ANL/ESD-17/7

Cow Power: A Case Study of Renewable Compressed Natural Gas as a Transportation Fuel

Energy Systems Division

Covers photos
Left, Courtesy of Matthew Tomich. Right, Courtesy of Linda Gaines.

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GLOSSARY

Anaerobic Digestion A process employing heat and beneficial bacteria in an oxygen-free environment to break down organic materials and produce a methane-rich gas mixture (biogas), which can be purified to produce a renewable form of natural gas (RNG).

Feedstock The base material from which a fuel is produced. Feedstock for renewable natural gas typically includes animal manure, sludge from wastewater treatment plants, food or yard waste, and the organic fraction of municipal solid waste.

GREET The Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model (available at https://greet.es.anl.gov/) calculates energy use, greenhouse gas emissions, and air pollutant emissions associated with over 100 different vehicle and fuel pathways.

Renewable Fuel Standard (RFS/RFS2) The RFS/RFS2, required by the Energy Independence and Security Act of 2007, ensures that transportation fuel sold in the United States contains a certain volume of renewable fuel. RFS2 is an expansion of the initial RFS. It stipulates minimum volumes of specific types of renewable fuels that must be produced each year and combined with conventional motor fuels. Parties obligated to adhere to the RFS/RFS2—refiners, blenders, or importers—may produce those fuels or purchase the legal right to them. More information is available at https://www.epa.gov/renewable-fuel-standard-program/renewable-fuel-standard-rfs2-final-rule.

Renewable Identification Number (RIN) RINs are the "currency" of the RFS2 program; RIN credits are used to demonstrate compliance. A unique number is associated with each unit of fuel qualified under the RFS2 program. RINs can be sold to obligated parties to satisfy the requirement that the parties include a minimum renewable content in the fuel they produce, blend, or import. More information is available at https://www.epa.gov/renewable-fuel-standard-program/renewable-identification-numbers-rins-under-renewable-fuel-standard.

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NOTATION

AD	anaerobic digester/digestion
ARRA	American Recovery and Reinvestment Act
BOC	back of cab
Btu	British thermal unit
CARB	California Air Resources Board
CNG	Compressed Natural Gas
CO	carbon monoxide
CO_2e	carbon dioxide equivalent
d	day
DGE	diesel gallon equivalents
(U.S.) DOE	(United States) Department of Energy
(U.S.) EPA	(United States) Environmental Protection Agency
GDE	gallon of diesel equivalent
GGE	gallon of gasoline equivalent
GHG	greenhouse gas
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model
GVWR	gross vehicle weight rating
GWP	global warming potential
kW	kilowatt
lb	pound
MJ	megajoule
MW	megawatt
mmBtu	million Btu
Nm^3/h	normal cubic meters per hour
NOx	nitrous oxides
PETA	People for the Ethical Treatment of Animals
PM	particulate matter
psig	pounds per square inch gage
R-CNG	renewable compressed natural gas
RDF	renewable dairy fuels
RFS	Renewable Fuel Standard

RIN	Renewable Identification Number
RNG	renewable natural gas
SCADA	supervisory control and data acquisition
SCF	standard cubic feet
SOx	sulfur oxides
y	year

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1 BACKGROUND

This case study explores the production and use of **renewable compressed natural gas (R-CNG)**—derived from the anaerobic digestion (AD) of dairy manure—to fuel 42 heavy-duty milk tanker trucks operating in Indiana, Michigan, Tennessee, and Kentucky.

Similar to fossil compressed natural gas (CNG), waste-derived R-CNG enables fleets to save on fuel costs, operate more quietly, and significantly reduce greenhouse gas (GHG) emissions relative to gasoline or diesel.[1] By capturing biogas from decomposing manure and processing it into R-CNG fuel, the release of methane is eliminated, and when combined with petroleum displacement, the resulting reduction in lifecycle GHG emissions is 80% or more as compared to gasoline or diesel fuel use (Figure 1).

FIGURE 1 A truck in the Fair Oaks Dairy fleet, showing back-of-cab and saddle tanks. (Photo courtesy of ampCNG.)

This case study looks at a joint endeavor by ampCNG, a provider of natural gas refueling infrastructure, and Fair Oaks Farms, a large dairy cooperative with roughly 36,000 cows, to create a closed-loop dairy manure-to-vehicle fuel project in Fair Oaks, Indiana. Under an agreement between the two parties, ampCNG buys cleaned, upgraded biogas from Fair Oaks Farms' anaerobic digester (AD) and upgrading plant, and dispenses it as R-CNG from the fueling station it owns and operates at Fair Oaks (Figure 2); it also dispenses nonrenewable CNG at another station used by the Fair Oaks Dairy fleet in Sellersburg, Indiana. ampCNG also contracts for fleet management services on behalf of Fair Oaks and helps to monetize the environmental credits (known as RINs; discussed in Sections 2.3 and 4.4) associated with the production and use of R-CNG.

FIGURE 2 The ampCNG R-CNG refueling station at Fair Oaks. (Photo courtesy of ampCNG, http://www.ampcng.com/stations/.)

Sources for this case study include case studies generated by project participants; interviews with representatives of ampCNG and Fair Oaks Farms; and articles in the national, regional, and trade press.

