PATHWAYS FOR PROMOTING ANAEROBIC DIGESTION IN WASHINGTON STATE

An Analysis of Benefits and Production Capacity with Recommendations for Advancement

by

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ABSTRACT

Pathways for Promoting Anaerobic Digestion in Washington State

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Anaerobic digestion (AD) of organic waste into renewable fuel and value-added coproducts has a myriad of environmental, social and economic benefits, yet relatively few AD projects have been established in Washington State. This thesis quantifies current and potential production capacity for AD biogas in Washington and identifies pathways for achieving large-scale deployment of AD as an environmental mitigation strategy and renewable fuel source. Quantitative methods used to estimate current and potential AD production show that Washington is currently only producing 15% of its biogas capacity, whereby the state has the potential to generate approximately 1,614,249 MWh/yr of electricity or 160,180,991 DGE/yr.[1] The participant-observation methodology was employed to qualify costs, benefits and development strategies for AD. Washington's low power prices were identified as a main obstacle to the development of AD projects with the conventional method of selling biogas-generated electricity. New development models and value-added coproducts (e.g. biomethane, concentrated fertilizer, *green*-chemicals) can not only make AD projects financially feasible in the state but potentially very profitable. Recommendations offered herein include research and development priorities, incentive policies, co-location of symbiotic facilities and partnerships between stakeholders.

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[1] MWh/yr = megawatt hours per year DGE/yr = diesel gallon equivalent per year

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ABBREVIATIONS

AD = anaerobic digestion

Btu = British thermal units

CHP = combined heat and power

CO_2 = carbon dioxide

CO_2e = carbon dioxide equivalent

CH_4 = methane

CO_2e = carbon dioxide equivalent

DGE = diesel gallon equivalent

DGE/yr = diesel gallon equivalent per year

EFP = Energy Freedom Program

EPA = United States Environmental Protection Agency

EQIP = Environmental Quality Incentives Program

FIT = feed-in-tariff

GHG = greenhouse gas(es)

HSAD = high-solids anaerobic digester

I-937 = Washington State's Ballot Initiative 937

MGD = million gallons a day

$MMTCO_2e$ = million metric ton of carbon dioxide equivalent

MW = megawatt

MWh/yr = megawatt hours per year

NG = natural gas

PGC = purpose grown crops

PPA = power purchase agreement

ABBREVIATIONS

PPM = parts per million

PUD = public utility district

PURPA = Public Utilities Regulatory Policies Act

REAP = Rural Energy for America Program

RECs = renewable energy credits/certificates

RFS = Renewable Fuel Standard

RINs = renewable identification numbers

RNG = renewable natural gas (same as *biomethane*)

SOC = standardized offer contracts

scfm = standard cubic feet per minute

VFA = volatile fatty acid(s)

WSDA = Washington State Department of Agriculture

WSU = Washington State University

WWTP = wastewater treatment plant

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Great appreciation goes to Martha Henderson, Director of The Evergreen State College's Graduate Program on the Environment, for the patient guidance she offered me throughout my graduate studies at Evergreen. I am very grateful for the mentorship and generous opportunities afforded to me in researching this topic by Peter Moulton, Washington State Bioenergy Coordinator, State Energy Office, Department of Commerce. Sincere thanks to Mitch Redfern for his valuable contributions and to my friends and family for their enduring support.

“When nature’s systems are working, every kind of waste nourishes another part of the system. Nature is a self-organizing and adaptive network of relationships. Except when these relationships are disrupted, this network generates yet more life and relationships, in forms that are competitive and cooperative, and unimaginably diverse. Nature uses current energy (mostly from the sun), not fossil energy. And it does not draw down the principal of the Earth’s largeness. It lives off the interest, able to continue indefinitely.”

~ Sarah van Gelder (Executive Editor, YES! Magazine) ~

1. INTRODUCTION

This thesis examines the benefits, obstacles and development pathways for the conversion of organic waste to fuel and other marketable byproducts through anaerobic digestion (AD) in Washington State. Source material (feedstock) from landfills, separated organics, wastewater treatment plants, and dairies were quantified to provide an assessment of the state's current and potential capacity for AD, using renewable natural gas (biomethane) production as a key indicator. Employing the research method of participant-observation, this study identifies value-added co-products and processes that warrant intensified research and development, policy recommendations and funding mechanisms that would help promote the sector. Following is a synopsis of AD technology, the current state of its development and contextual frameworks for AD in the environmental, political and social arenas.

1.1 OVERVIEW: Anaerobic digestion is a mature and scalable technology widely used around the world to safely manage organic waste while allowing for the capture of marketable byproducts. Organic material such as animal waste is processed in air-tight vessels where it is consumed by specialized anaerobic bacteria. This naturally occurring process results in methane-rich biogas, nutrient-rich liquid effluent and (~97% sterilized) fiber.[1] These byproducts are commonly used for renewable energy generation, fertilizer, cattle bedding and as a soil amendment (Fig. 1), while innovative processes are currently under development for new end-uses.

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[1] "Commercial Demonstration of Nutrient Recovery of Ammonium Sulfate and Phosphorus Rich Fines from AD Effluent (S. Dvorak, PE and C. Frear, PHD)."

Biogas: 50-70% methane (500-700 BTU/ft^3) **Uses:** heat, power, fuel (renewable natural gas)	**Solid Digestate:** ~97% pathogen-free fiber **Uses***:* cattle bedding, peat moss substitute, soil amendment/compost	**Liquid Digestate***:* liquid concentration of nutrients **Uses***:* fertilizer, aquaculture feed, biochemicals, other

Figure 1: Byproducts of Anaerobic Digestion (Sources: jcwinnie.biz, tumblr.com, lincoln.ne.gov)

China has an estimated eight million small-scale digesters, while Germany has around 4,000 large-scale digesters.[2] Although AD is commonly used at wastewater treatment plants in the United States, the technology has not been widely adopted in other sectors such as agriculture, where excessive nutrient runoff from livestock manure has led to serious water quality issues.[3] As of 2013, there are just under 200 farm-based digesters in the U.S., of which eight are operating in Washington State.[4] The tide is turning however, as there is increasing interest in AD as a means of protecting water quality, reducing waste streams, averting greenhouse gas emissions, expanding the *green economy* and helping the state meet its renewable energy goals.

Washington's historically low power prices have inhibited the typical financing mechanism of selling biogas-generated electricity, therefore new approaches are needed to further monetizing the environmental benefits of AD.[5] True to the saying, "desperation begets innovation," Washington State is pioneering new processes for

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[2] "Anaerobic Digesters | Center for Climate and Energy Solutions."
[3] Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, *Livestock's Long Shadow*.
[4] "Projects | AgSTAR | US EPA."
[5] *Renewable Natural Gas and Nutrient Recovery Feasibility for Deruyter Dairy, 2012*.

recovering nutrients from AD effluent and ways to market refined biogas (biomethane) as a stand-in replacement for natural gas.

