storage mandate
- Existing policy measures heavily favor non-transportation purposes such as power generation
- Pipeline injection of RNG is not targeted or encouraged

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