1.1 ABOUT FAIR OAKS DAIRY

Fair Oaks Dairy, located in Fair Oaks, a community in northwest Indiana, about 75 miles southeast of Chicago, was established in 1999 by husband-and-wife dairy-farming team Mike and Sue McCloskey (see Figure 3).[2] The Dairy has grown into a co-op, Fair Oaks Farms, encompassing 30,000 acres[3] and 12 area family farms. With 36,000 cows, the co-op falls into the largest 1% of American dairy farms with more than 2,500 head.[4] The Fair Oaks Farms fleet of 42 CNG/RNG powered trucks delivers 53 loads of milk daily, totaling 90 million gallons per year, to Kroger dairy processing plants[5] in Indiana, Kentucky, and Tennessee.[6]

FIGURE 3 Location of Fair Oaks Farms

Part of the motivation behind the use of RNG at Fair Oaks Dairy is the sustainability goals of its founders. Mike McCloskey is a veterinarian by training who, after establishing a successful operation in New Mexico, moved to Indiana with ideas about changing the largely negative perception of large-scale agriculture at the time—which included opening the operation to the public in 2004—and "dreams" of a zero-carbon dairy.[7]

Fair Oaks' livestock are housed in barns specifically designed to keep cows from standing in their own waste, which also facilitates the collection of manure three times daily to feed the farm's two anaerobic digesters.[8] The farm has given up tail docking, a common practice of cutting off part of cows' tails, and after an approach from **PETA**, is also phasing out the common practice of de-horning.[9,10] Mike McCloskey has been quoted as saying that "when animals are happy and treated well, they respond by producing a greater amount of milk.[11,12]

The anaerobic digester that is the subject of this case study was installed in 2008. Another, smaller anaerobic digester has been operating at Fair Oaks Dairy since 2003. The original, smaller digester is a vertical plug-flow system that processes manure from about 3,000 cows daily, and uses the gas to drive two 350-kW generators. The electricity produced goes primarily to power the cattle barns, with excess being used at the visitors' center and/or sold back to the grid. Waste heat from the generators is recycled to heat the digester.[13,14,15]

1.2 ABOUT AMPCNG

ampCNG, and its precursor company AMP Americas, was Fair Oaks' primary partner in bringing the dairy-manure-to-vehicle-fuel project together.

AMP Americas (AMP) was formed in 2010 as a renewable energy company. AMP assessed a number of renewable technologies before focusing on dairy methane as one of the most accessible and highest impact strategies to pursue.

The company first became involved in the Fair Oaks AD project in response to declining renewable electricity prices. In 2011 AMP worked with the farm on the transition from renewable power to transportation fuel. AMP acted as the overall project manager, building and managing fueling stations and biogas upgrades, and helping to identify financing and incentives. AMP was Fair Oaks' primary financial partner in the manure-to-RNG project.[16]

In 2014, the company's name was changed to ampCNG to reflect its primary business of building, owning, and operating CNG stations. The company now has a network of 19 CNG fueling stations in the Midwest and South, with another in development. (In addition to building and owning-managing stations, ampCNG offers fleet-scale fueling contracts, provides fleet transition consulting, and sources R-CNG for fleets.[17])

According to Steve Josephs, ampCNG co-founder, when it became clear what the environmental potential was of "switching 18-wheelers from diesel, [source of] a very large percentage of U.S. greenhouse gas and NOx emissions," to natural gas—"we decided to focus on building more stations. We always intended to backfill with R-CNG, but the stations are much quicker projects."[18]

The Fair Oaks renewable natural gas project jumpstarted ampCNG's commitment to and investment in expanding natural gas refueling infrastructure throughout the Midwest and Southeast. Before Fair Oaks, the company's founders had limited experience in alternative fuels or heavy-duty trucking. But by working with Fair Oaks and Ruan to convert the 42-truck milk delivery fleet to run on natural gas, ampCNG recognized an investment opportunity that could yield positive financial returns in addition to significant environmental benefits. Due to the early success of the fleet conversion, ampCNG (then Amp Americas) has since developed and built 19 CNG refueling stations along major trucking routes. This build-out has deployed close to $50 million in capital invested, created hundreds of construction jobs, and facilitated the conversion of additional fleets—especially those serving large dairy co-ops—from diesel to CNG. In late 2015, the company even launched a division, ampRenew, to source and deliver RNG throughout its growing station network.

1.3 PROJECT TIMELINE AND ADDITIONAL PROJECT PARTICIPANTS

2006—Planning begins. With one digester already in place and providing electricity, Fair Oaks Dairy begins considering the installation of a larger one. The options to sell surplus electricity or upgraded gas to local utilities both prove to have negative returns. After consultation with its then-fleet manager, **AMP Americas**, Fair Oaks makes the decision to use the gas itself, as fuel for its fleet of dairy trucks.

2008—Second digester installed. Iowa-based GHD (later DVO), a leading provider of agricultural AD technology, builds a two-stage, mixed plug-flow digester—its signature technology—at Fair Oaks. The new digester, with a capacity to process manure from 10,500 cows, initially produces additional electricity for the dairy operation.

2010—Fair Oaks establishes Renewable Dairy Fuels LLC. The new entity runs the CNG/RNG fleet project.

2011—Contract with national supermarket chain Kroger. To justify the expense of converting the fleet, Fair Oaks needs a guaranteed market for its milk. In 2011, Kroger agrees to make Fair Oaks its exclusive Indiana supplier.[19,20]

2011—First fleet swap out. AMP Americas begins to switch the Fair Oaks diesel fleet to CNG. Delivery by Indianapolis-based Palmer Leasing of 42 Kenworth 440 tractors with 9-liter Cummins Westport CNG engines begins in August. The new fleet is managed by Ruan Transportation Management Systems, an Iowa-based transport and logistics company, under contract to AMP Americas.

2011—Fueling stations open. In the second half of the year, Clean Energy Fuels, a national developer of CNG/RNG fueling stations and infrastructure, opens two of its own CNG fueling stations; one in Fair Oaks and the other in Sellersburg, Indiana, 200 miles south, near the Kentucky border. Both stations initially pump fossil CNG; only the Fair Oaks station is slated for future dispensing of R-CNG.

2012—Gas upgrading system installed. UTS Residual Processing (later Anaergia), a Canadian engineering firm specializing in waste-to-resources and renewable energy, begins construction of a gas-upgrading plant. The plant uses technology from the United Kingdom (UK)-based Greenlane Biogas, and is connected to the Fair Oaks fueling station by a three-mile pipeline.

2013—Gas upgrading system goes online. A ribbon-cutting event for the new R-CNG fueling station at Fair Oaks is held on March 4, 2013.