Process, Products & Uses: The AD process involves four stages that successively break down matter until only simple molecules remain - namely methane (CH_4), carbon dioxide (CO_2) and water.[6] AD begins with hydrolysis, which deconstructs complex organic matter into simple sugars, amino acids and fatty acids. Acidogenesis breaks down these sugars and acids further into alcohols and volatile fatty acids, creating CO_2, ammonia and hydrogen sulphide. Acetogenesis is the third stage which produces hydrogen, CO_2 and acetic acid. The final stage, methanogenesis, involves specialized microorganisms that convert the remaining hydrogen and acetic acid into biogas, which consists of roughly 60% methane, 40% carbon dioxide, water vapor and various trace gasses (Fig. 2).[7]

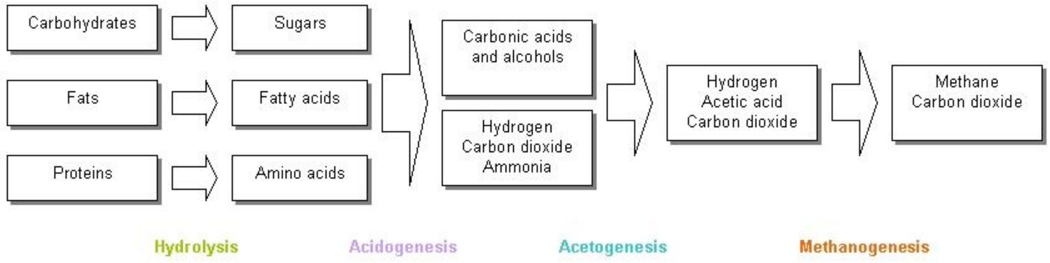

Figure 2: Basic Biochemical Process of Anaerobic Digestion (Source: Alex Marshall, Clarke Energy)

Methane yields approximately 1,000 British thermal units (Btu), or 252 kilocalories, of heat energy per cubic foot (0.028 cubic meters) and is the same combustible compound found in natural gas.[8] Biogas can be used remotely for power generation, heat, lighting and as a cooking fuel or refined into a direct replacement for

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[6] "The AD Cycle | The Anaerobic Digestion & Biogas Association."
[7] McCarty and Mosey, "Modelling of Anaerobic Digestion Processes."
[8] "Energy Basics: Anaerobic Digestion, EERE, US Dept. of Energy."

natural gas.[9] Figure 3 shows several common small-scale digester designs as well as a cooking stove and generator converted for biogas use.

Figure 3: Small-Scale Digesters and Uses for AD Biogas (Sources: Nova Energie, WikiCommons)

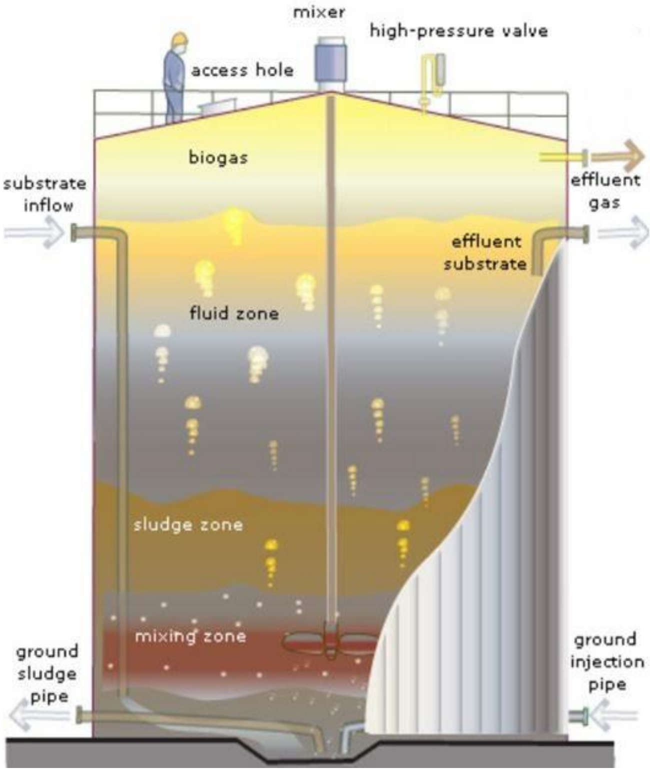

Figure 4: Dairy Digester Diagram (Source: IHAASE Energietechnik)

Commercial-scale digesters are large air-tight vessels that speed up the decomposition/fermentation process through temperature control, feedstock selection and/or mechanical agitation. Most commonly employed at dairy farms and wastewater treatment plants to avert air and water pollution, digesters can be used to capture biogas from many forms of organic material. An above-ground 'complete-mix' dairy digester is illustrated in Figure 4, showing the accumulation of biogas at the top of the digester tank.

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[9] Mata-Alvarez, Macé, and Llabrés, "Anaerobic Digestion of Organic Solid Wastes"

1.2 CONTEXTUAL FRAMEWORKS: The successful development and implementation of AD requires consideration for a broad array of issues, from its historical and political context to its social and environmental significance. This section presents environmental, political and cultural frameworks that can help inform our discussion of AD as a promising environmental mitigation and renewable energy strategy for the future.

Environmental: First used at a leper colony in 1859 to decontaminate waste in a confined environment, AD was identified as an effective method of killing pathogens to mitigate health threats. As agriculture expanded in the 20th century in step with human settlements, AD was employed as a way to avert water pollution from livestock manure. Today, AD's ability to reduce atmospheric methane levels is gaining increasing value.

Recent research suggests that methane is as important, if not more, as carbon dioxide for near-term climate change factors. Methane has 72 times the heat-trapping capacity of CO_2 over a twenty year period and 21 times over 100 years.[10] A recent study conducted by NASA's[11] Drew Shindell and an international team of seventy scientists concluded that reducing methane emissions would be among the most effective short-term responses to climate change that we could make.[12]

In 2012 our planet reached an ominous milestone. For the first time in human history our atmospheric CO_2 levels hit a daily average of 400 parts per million (ppm).[13] Climatologists and ecologists agree that we are quickly approaching an absolute

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[10] US EPA, "Methane Emissions."

[11] NASA - National Aeronautics and Space Administration

[12] Anenberg et al., "Global Air Quality and Health Co-Benefits of Mitigating Near-Term Climate Change through Methane and Black Carbon Emission Controls."