2013—Fleet upgrade. The fleet of 9-liter CNG tractors delivered in 2011 reflected the engine technology available at the time; while the engines worked well, they were not ideal for the loads and distances involved. Starting in September 2013, Palmer Leasing provides Ruan with Kenworth T660 tractors equipped with new, more powerful 12-liter Cummins Westport CNG engines.

2 PROJECT DRIVERS AND MOTIVATION

The Fair Oaks RNG project was assisted in its development by a number of policy/regulatory drivers and incentives. These benefits and drivers are summarized below.

2.1 FINANCIAL BENEFITS

To ampCNG. The transition from diesel to natural gas milk delivery trucks, the development of the CNG fueling stations, and the connection of the Fair Oaks station to the Farms' abundant biogas have brought ampCNG a source of fixed-price and lower cost vehicle fuel (R-CNG). The on-site production and use of R-CNG and associated environmental credits proved financially attractive, which led ampCNG to invest as the largest equity partner in the project.

Converting the Fair Oaks Dairy fleet from diesel to natural gas also provided AMP Americas the opportunity to prove that natural gas could work for the long-haul trucking sector. The initial success at Fair Oaks led AMP Americas to re-invent itself as ampCNG, a company "leading the transition to compressed natural gas (CNG) as a transportation fuel in the commercial trucking industry."[21] Moreover, managing the Fair Oaks fleet has been a growth opportunity for Ruan, which hired 110 drivers (68 at Fair Oaks and 42 at Sellersburg) to keep the fleet running "virtually around the clock."[22]

To Fair Oaks Farms: Fair Oaks originally intended to use the new digester to generate electricity, and sell the considerable surplus back to the grid. However, the low rate the local utility would pay made the project a financial loser. Similarly, the option to scrub the gas and sell it to the grid proved unprofitable when natural gas prices started a long, largely fracking-driven, slide in the second half of 2008. That was when Fair Oaks, after consultations with AMP Americas, decided to convert its fleet from diesel to natural gas and use the RNG to fuel its 42 milk delivery trucks.[23,24]

The conversion to CNG displaces approximately **1.5 million gallons of diesel** annually,[25] which represents significant savings in fuel cost. (Depending on diesel vs. CNG pricing, it can be as high as $2/DGE).[26] Fair Oaks also **saves on purchased electricity**: in addition to the R-CNG generated to power the fleet, excess digester gas powers a 1-MW generator.[27,28,29]

The use of manure-derived R-CNG at the Fair Oaks station not only reduces the cost of refueling the fleet, it also generates additional revenue through the sale of environmental credits under the U.S. Environmental Protection Agency's (EPA) **Renewable Fuel Standard** (discussed in Sections 2.3 and 4.4).

Development of the RNG fleet, and the need for guaranteed milk sales, provided an impetus for successfully pursuing the Kroger agreement. This makes Fair Oaks the supermarket chain's exclusive milk supplier in Indiana, providing enough to supply 500-plus Kroger stores in eight states.[30]

2.2 HEALTH AND ENVIRONMENT, ENERGY SECURITY, AND CLIMATE BENEFITS

Overall, including the use of digesters and R-CNG, Fair Oaks has cut the GHG emissions associated with producing and delivering a gallon of its milk by about 43%, from 17.6 pounds to about 10 pounds, with plans to go further.[31] On the production side, the use of anaerobic digesters at Fair Oaks to generate renewable electricity supplements grid-supplied power from largely fossil fuel sources, thereby reducing the emissions and carbon footprint associated with the Farm's electricity needs. On the delivery side, the use of natural gas in vehicles eliminates the need for filters or other emission controls, and results in far fewer air pollutants linked to negative environmental and health impacts than do petroleum-based fuels—such as particulate matter (PM), nitrous oxides (NOx), sulfur oxides (SOx), and carbon monoxide (CO), while achieving a 10–15% reduction in GHG emissions compared to conventional gasoline or diesel.

The use of *renewable* natural gas greatly improves on that achievement. According to the Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model developed at Argonne National Laboratory (Argonne), on a lifecycle basis, the anaerobic digestion of dairy manure to create R-CNG—including production, use, and avoided emissions—is among the lowest-carbon transportation fuel options available today, achieving an 80% or more reduction compared to gasoline or diesel.[32] In fact, when R-CNG is used on-site to fuel natural gas vehicles—as at Fair Oaks—the entire process can be **net-carbon-negative.**

Nationwide, "manure management"—field spreading for fertilizer, storage in ponds, among others—is a major source of methane emissions: 61.2 million metric tons of carbon dioxide equivalent (CO_2e),[33] or 8.6% total U.S. annual anthropogenic methane emissions,[34] in 2014. (According to a European study, one U.S. short ton of dairy manure in a storage pit generates 75.9 lb CO_2e.[35]) Since methane is a potent greenhouse gas with 28–36 times the global warming potential of carbon dioxide (over a 100-year period),[36,37] the avoidance of these emissions, plus petroleum displacement (both diesel fuel and synthetic fertilizers) outweigh the direct CO_2 emissions generated by the production and use of R-CNG in vehicles, according to Argonne's GREET 2016 model (see Figure 4).

Both the CNG and the R-CNG used to power the Fair Oaks fleet are locally sourced, reducing dependence on imported fossil fuels and promoting energy security. Similarly, the use of digesters to generate electricity on the Farm eliminates the need for fossil fuel-derived power.