[13] "Carbon Dioxide at NOAA's Mauna Loa Observatory Reaches New Milestone: Tops 400 Ppm."

maximum for greenhouse gasses (GHGs) with which our planet can sustain life as we know it.[14] The last time we reached 400 ppm of CO_2, some three million years ago during the Pliocene Epoch, the Earth's climate was drastically warmer, polar ice was at a minimum and sea levels were at least 82 feet (25 meters) higher.[15] The severe Midwest drought and Hurricane Sandy of 2012 were but a few of the more recent extreme weather events likely attributed to climate change.[16]

The increase in CO_2 levels is accompanied by other GHG concentrations such as methane. In May 2012, extremely high levels of methane were detected over the Arctic, coinciding with a hastened retreat of the Arctic ice sheet (Fig. 5). Scientists hypothesize this spike in methane was largely due to intensified anaerobic digestion within recently uncovered Arctic land and warmer surface waters.[17]

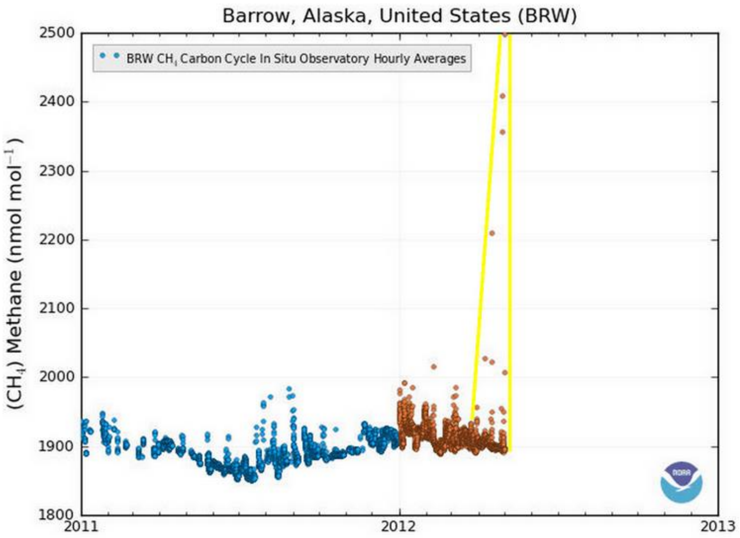

Figure 5: Anomalous Atmospheric Methane Concentrations in May, 2012 (Source: NOAA ESRL/GMD)

In light of increasing methane emissions, a new awareness is developing for the need to focus on reduction opportunities for those sources we can control. Agricultural and municipal waste streams are primary areas in which methane can be captured and

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[14] Rockström et al., "A Safe Operating Space for Humanity."
[15] Dowsett et al., "Joint Investigations of the Middle Pliocene Climate I."
[16] Howes et al., "The Challenge of Integrating Climate Change Adaptation and Disaster Risk Management."
[17] Raloff, "Puffs of Methane Found over Arctic."

used to offset fossil fuels. In addition, the refinement of AD byproducts into renewable replacements for petrochemicals and synthetic fertilizers can further decrease GHGs.

Political: In a November 2012 letter to state agency directors, former Washington State Governor Christine Gregoire expressed concern for the growing economic loss, health effects and ecological damage resulting from declining water quality. The Governor asked that key agencies focus and accelerate efforts to eliminate nutrient pollution from sources such as livestock, with AD being a proven best management practice (BMP).[18]

Washington's current Governor, Jay Inslee, has been proactive in supporting environmental mitigation strategies such as those exemplified by AD and has great interest in the potential for biogas to help the state meet its renewable energy goals. With bipartisan support, the Washington State Legislature passed several policies in support of AD as first-order business of the 2013 legislative session. Additionally, Governor Inslee has proposed that state funds be used to construct new natural gas pipeline injection ports to facilitate the distribution of biomethane. Other policies that would support AD development, such as in the funding and regulatory arenas, have yet to be addressed by the Legislature.

Cultural: The intrinsic value of AD can be seen through a social context as well. The indigenous cultures of Washington State hold a shared view that our natural environment is maintained by the balance of interrelated systems in which there is no option of throwing things *away*. Through this perspective, there is no separation between humanity and nature, whereby the concepts of *waste* and *away* are anthropomorphic constructs that devalue the cyclical process of nature.

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[18] "2008 Climate Advisory Team - 10072008_10_iwg_final_report.pdf."

Native American principles that reflect this holistic view of nature are emphasized in the Washington State Indian Education curriculum *Since Time Immemorial: Tribal Sovereignty in Washington State*. Learning objectives from the curriculum state the following: “The continuous replacement of one natural community of life by another is considered natural. All animal and plant life are inter-related. Every life form is considered to have significant and contributing factors to the larger environment. The Indian way respects the delicate balance of the food chain of which we are a part.”[19]

The contemporary culture of Washington State is seen by many as progressive and being on the forefront of environmentally responsible technology. In this respect, the successful deployment of AD in Washington may help further its development well beyond state lines. Governor Inslee expressed his desire to help the state lead with innovative energy solutions in stating, “We need visionary leadership to spark a new revolution. We led the first technological revolution in aerospace, a second technological revolution in computers and software, and we will lead yet another technological revolution in clean energy technology.”[20]

With strong political support, proven science, mature technology, and a favorable cultural climate, the stage is set for Washington to lead the development of AD with a fresh approach and new market streams. Yet intensified research, innovative development models and supportive legislation is essential for AD to reach its potential in Washington. Considerable obstacles exist as discussed herein, yet factors such as the growing need for renewable fuel and effective strategies to counter environmental threats point to anaerobic digestion as a best management practice we cannot afford to dismiss.

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[19] “Indian-Ed.Org | Since Time Immemorial.”
[20] “www.JayInslee.com - Building a New Economy for Washington.”

2. DATA SOURCES & METHODS OF EVALUATION

This thesis synthesizes a large amount of data, supplemented by interviews, to provide a comprehensive assessment of the costs, benefits and potential for expanding the AD sector in Washington State (WA) with recommendations on how to most effectively proceed. This chapter reviews the data sources used in this research, an explanation of the methods employed by the author and limitations of the study.

2.1 DATA SOURCES: To assess the viability of AD development in Washington, this research evaluated available feedstock, facilities, policies, ongoing research and effective development models. Analyses are presented with both quantitative and qualitative data and sources are described below in the following six categories: environmental, economic, biogas, feedstock/facilities/production, research/development, and policy.

<u>Environmental:</u> An abundance of peer-reviewed scientific data exists concerning the environmental issues associated with AD. This study considers the ecological effects of waste streams and the biological process of using AD to mitigate their effects. Data concerning greenhouse gas emissions and water quality are predominantly cited from the U.S. Environmental Protection Agency (EPA). The U.S. Department of Agriculture (USDA) provided verified statistics on agricultural emissions, while well-to-wheel models were cited from The German Energy Agency and Argonne National Laboratories. Mark Fuches from the WA Department of Ecology provided updated information specifically for the region.

<u>Economic:</u> Two feasibility studies were examined in the economic evaluation of digesters in Washington State. The studies were conducted at the DeRuyter and

VanderHaak dairies, titled *Renewable Natural Gas and Nutrient Recovery Feasibility for DeRuyter Dairy* and *The Economics of Dairy Anaerobic Digestion with Co-product Marketing*, respectively. The studies were commissioned by the WA Department of Commerce in recognition that digester projects are having difficulty with financing their operations. Summarized herein, they looked at alternate financing mechanisms such as the sale of refined biogas and concentrated fertilizer.