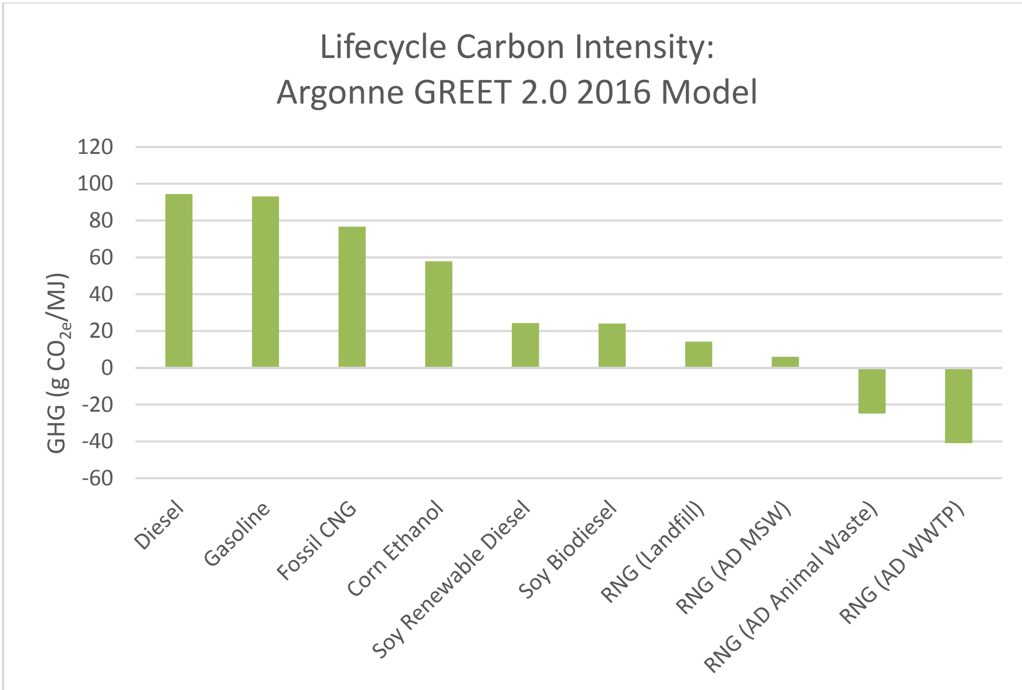

FIGURE 4 Lifecycle carbon intensity of various fuels (grams/CO_2e/MJ) based on GREET 2016 model. (MSW, municipal solid waste; WWTP, wastewater treatment plant.)

2.3 REGULATORY AND POLICY DRIVERS

The Fair Oaks cow power project benefited from several government policies that helped move it forward, both as financial incentives and as compliance requirements. Overall, regulatory and policy drivers related to the production and use of R-CNG for transportation tend to address the feedstock (organic waste), the fuel, and/or vehicle and refueling infrastructure components of a project.

Fuel and feedstock. The production and use of R-CNG as a transportation fuel generates additional revenue for Fair Oaks and ampCNG through the sale of environmental credits under the **U.S. EPA's Renewable Fuel Standard (RFS2)**. The RFS2, which sets a minimum volume for the amount of renewable fuel that must be used in the transportation sector overall, is the primary federal policy driver relevant to RNG production for use as a vehicle fuel. To incentivize the production of renewable transportation fuels, credits known as **Renewable Identification Numbers (RINs)** are generated for each unit of renewable fuel produced at an EPA registered facility. For consistency across a wide range of renewable fuels, one RIN is equal to the energy content of one gallon of ethanol, or approximately 77,000 Btus.[38,39] (See Section 4.4 "Monetizing Environmental Attributes" for additional details on the RFS2 and RINs.)

R-CNG, derived from a variety of organic waste sources—including landfills, dairy, hog and chicken manure, wastewater, and source-separated food and yard waste—is an approved renewable fuel under the RFS2 program. It qualifies as both renewable fuel type "D3" (cellulosic biofuel) and "D5" (advanced biofuel).[40] Since R-CNG qualifies as a cellulosic biofuel (D3), it is eligible for the highest-valued credit available under the RFS2.

Refueling infrastructure. For the Fair Oaks project, the **American Recovery and Reinvestment Act** (ARRA) of 2009, through Clean Cities of Greater Indiana, provided $750,000 toward the construction of the two CNG stations.

Vehicles. A $2 million grant from **Indiana's State Energy Program** covered the incremental cost of CNG storage tanks on the CNG trucks for extended range use, enabling them to deliver milk to distant processing facilities in Kentucky, Michigan, and Tennessee.[41]

3 PROJECT SPECIFIC ACTIVITIES

3.1 FEEDSTOCK

R-CNG is derived from the anaerobic decomposition of solid and liquid organic wastes, referred to as feedstock(s). At Fair Oaks, the feedstock is liquid manure. The barns at Fair Oaks are set up to help keep the cows clean and make manure easy to collect. Three times daily, "Honey Vac" suction-equipped tanker trucks[42,43] collect the liquid manure from the floors, and then delivers it to a receiving point adjacent to the digester, where sand, grit, and other contaminants are removed before the manure flows into the in-ground digester. The total volume of manure collected from the 10,500 cows is approximately 189,000 gallons, or 1.5 million pounds, daily.[44] While water and contaminants account for the bulk of this volume, "volatile solids," the organic material that is broken down to produce biogas, typically comprise 7–14% of the feed to the digester.[45]

3.2 TECHNOLOGIES AND INFRASTRUCTURE UTILIZED/DEPLOYED

3.2.1 Digester

The anaerobic digester at Fair Oaks Farms was designed and constructed by Iowa-based **DVO Inc. (formerly GHD)**, the largest provider of agricultural AD systems in the United States (see Figure 5 and Figure 6). DVO specializes in "two-stage, mixed plug-flow" technology, which, according to the company, combines the merits of mixed and plug-flow systems, continually mixing feedstock at controlled temperatures using a "first-in, first-out design that guarantees retention time to maximize waste digestion."[46] The systems are billed as easy to maintain, and designed for operation by the farmer/owner, rather than technicians.[47]

FIGURE 5 The Fair Oaks Dairy anaerobic digester. (Photo courtesy of Matthew Tomich, Energy Vision.)