<u>Biogas:</u> Just in the last few years, the opportunities for biogas have been given serious consideration, with various studies being commissioned by the state. The key document concerning refined biogas used in this analysis is titled *Biomethane for Transportation: Opportunities for Washington State.* The research was conducted for the Western Washington Clean Cities Coalition in 2011 and involved the Washington State University (WSU) Extension Energy Program. Background information regarding electrical power production from biogas was largely extracted from the 2009 report titled *Capitalizing on Energy Opportunities on New York Dairy Farms*. Discussions regarding thermal power production were based on the *Washington State Thermal Energy Efficiency Opportunities* report prepared by WSU Extension Energy Program in 2012. The DeRuyter feasibility study, mentioned previously, provided a comprehensive analysis of the economic viability of the aforementioned energy conversion technologies.

<u>Feedstock/Facilities/Production:</u> Data regarding AD feedstock and facilities was largely sourced with the assistance of Peter Moulton (Bioenergy Coordinator, WA Department of Commerce) and Jim Jensen (Sr. Bioenergy and Alternative Fuels Specialist, WSU Extension Energy Program). Mary Beth Lang (Bioenergy and Special Projects Coordinator, WA Department of Agriculture) provided verification of agricultural AD

facilities and inputs including co-digestion feedstock. The on-line *Washington State Biomass Inventory* was used to identify feedstock by type, location and quantity. The USDA's agency concerned specifically with AD, AgSTAR, provided current information on agricultural AD projects nationwide, while the American Biogas Council covered other facilities such as wastewater treatment plants and landfills. Current AD production capacity was assessed by compiling data from the WA Department of Agriculture (WSDA), county waste management agencies and the WA Department of Ecology.

<u>Research and Development:</u> Research reports published by Dr. Craig Frear of WSU-Pullman informed the discussion on nutrient recovery and co-digestion research, with particular weight to the publication *Commercial Demonstration of Nutrient Recovery of Ammonium Sulfate and Phosphorus Rich Fines from AD Effluent*, co-authored with Stephen Dvorak. Additional updates were received by Frear via personal correspondence in order to present current and accurate information. Communications with BioLogical Carbon LLC researcher John Miedema provided insight into strategies for sequestering carbon by pyrolyzing AD solids and using the resulting biochar as a transportation method for AD nutrients into fields. A brief discussion on the benefits and efforts of creating biodegradable commodity chemicals from AD byproducts was summarized from a report titled *A Roadmap for Advancing Green Chemistry in Washington State*, published in 2012 by the WA Department of Ecology.

<u>Policy:</u> A thorough review of Washington State policies regarding AD was conducted in tandem with Mitch Redfern, a fellow Evergreen colleague, through an examination of legislative actions such as the Washington State Energy Policy and their effects on AD project development and operation. *Growing Oregon's Biogas Industry*, prepared by The

Climate Trust and Energy Trust of Oregon in 2011, offered its own policy recommendations and was valuable as a comparison to other Northwest initiatives for AD development.

Two state-funded reports, *Washington State Thermal Energy Efficiency Opportunities* and *Biomethane for Transportation*, provided political analysis that informed this study. Policy recommendations presented herein were informed by personal communications the author had with Charles Egigian-Nichols (Tetra-Tech Bioenergy LLC), Dan Evans (Promus Energy LLC), Daryl Mass (Farm Power Northwest), Peter Moulton (WA Department of Commerce), Daryl Williams (Tulalip Tribe) and dairymen who requested to remain anonymous.

2.2 METHODS OF EVALUATION: This thesis is largely a product of the author's work with the Washington State Bioenergy Coordination Team (WA Bioenergy Team) for which data regarding the state's AD research and development efforts was compiled by the author from September 2012 to June 2013. An extensive literature review was conducted of peer-reviewed studies, agency documents and industry reports. Personal communication was had with various authors of the reports sited herein in order to gain clarification on individual research results and acquire supplemental information that had not yet been published. The author's participation in weekly meetings of the WA Bioenergy Team, research symposiums and conferences offered significant input for this thesis with the methodology of participant-observation.

Established by anthropologists such as Hamilton Cushing and Margaret Mead, participant-observation (P-O) is a data collection method typically used to acquire qualitative data by immersing oneself in the work and culture of the subject(s) of study while maintaining objectivity.[21] While this method can be conducted covertly, the author of this thesis did so overtly. The author explained to members of the WA Bioenergy Team, with which he worked, that data and discussions encountered by the author could be used in this thesis. Advantages afforded the author with this method include the ability to acquire internal data (i.e., state records) and unpublished information and viewpoints (i.e., developing research) to amass a holistic understanding of the social, political, environmental and economic issues regarding AD development. A disadvantage of overt P-O encountered by the author was the necessity of having to omit sensitive information and interviewee identities for inclusion in this research.

Discussions and interviews were held with representatives of the AD industry, dairy farmers, state agencies, researchers and the Tulalip Tribe. Interviewees were chosen to represent the broad scope of stakeholders involved with AD in Washington and selected based on the individual's level of contribution to the field. Questions were designed individually for the participants according to their area of expertise.

Estimates for Washington's potential biogas production were formulated in tandem with the WA Bioenergy Team Coordinator, Peter Moulton. Available feedstock amounts suitable for AD were determined for the four categories covered in this study (landfills, municipal solid waste, wastewater, dairies) through an analysis of biomass inventories provided by WSU's Agri-Environmental and Bioproducts Engineering Research Group, The Pacific Region Bioenergy Partnership and state-commissioned

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[21] DeWalt and DeWalt, *Participant Observation*.

reports. A key report used in this quantification was prepared by Jim Jensen of WSU's Extension Energy Program in 2011, titled *Biomethane for Transportation.*

Biogas production potential was calculated by assigning capacity factors to each category, as the substrate's composition (i.e., carbohydrates, proteins, fats, cellulose) is a key determinant in the quantity of biogas produced by each feedstock through AD. Using established research, the estimated yields assume 50% biomethane in biogas from landfills and dairy digesters, 60% from wastewater treatment, and 70% from municipal organic wastes. In some cases where previously determined calculations were offered in units such as Btu, they were converted into megawatt hours per year and diesel gallon equivalents. Basic mathematical calculations were performed to estimate the monetary value for AD byproducts, ecosystem payments and GHG equivalencies.

The main limitation of this study is that feedstock from industrial processes was not accounted for in estimates for biogas production. Research did not find sufficient data to include it in projections and efforts to collect the data encountered the obstacle of needing U.S. Food and Drug Administration tracking codes for source material from commercial food and beverage facilities. The addition of sugars and fats from such facilities would likely increase biogas production estimates significantly.

In summary, this thesis offers both quantitative and qualitative assessments informed by research and interviews with influential players in the field of AD development and policy. The insider perspectives presented herein are unique to the author's method of participant-observation and his work with the WA Bioenergy Team.