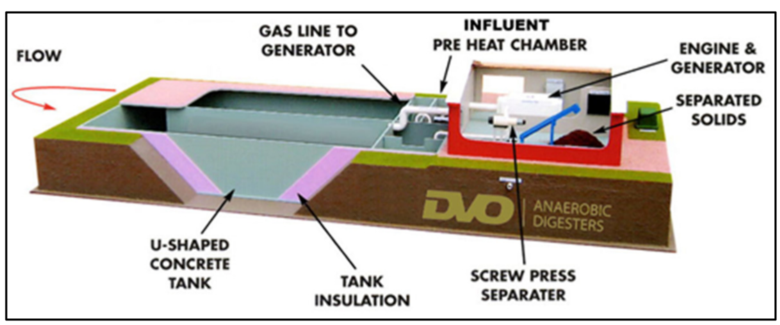

FIGURE 6 Schematic of a mixed plug-flow unit. (Graphic courtesy of DVO, http://www.dvoinc.com/howitworks.php.)

Once the cleaned manure has been fed into the digester, it stays there for 13–15 days ("retention time"). The post-digestion effluent is a slurry mixture that is further separated into liquid and solid digestate. At present, the liquids are land applied as fertilizer at Fair Oaks Farms; solids are being evaluated for conversion to nutrient-rich fertilizer(s).

3.2.2 Biogas Upgrading System

The biogas produced is composed primarily of methane (55–60%) and carbon dioxide (35–40%), plus a host of trace constituents (<1%). To refine the raw biogas to vehicle grade, carbon dioxide, hydrogen sulfide, water vapor (if the gas is injected into a pipeline, gas specifications limit the water content to less than 7 lb of water/mmBtu) and other impurities must be removed. This is accomplished by pumping the raw biogas from the digester to a **gas-cleaning skid** that creates a nearly pure stream of methane (RNG), which is chemically almost identical to fossil gas.[48]

Anaergia was awarded the contract for gas upgrading—including technology selection, equipment production, installation, and construction of the fuel delivery and storage system (except the fueling stations).[49] In 2012 the company installed the Totara+ biogas upgrading system from UK-based **Greenlane Biogas**, with a processing capacity of 2,500 normal cubic meters per hour (Nm^3/h).[50] Greenlane's technology is based on a "water scrubbing system" that uses plain water without chemicals or heat (see Figure 7). Pressurized biogas (at 140 psig) is fed through pressurized water, where impurities are stripped off and absorbed; moisture is removed in a drying stage. Greenlane specifications indicate that resulting gas purity is typically higher than 98% methane.[51,52]

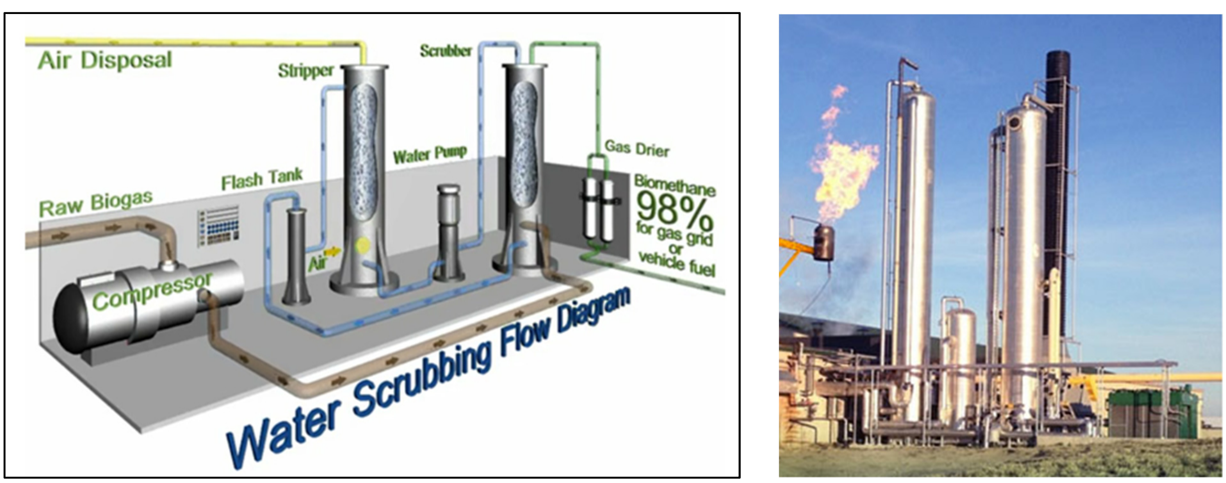

FIGURE 7 Schematic of Greenlane water scrubbing system (left panel; graphic courtesy of Greenlane Biogas, http://greenlanebiogas.co.uk/americas/greenlane-technology.); the Fair Oaks biogas upgrade plant (right panel; photo courtesy of DVO, Fair Oaks Dairies Gallery, http://www.dvoinc.com.)

The upgrading facility became operational on March 4, 2013, and was marked with a ribbon cutting at the Fair Oaks fueling station, where the R-CNG pumps opened for business. The event was attended by representatives from the Indiana Governor's Office, the Indiana Office of Clean Energy Development and the U.S. Department of Energy's Clean Cities program.[53,54]

3.2.3 Fueling Stations

Clean Energy Fuels, under contract to AMP Americas, built and originally operated two CNG fueling stations. Today, the stations are jointly owned by ampCNG and Renewable Dairy Fuels (RDF), and its affiliates.[55] One station is at Fair Oaks, and the other is at Sellersburg Indiana, 200 miles southeast, near the Kentucky border (see Figure 8). (With trucks pushing the limits of their fuel supply on the Kentucky and Tennessee routes, Sellersburg was chosen as the best place for refueling and switching trucks in Ruan's trailer-relay system. (See "Vehicles" in the next section.[56]) Both stations are open to the public. Other fleets and retail consumers represent 10–20% of the station sales at this time.[57]