3. COST/BENEFIT & PRODUCTION EVALUATION

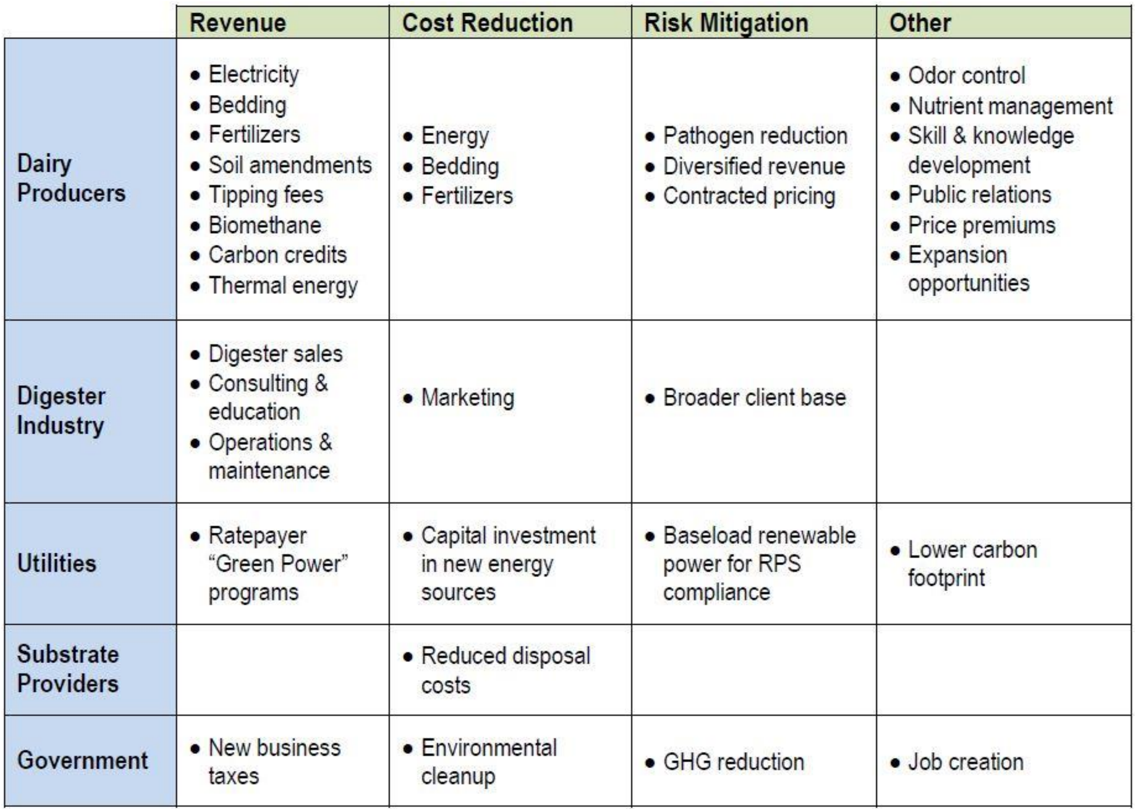
Although much of the world has already embraced AD as an environmental mitigation and renewable energy strategy, the technology is still new to much of America. As with any emerging technology, it is prudent for us to consider the totality of its costs and benefits. The surge in corn ethanol production and investment followed by its recent decline is a reminder that vigilance is needed with all new innovations to ensure that they live up to their promises. Ongoing research is needed to assess the effects of AD as it expands in the United States. This chapter presents a compilation of current research regarding the pros and cons of AD along with an evaluation of the current and potential production capacity of AD in Washington State.

3.1 COST/BENEFIT EVALUATION: A myriad of benefits are currently being realized by AD in Washington, while environmental and social costs have so-far been minimal. The economic cost of getting a digester on-line remains the greatest obstacle, for which the recommendations offered herein are designed to address.

Global benefits involve the reduction of GHGs, while local benefits include improved air and water quality and job creation. Social and economic advantages of AD are intrinsically related to healthy and productive environments for the ecological services they provide, while a vast array of revenue streams benefit producers and consumers alike. Table 1 categorizes benefits afforded by AD at dairy operations as realized by five stakeholder groups; dairy producers, digester industry, utilities, substrate providers and government. Costs and benefits of AD are discussed in the following section in the context of ecology and energy, social considerations and economics.

Table I: Potential Benefits from Dairy-based Digesters

(Source: Adapted from Washington Dairies and Digesters, WSDA)



	Revenue	Cost Reduction	Risk Mitigation	Other
Dairy Producers	• Electricity • Bedding • Fertilizers • Soil amendments • Tipping fees • Biomethane • Carbon credits • Thermal energy	• Energy • Bedding • Fertilizers	• Pathogen reduction • Diversified revenue • Contracted pricing	• Odor control • Nutrient management • Skill & knowledge development • Public relations • Price premiums • Expansion opportunities
Digester Industry	• Digester sales • Consulting & education • Operations & maintenance	• Marketing	• Broader client base	
Utilities	• Ratepayer "Green Power" programs	• Capital investment in new energy sources	• Baseload renewable power for RPS compliance	• Lower carbon footprint
Substrate Providers		• Reduced disposal costs		
Government	• New business taxes	• Environmental cleanup	• GHG reduction	• Job creation

3.1.1 Ecology & Energy: The environmental and energy benefits of AD are many-fold, as methane is captured before atmospheric release and can in turn be used to produce renewable energy and fuel. Methane is a potent GHG that has 72 times the heat-trapping capacity of CO_2 over a twenty year period.[22] Roughly 30% of U.S. methane emissions are from livestock manure, wastewater and landfills (Fig. 6); all of which AD can address. Due to regional differences in energy production and distribution, these same sources account for 63% of Washington's methane emissions, as quantified by the WA Department of Ecology.[23]

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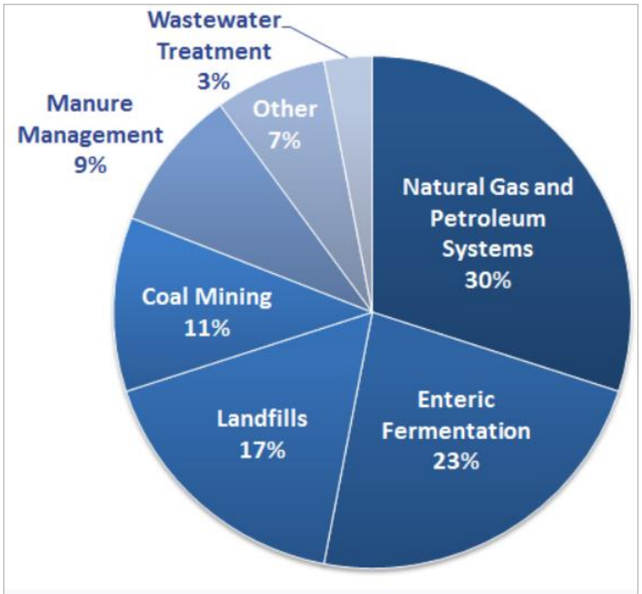
[22] US EPA, "Methane Emissions."

[23] "Washington State Greenhouse Gas Emission Inventory, 1990-2008 - 1002046.pdf."

Using biogas as a renewable power source further reduces methane emissions attributed to energy production as it can serve as a stand-in replacement for fossil fuels. Approximately one kilowatt per day of net energy can be generated with the biogas captured from the manure of four cows.[24] Surplus heat from the process can be used for such purposes as drying crops and heating water and buildings (co-generation).[25]



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2011*.

Figure 6: U.S. Methane Emissions by Source (Source: U.S. EPA)

The combustion of biogas at U.S. dairy digesters prevented the atmospheric release of approximately 68,000 tons of methane in 2011.[26] The WSDA estimated that the six digesters operating in 2011 were capturing 2,500 tons of methane annually.[27] Two additional digesters have come on-line since the WSDA report; Rainier Biogas in King County and Edaleen Cow Power in Whatcom County. Researchers at WSU project that 50,000 tons of methane could be captured each year if half of the state's dairy cows were on farms using anaerobic digesters.

As a source for renewable energy, the *waste-to-energy* conversion attained by AD is considered to be one of the most promising avenues for averting fossil fuel emissions,

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[24] "Washington Dairies and Digesters, WSDA."
[25] Ibid.
[26] Chen & MacConnell, 2006
[27] "Washington Dairies and Digesters, WSDA."

as its carbon-balance is superior to most other methods of energy production.[28] Unlike many renewable energy sources that generate power on an intermittent basis (e.g. wind, solar), biogas can provide predictable base-load power, making it an active option for utilities seeking to fulfill their obligations under Washington State's Ballot Initiative 937 (I-937). The mandate requires large utility providers to obtain at least 15% of their electricity from renewable resources (excluding existing hydropower) by the year 2020 with incremental steps of 3% by 2012 and 9% by 2016.[29] All of Washington's seventeen large utilities covered by I-937 have so far met their targets for 2012 yet a substantial challenge exists to triple this amount by 2016.

Furthermore, when biogas is "cleaned" to at least 97% pure methane it can be used as a natural gas substitute for pipeline injection or as a renewable transportation fuel. Referred to as biomethane, or renewable natural gas (RNG), refined biogas has the unique potential of benefiting from the rapidly expanding natural gas (NG) market as a renewable stand-in replacement with minimal cost to its own infrastructure. The proximity of NG pipelines to viable AD facilities in Washington is identified in this study as favoring AD development.

Biomethane is significant on a national level, as the Federal Renewable Fuel Standard (RFS) has ambitious goals for percentages of renewable fuel that must be blended into transportation fuel. As of present, ethanol is the main contributor in fulfilling RFS obligations, yet the environmental benefits of this first-generation biofuel are under serious scrutiny. Even conservative estimates suggest that the energy-intensive production of corn-derived ethanol has a very modest overall net benefit and depending

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[28] Appels et al., "Anaerobic Digestion in Global Bio-Energy Production."
[29] "Initiative 937 - I937.pdf."

on production methods, may consume more energy than it delivers.[30] When factoring in the loss of ecosystem services due to land-use conversion, there can be a net-increase of GHGs with ethanol.[31] Competition with our food supply is another factor presented with first-generation biofuels such as corn ethanol, which is not an issue with AD biogas when produced from waste material.[32] For these reasons, biogas is considered an *advanced biofuel* and is among the short-list of most desirable fuel sources.

Life-cycle models also referred to as "well-to-wheel" analyses found that biomethane derived from dairy AD offered a drastic reduction in GHG emissions between 81-97% when compared to petroleum and natural gas. The German Energy Agency concluded that biogas produced from manure for use as a transportation fuel reduces GHG emissions by 97% compared to petroleum (Fig. 7).[33] Models developed by Argonne National Laboratories produced similar estimates with their 2009 "Waste-to-Wheels" lifecycle assessment which found that biomethane derived from dairy AD and used as compressed natural gas (CNG) offered an 81-91% reduction in GHGs compared to gasoline (Fig. 8).[34] The same study found that biomethane used as a substitute for liquefied natural gas (LNG) offered an 86-94% reduction in GHGs when compared to diesel.

Environmental safeguards provided by AD processing of dairy manure have valuable benefits to aquatic ecosystems. According to the EPA, more than half of the country's fresh water sources are impaired with excessive levels of nitrogen and

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[30] Farrell et al., "Ethanol Can Contribute to Energy and Environmental Goals."
[31] Timilsina and Shrestha, "How Much Hope Should We Have for Biofuels?".
[32] Scharlemann and Laurance, "How Green Are Biofuels?".
[33] "Deutsche Energie-Agentur (DENA)."
[34] "Argonne National Laboratory - Waste-to-Wheel Analysis of Anaerobic Digestion Based Renewable Natural Gas Pathways with the GREET Model."

phosphorus, with dairy manure run-off being a major contributor.[35] Manure stored in traditional lagoons can leach into waterways and groundwater, causing eutrophication of aquatic habitats such as that exemplified by the Gulf of Mexico "Dead Zone."[36] Digesters not only prevent harmful runoff but destroy a vast majority of pathogens present in the waste material through the high-heat biological process of digestion.

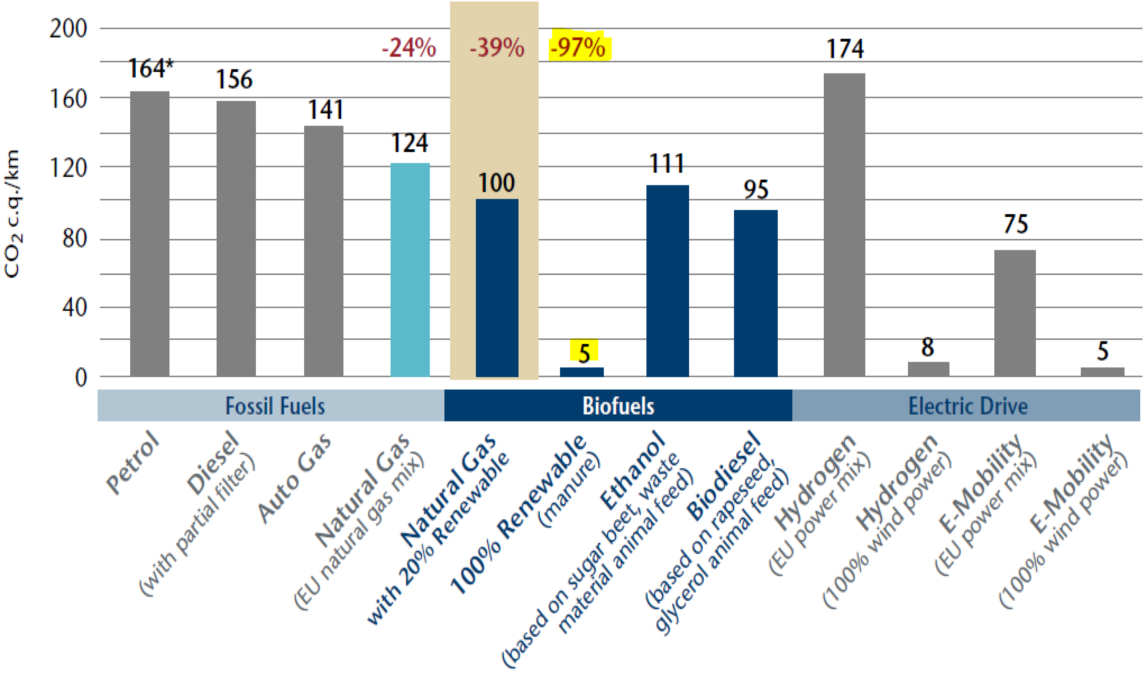

Figure 7: Well-to-Wheel GHG Emissions
(Source: DENA-German Energy Agency)

AD digestate used as a soil amendment displaces fossil fuel-based fertilizers and their associated GHG emissions. Nutrient recovery technologies currently under development enhance this process and produce concentrated nutrient products (i.e., struvite, phosphate solids) that can be sold as substitutes for industrial fertilizer. This

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[35] "Nutrient Pollution | US EPA."