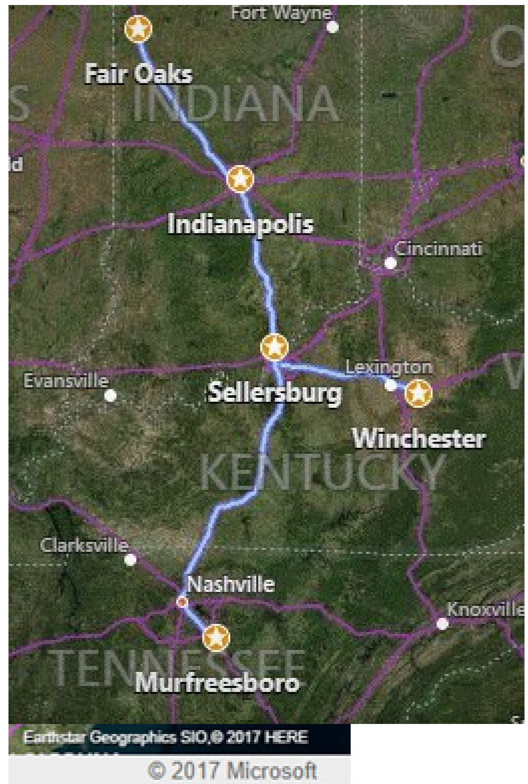

FIGURE 8 The delivery route. Fair Oaks and Sellersburg, IN, are fueling stations. Indianapolis, Winchester, KY, and Murfreesboro, TN, are fleet destinations. (Earthstar Geographics SIO, © 2017 HERE, © Microsoft.)

The two stations opened separately in the second half of 2011,[58] initially dispensing fossil CNG. The Fair Oaks station began dispensing R-CNG when the upgrading plant became operational, supplemented as necessary by fossil CNG from the local gas utility, **NIPSCO**. Similarly, if/when R-CNG supply is greater than on-site demand, excess gas can be injected into the NIPSCO pipeline, generating additional revenue and ensuring that the resource is not wasted. Sellersburg has been a strictly fossil CNG operation, buying gas from its local gas utility, **Vectren**.[59] However, in May 2016, ampCNG launched a renewable fuels division known as **ampRenew**, which may enable the company to source (from Fair Oaks today, but potentially from other locations in the future) and sell R-CNG throughout its growing network of CNG stations.[60]

3.2.4 Vehicles

Fair Oaks Farms utilizes a 42-truck milk tanker fleet to deliver as much as 300,000 gallons of raw milk daily to processing facilities in Indiana, Michigan, Tennessee, and Kentucky (Figure 9). In total, these trucks consume about 1.5 million diesel gallon equivalents (DGEs) of R-CNG annually.

FIGURE 9 A truck from the fleet serving Fair Oaks Dairy, managed by Ruan and owned by Renewable Dairy Fuels. (Photo courtesy of Linda Gaines.)

The CNG fleet, which replaced the original diesel trucks, was made up of Kenworth T440 daycab tractors with 9-liter Cummins Westport ISL G engines rated at 320 horsepower, and a fuel storage capacity of 130 DGEs via two Back of Cab (BOC) and two saddle (under cab) tanks.[61] The fleet hauled an average of 80,000 gross vehicle weight rating (GVWR) loads up to 220 miles on a single leg trip, which is greater than the rated capacity of 66,000 pounds.

In September 2013, RDF started upgrading the fleet to Kenworth T660s, using just-released Cummins Westport 11.9-liter ISX 12G natural gas engines. Trucks in the current fleet have a 93 DGE tank package composed of a 50 DGE tank in a BOC configuration, as well as 43 DGE in saddle tanks. By transitioning from 9-liter to 12-liter natural gas engines, the trucks achieve greater fuel economy and range (approximately 550 miles), despite the reduction in fuel capacity. According to a case study by the Department of Energy's Alternative Fuels Data Center, the first- and second-generation CNG fleets have run a combined 38 million miles on RNG.[62]

The Kentucky- and Tennessee-bound trucks run on a relay system. At Sellersburg, a southbound driver with a full load will switch trucks with a northbound driver whose trailer is empty after both trucks are refueled. The formerly southbound driver will head back to Fair Oaks to reload the trailer, while his formerly northbound counterpart finishes the run into Kentucky and Tennessee.[63]

The CNG trucks undergo routine maintenance at a pre-existing, on-farm garage designed for diesel vehicles, which was retrofitted with a ventilation system to handle natural gas. Any maintenance or repairs that cannot be performed on-farm can be taken care of at the nearby Kenworth dealership.

As of January 31, 2016, the fleet had run 30.5 million miles using the 12-L engine and 15.9 million miles using the 9-L engine.[64]

3.3 PUBLIC AND PRIVATE PARTNERSHIPS

No public-private partnerships were involved in the Fair Oaks fleet project.

3.4 FINANCING

The private financial partners are Fair Oaks Dairy and New Frontier Holdings, the parent company of ampCNG (formerly AMP Americas). Together, they covered the majority of the $18.5 million investment, almost half of which was the AD system built by Fair Oaks prior to AMP's involvement. ampCNG now has a long-term lease on the digester and the biogas it produces. The remaining capital investment by AMP covered the following: biogas upgrading and compression equipment, 3-mile pipeline, two new CNG fueling stations, and 42 new CNG Kenworth tractor-trailers.[65]

Public funds provided under the American Recovery and Reinvestment Act of 2009, through Clean Cities of Greater Indiana, totaled $750,000 for the two CNG stations. A grant from Indiana's State Energy Program of $2 million covered the incremental cost of equipping the CNG trucks with additional CNG tanks for extended range use.