[36] Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C., *Livestock's Long Shadow*.

displacement of energy in crop production can be significant, as industrial fertilizers are synthesized from atmospheric nitrogen and natural gas or mined from limited reserves using energy-intensive processes. A study conducted by the Soil Conservation Council of Canada found that the production and transport of nitrogen fertilizers was the largest source of carbon emissions in Saskatchewan.[37]

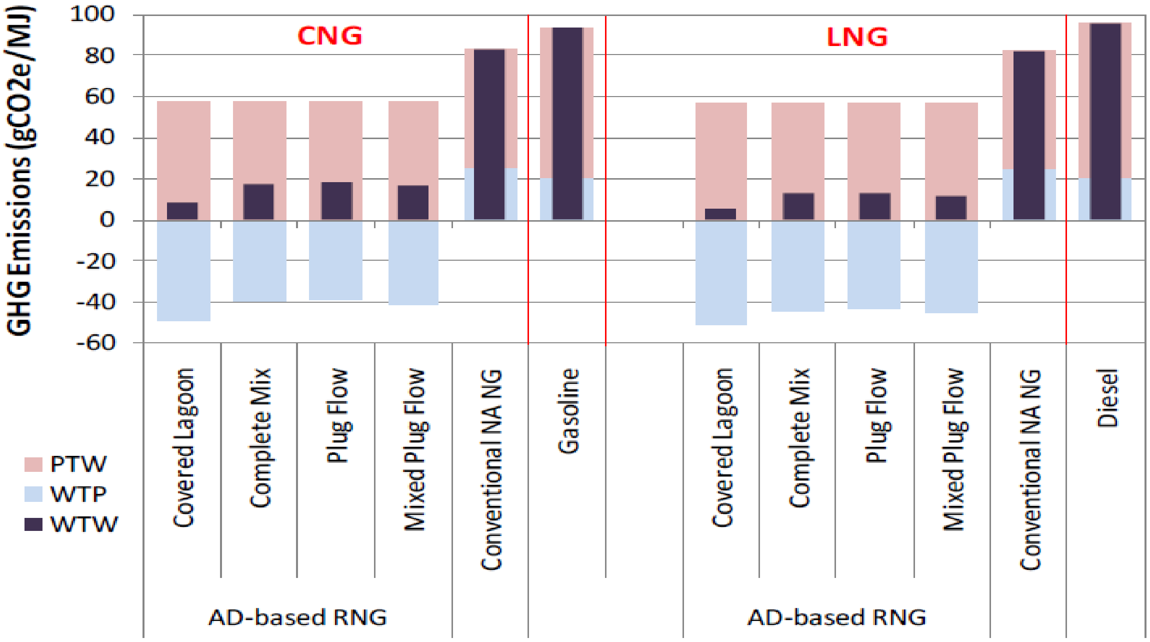

Figure 8: Emission Reductions from Use of Dairy RNG Compared to Petroleum Fuels (Source: Argonne National Laboratories)

While emissions vary between forms of nitrogen fertilizer, an average of one pound of nitrous oxide (N_2O) has a global warming potential (GWP) 300 times that of carbon dioxide on a 100-year timescale.[38] Producing and distributing synthetic fertilizer

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[37] "Factsheet 3 -Fossil Fuel.qxd - Factsheet 3 -Fossil Fuel.pdf."
[38] US EPA, "Nitrous Oxide Emissions."

requires roughly 5.5 gallons of petroleum per acre of application.[39] Additionally, over 300 billion cubic feet of natural gas is consumed in the industrial production of ammonia for U.S. crop production.[40]

It should be noted that methane released from the gastric emissions (burps and flatulence) of livestock can be reduced through selective feed choices and breeding practices. Proper balancing of proteins and carbohydrates, as well as the inclusion of lipids and ionophores, in cattle feed has been found to reduce methane release from livestock.[41] In addition, certain breeds of cattle digest feed more efficiently than others and release less methane as well as nitrous oxide from the ammonia in their urine.[42]

Concerns: A top environmental concern encountered in this research relates to the GHG emissions of biogas generators. Biogas power generation in Washington is regulated similarly to industrial power production facilities and airborne particulates and gases such as nitric oxide (NO) can exceed air quality regulations.[43] In these instances, small-scale digester owners may resort to flaring their biogas instead of using it to fuel generators for power production. The relatively small scale of digester operations can make it difficult for owners to afford the cleanest, and more expensive, technology that the larger energy sector can invest in. Further discussion regarding changing biogas emissions regulations to account for AD's net benefits is provided in section 4.5.1 on page 66.

A more global environmental concern with AD is in regards to the choice of feedstock used in the process. As noted, the models above are based on biomethane

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[39] "The Oil We Eat | Harper's Magazine."

[40] "Primer on Ammonia, Nitrogen Fertilizers, and Natural Gas Markets."

[41] Beauchemin et al., "Nutritional Management for Enteric Methane Abatement."

[42] Hegarty et al., "Cattle Selected for Lower Residual Feed Intake Have Reduced Daily Methane Production."

[43] "Investigations Of Exhaust Emission Of Biogas Si Engine - Tadeusz Borkowski."

produced from waste material, yet this carbon benefit is in question when agricultural crops are produced specifically to fuel digesters. Critics attribute this loss in carbon balance to the petroleum-intensive nature of industrial agriculture and the loss of ecosystem services such as carbon sequestration when virgin land is put into cultivation for the purpose of AD.

Although not yet an issue in the United States, primary crop production for AD (also referred to as Purpose Grown Crops (PGC)) is becoming a common practice in Europe, where biogas is increasingly relied upon for base-load power generation. A 2011 report prepared by representatives of farm organizations, land management agencies, the renewable energy sector and biogas specialists in England, titled *The Case for Crop Feedstocks in Anaerobic Digestion*, asserts that PGC have net benefits that outweigh their drawbacks.[44] However, the report identified legitimate concerns, echoed by other studies regarding the use of PGC for AD, needing further research.

PGC are generally grown in a monoculture which implies a loss of biodiversity and potential adverse landscape and environmental impacts. Additionally, when bioenergy crops are grown on margin farmland in an attempt to reduce competition with our food supply, these soils are often more susceptible to erosion and taken out of conservation for cultivation.[45] Finally, the use of PGC for AD deters the use of waste materials for AD, negating the primary sustainability trait of AD.