4 PROJECT LOGISTICS

4.1 CONTRACTS (FEEDSTOCKS AND FUEL)

AmpCNG buys RNG (upgraded biogas) from Fair Oaks Farms, through a fixed-price, long-term contract. The RNG is transported via pipeline to the fueling station in Fair Oaks, where it is further compressed and dispensed as R-CNG. ampCNG also has a contract with the local gas utility, NIPSCO, to purchase any supplemental gas required to meet fleet demand, which provides redundancy in the event that the digester or associated equipment are not operating. Alternatively, NIPSCO has a contract to buy any surplus R-CNG from ampCNG if/when supply exceeds demand. Finally, the Sellersburg CNG fueling station is supplied by Vectren, the natural gas provider for central Indiana (Clark County).[66]

4.2 SITING AND PERMITTING

The anaerobic digester (already in place), gas upgrading skid, pipeline, and station are all on Fair Oaks-owned land, which enabled expedited siting. A long-term lease is in place for the gas upgrading skid and the station. In terms of permitting, all the appropriate local and state authorities were involved, ultimately granting permits to proceed—and the project passed all necessary inspections to commence.[67]

4.3 RNG TRANSMISSION AND STORAGE

Once refined, RNG is injected into a three-mile pipeline connecting the gas cleanup skid to ampCNG's natural gas refueling station. The total cost of this pipeline and interconnection with the NIPSCO line was in the $600,000 range.[68] It provides not only a conduit to deliver gas, but also a form of short-term storage. Before transmission from the cleaning skid to the refueling station, the gas is further compressed from 110 psig (pounds per square inch gage) to 400 psig, and ultimately to almost 4,000 psig at the fueling station, where it is dispensed throughout the day to the fleet of milk delivery vehicles. The fueling station was strategically located adjacent to an existing high-pressure pipeline, owned and operated by local natural gas utility NIPSCO, as well as the Fair Oaks off-ramp from I-65. This location not only provides trucks easy access to the station, but also access to a back-up supply of natural gas and the ability to sell excess RNG when production exceeds storage capacity plus fleet demand.

4.4 MONETIZING ENVIRONMENTAL ATTRIBUTES

As highlighted in "Regulatory and Policy Drivers," Section 2.3, the EPA's Renewable Fuel Standard (RFS2) has become the primary federal policy driver behind RNG (either compressed or liquefied) transportation projects. Under this program, EPA-registered facilities are able to generate one credit—known as a Renewable Identification Number (RIN)—for each gallon equivalent of approved renewable fuel produced and delivered to the transportation market, which includes RNG made from most organic waste sources. As a result, the value of each gallon equivalent of R-CNG is determined by not only the current commodity value of natural gas, but also the additive value of RIN credits.

To qualify as an approved production facility under the RFS program requires a thorough registration process. The process is designed to prevent fraud. The Fair Oaks facility was registered with the EPA as a qualified producer under the RFS2 in 2013, and RIN generation commenced shortly thereafter.

R-CNG, as a gaseous fuel, is quantified in terms of million British thermal units, or mmBtus. The energy content of one mmBtu is equivalent to approximately 7.8 gallons of diesel, or DGEs. However, since the RFS2 was primarily developed around liquid biofuels, a RIN credit is based on the energy equivalency of one gallon of ethanol, which has lower energy density than gasoline, diesel, or natural gas. Therefore, each mmBtu of R-CNG delivered to the transportation market generates approximately 11.7 RINs (although fractional RINs cannot be bought or sold).

The political uncertainty and ongoing legal battles surrounding the Renewable Fuel Standard have made credit values highly volatile and difficult to predict. However, recent RIN pricing has been highly favorable to the economics of RNG transportation projects as highlighted in Table 1, which provides an example of empirical commodity and credit values from February 2017.[69] Moreover, while it has traditionally been difficult to secure any kind of long-term or fixed-price contracts to sell RINs, in 2016, RIN buyers and sellers have entered into five- and seven-year agreements, providing much-needed financial stability. *In an era of record low fossil natural gas prices, producers are currently able to generate as much as $33 in value per mmBtu of RNG (~$3/DGE) delivered to the transportation market.*

The "effluent" that remains in the chamber following anaerobic digestion is not currently a source of revenue. This material consists of liquid (digestate) and solid (biosolids) streams. At the moment the liquids are land applied as fertilizer at Fair Oaks Farms. Solids are not being used or monetized, but they are being evaluated for conversion to nutrient-rich non-synthetic fertilizer(s).

TABLE 1 Breakdown of RNG and RIN Values from the Fair Oaks Project

Attribute	Value
Commodity Gas Value	$3.00 / mmBtu
R-CNG (D3) RIN Value	$2.60 / RIN (February 2017)
RINs/mmBtu	11.7
Total R-CNG Value	$3.00 + ($2.60 * 11.7) = $33.42 / mmBtu

4.5 PROJECT HURDLES

According to representatives of ampCNG and Fair Oaks, the project did not face any significant setbacks with installation or maintenance of the various components and systems. The seasonality of the waste stream had to be accounted for during design, but fortunately, the system installed can tolerate changes in feedstock composition as well as related fluctuations in biogas quality and flow-rate. Spikes in hydrogen sulfide (H_2S) are common, for example, but the gas upgrading system can easily deal with these. Other equipment, such as pumps and pipes that are less resistant to corrosion, do suffer and some have had to be replaced.

A separate but persistent challenge has been securing other organic waste "substrates" to combine with manure. These energy-rich materials permit greater biogas production, since manure is relatively low in biogas potential. Because consistent, reliable supplies of substrates have been difficult to obtain, the digester has primarily handled manure alone to ensure the health of the microbial community responsible for the digestion process. Thus, if a relatively homogenous organic waste stream were to become available, biogas production could be boosted significantly.

A potential impediment to consistent and reliable digester operation is the sand used in bedding for the cows. Fair Oaks uses sand bedding, which is considered more comfortable and humane for the animals, but can be problematic for digesters. To prevent sand accumulation, which would gradually reduce digester volume and biogas production and could require excavation,[70,71] the manure at Fair Oaks goes through a water separation process that removes between 85% and 98% of the sand prior to digestion.[72,73]

5 DATA ANALYSIS RESULTS

5.1 GAS PRODUCTION AND QUALITY DATA

Biogas quality and flow rates are monitored in real-time using a specially designed Supervisory Control and Data Acquisition (SCADA) system, before and after processing by the Totara+ biogas upgrading skid. On average, biogas composition coming off the digester is approximately 60% methane and 39% CO_2, and it contains 3500 parts per million (ppm) of hydrogen sulfide (H_2S). As a result, daily biogas production—prior to upgrading—is approximately 1,257,000 standard cubic feet (SCF). After upgrading, this equates to 221,000 mmBtu/year of RNG at 98% methane, or more than 1.7 million DGEs. Excess RNG—above and beyond milk delivery fleet needs and/or sale to the gas utility—is used to power a 1-MW gas turbine, which provides electricity to the digester, the gas upgrading skid, and the Fair Oaks fueling station. Waste heat from the generator is used to heat the digester.[74]

5.2 ENVIRONMENT, HEALTH, AND ENERGY SECURITY IMPACT DATA

The collection and processing of dairy manure from 10,500 cows at Fair Oaks Farms has had profound positive environmental, energy security, and public health impacts.

The production and use of manure digester-derived R-CNG to displace approximately 1.5 million gallons of diesel results in annual lifecycle emissions reductions of more than 19,500 tons of carbon dioxide equivalent (CO_{2e}), according to Argonne's GREET Model.[75,76] (See Figure 4 in Section 2.2.) Moreover, the use of excess RNG to provide on-farm renewable electricity further reduces environmental impacts.

Despite great strides in domestic petroleum production since 2010, diesel displacement with local, domestic, renewable fuel sources, such as R-CNG at Fair Oaks, further reduces dependence on imported oil. In addition, organic waste-derived R-CNG is immune to the volatile price swings associated with the global market for petroleum-based fuels, regardless of where the latter are produced.

Finally, natural gas vehicles (powered by either renewable or geologic natural gas) provide an array of public health benefits—especially for drivers—compared to gasoline or diesel. These include reductions in emissions of carbon monoxide (CO) of up to 70%, in NOx of up to 87%, and in particulate matter of up to 90%, as well as noise reductions of up to 90%.[77]

5.3 BUSINESS CASE DATA

Ultimately, the business case for converting the 42-truck milk delivery fleet from diesel to locally-produced R-CNG was driven by the combination of potential long-term fuel cost savings and Fair Oaks Farms' sustainability goals. In short, the significant price advantage for natural gas (fossil or renewable) compared to diesel at the time—on the order of $1.50/DGE—

could justify the $18.5M in capital costs required to make this transition. Moreover, committing to substantial reductions in carbon emissions—as much as 43% per gallon of milk—would facilitate the exclusive agreement with Kroger and its network of grocery stores throughout the Midwest.[78] Additional revenue-generating/cost-saving opportunities, such as the sale of RINs and marketing/use of digestion co-products (biosolids and digestate), also played a role.

Table 2 illustrates the effect of capacity factor and RIN monetization on investment payback. Assuming 100% equity (i.e., no debt to repay), a capital investment of $18,500,000, and annual operating and maintenance expenses of $925,000, current RIN values permit payback in 1.5 to 7.6 years, depending on RNG production and the ability to garner RINs for that production (i.e., RIN monetization). Payback can be reduced further with federal and state grants. As shown in Table 2, grants on the order of those received for the Fair Oaks project ($2,750,000) can reduce payback by 0.2 to 1.1 years, depending on production and RIN monetization.

TABLE 2 RNG Production and Investment Payback from the Fair Oaks Project as a Function of Capacity Utilization and Ability to Monetize RINs at Current Values

				Paybacks at RIN Monetization Rates* (y)			
	Production			Investment Excluding Grants		Total Investment	
Percent of Capacity	Biogas SCF/d	RNG SCF/d	RNG MMBtu/y	100%	50%	100%	50%
50%	1,080,000	628,560	201,446	2.7	6.5	3.2	7.6
60%	1,296,000	754,272	241,735	2.2	5.1	2.6	5.9
80%	1,728,000	1,005,696	322,314	1.6	3.5	1.9	4.1
100%	2,160,000	1,257,120	402,892	1.3	2.7	1.5	3.2

* RIN monetization rate is the percentage of RNG production for which RINs are obtained.

6 LESSONS LEARNED AND FUTURE PLANS

Project partners ampCNG and Fair Oaks Farms—involved in the largest (and still only) operational dairy digester-to-R-CNG vehicle fuel project in the United States—conclude that all the technologies utilized are commercial and working well. This includes the anaerobic digester, biogas upgrading system, the fueling station(s), heavy-duty natural gas engines, and various other components and equipment. Despite necessary maintenance and/or unforeseen hurdles, the project is up and running approximately 75–80% of the time. However, without backup fuel supply from NIPSCO at the Fair Oaks refueling station, milk delivery trucks would be stranded when digester R-CNG is unavailable. Therefore, having natural gas pipeline access has proven critical to the project's success, not just for fuel access, but also to ensure that excess RNG can be sold to generate additional project revenue.

According to Steve Josephs, ampCNG Co-founder and Director of Engineering, "the two biggest lessons from the project have been the importance of proper planning and logistics, due to the number of moving pieces, and one's ability to manage cash flow despite fluctuations in commodity pricing. For example, when the project was being developed, diesel prices were above $4.00 per gallon, while conventional CNG was around $2.00. That spread, which was the primary economic driver, began to disappear starting in 2013 when petroleum prices plummeted."[79]

> "The two biggest lessons from the project have been the importance of proper planning and logistics, due to the number of moving pieces, and one's ability to manage cash flow despite fluctuations in commodity pricing."

Josephs also emphasized the importance of policies promoting the use of biogas, particularly cash incentives under the Renewable Fuel Standard. "Fortunately, RIN pricing began to rise around the same time [that diesel prices fell], helping make up for the reduced margin between R-CNG and diesel."[80]

By all counts, the project has been a success. Fair Oaks continues to take steps to improve its carbon footprint and lead the way toward a sustainable U.S. dairy sector. Rather than launching additional R-CNG projects, ampCNG has chosen to focus on expanding its regional network of CNG stations (from the two original Indiana locations to 19 stations across seven states) and fleet customers. The company recently announced a new R-CNG division, ampRENEW, which will deliver excess R-CNG from Fair Oaks to fleet customers throughout its network, including Ruan in Indiana and Dillon Transport in Florida.

> "Fortunately, RIN pricing began to rise around the same time [that diesel prices fell], helping make up for the reduced margin between R-CNG and diesel."

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