The Anaerobic Digestion and Biogas Association has countered these concerns in saying “PGC for AD supports food production through improved crop rotations and the

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[44] “The Case for Crop Feedstocks in Anaerobic Digestion - 120730-PGC-Briefing-Doc.pdf.”

[45] Gelfand et al., “Carbon Debt of Conservation Reserve Program (CRP) Grasslands Converted to Bioenergy Production.”

recycling of nutrients and organic matter; enhancing soil quality and reducing the need for artificial fertilizers and pesticides."[46] The dispute regarding the carbon balance of PGC for AD deserves further research on a case-by-case basis specific to production method, land type and feedstock choice.

Finally, AD presents a unique problem for farmers when they accept industrial organic waste for co-digestion. On one hand, the addition of feedstock high in fats and sugars can significantly increase biogas production and bring in substantial revenue with tipping fees. On the other hand, the addition of off-farm waste steams increases the overall levels of nutrients farmers need to manage in the end, as most remain intact throughout the AD process. If additional measures are not taken, such as *advanced nutrient recovery*, these excess nutrients can exacerbate nutrient over-loading issues.

3.1.2 Social: Primary social benefits of AD are in the environmental health safeguards provided by the destruction of pathogens and containment of nutrients. Raw animal manure seeping out of containment ponds or applied to fields as fertilizer can contain more than 150 microbial pathogens and make its way into human water sources.[47] *E-coli* poisoning has been attributed to untreated manure, while excessive nitrates in drinking water has led to cases of Blue Baby Syndrome.[48] The enzymatic process and high temperatures of AD can kill up to 99% of all pathogens (with the exception of prions) in animal waste and convert organic nitrogen into ammonia.[49]

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[46] "Crop-Fuelled AD Plants a 'Major Concern' - TFA | News | Farmers Guardian."

[47] Gerba and Smith, "Sources of Pathogenic Microorganisms and Their Fate during Land Application of Wastes."

[48] Naidenko, Cox, and Bruzelius, "Troubled Waters: Farm Pollution Threatens Drinking Water 2012/Environmental Working Group."

[49] Frear et al. 2012

Currently, one of the greatest benefits is that digesters effectively help dairy owners process their cattle manure to meet the requirements of nutrient management plans required of them by the state. Additionally, AD eliminates much of the odor of manure, which is a growing issue as residential communities are being established closer to farms. Finally, digester projects create jobs in the construction, maintenance and operation of the facility, as elaborated upon in the following section.

Concerns: One of the few social concerns regarding AD again relates to the selection of feedstock. When crops are grown primarily for AD, this can increase the demand for productive and arable farmland, hence increasing the cost of land.[50] The diversion of land use from food production can fuel a competition between bioenergy and food crops. Food price increases and food scarcity are among these concerns.

Another issue lies in the discomfort of citizens living near digester facilities. Although digesters are very effective at neutralizing odor once in the tanks, there can be significant odor when manure is trucked in and transferred to the facility. Although unlikely, there is also the eminent danger of the methane in digester tanks exploding and causing harm to people and property. According to Michigan State University Extension, there have not been any deaths associated with on-farm digesters in the U.S.[51]

3.1.3 Economic: AD projects provide economic opportunities in the construction and maintenance of digesters as well as throughout the production and marketing of value-added byproducts. Digester owners can realize significant economic benefits through the sale of biogas power and fuel, tipping fees for receiving off-site

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[50] "Crop-Fuelled AD Plants a 'Major Concern' - TFA | News | Farmers Guardian."
[51] "Stay Safe in and around Anaerobic Digesters."

waste, solids sold as compost and cattle bedding and fertilizer derived from the liquid effluent. As processes improve and markets develop, new revenue streams will emerge for nutrient recovery, biomethane/RNG and *green*-chemicals, to name a few. Washington State is leading innovative research and development in nutrient recovery from AD effluent and is home to nearly a dozen nationally renowned companies that serve the AD industry. The development and marketing of new byproducts is a chief recommendation of this research.

In addition to the sale of actual byproducts, the environmental benefits of AD are monetized in various markets and can be essential for a project's economic viability. Carbon credits account for avoided GHG emissions while renewable energy credits/ certificates (RECs) are tied to power generation and renewable identification numbers (RINs) are associated with fuel-content requirements. Economic feasibility studies and market projections are offered in Chapter 5 (Economic Evaluations).

Concerns: As discussed here, there is a great variety of financial benefits from AD, yet the economics of digesters also presents the greatest challenge for project development. Digesters are capital intensive, typically costing between two to five million dollars to construct. In order to produce an adequate amount of biogas to power a sizeable generator, farms must have at least 500 to 700 cows, depending on the manure management system used in the feedlot. This scale factor, alone, limits the opportunities for AD. Even those dairies large enough to support a digester are confronted with the challenge of financing the construction costs and training personnel to operate the facility.

The recommendations section of this study provides various avenues of funding, policy recommendations and revenue streams that could help finance AD projects. The following section provides a closer look at the economics of AD, specific to Washington State, through market reports and feasibility studies.

Market Values for AD: Although a precise monetary value for Washington's AD projects could not be identified for this study, various projections for potential revenue exist. On a national level, the American Biogas Council estimates that 644 billion standard cubic feet of biogas could be produced if all available and accessible organic waste feedstock was processed by AD. This projected amount of biogas could produce upwards of 70 million MWh of electricity; enough to power roughly six and a half million American households.[52] Although this may be an overestimation, America's biogas potential is indeed enormous and could be the foundation of a biogas industry worth billions of dollars a year.

A more detailed analysis specific to the dairy industry was calculated by Informa Economics for The Innovation Center for U.S. Dairy and published in a February 2013 report titled *National Market Value of Anaerobic Digester Products.* The study looked at the AD potential of America's 2,647 largest dairies as identified by the USEPA's AgSTAR program and accounts for the co-digestion of off-farm feedstock.

In the most likely (mid-range) commodity price scenario presented by Informa Economics, producing only unrefined biogas for electrical generation has the potential to generate $228 in revenue per cow, per year, in a dairy with an operating digester. The ability to also market fiber (as bedding or soil amendment), fertilizer nutrients, and eco-

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[52] "American Biogas Council Projections- biogas101.pdf."

system market products such as RECs and GHG offset credits, provides an additional $487 more per cow, per year, in net economic benefits. The total revue potential of the AD market for our nation's 3.9 million cows found on large dairies comes to $2.9 billion dollars.[53] Appendix G provides a more comprehensive overview of the report, yet note that market values were calculated with the national average price for electricity which is, on average, one-third higher than Washington's.

<u>Economic Projections for Dairy AD in Washington:</u> A value for AD on Washington dairy farms was estimated for this study using figures from Informa Economics and WSDA. The 2011 WSDA report titled *Washington Dairies and Digesters* indicates that 72 dairy farms (one-third of our state's dairies) are large enough (500 head of cattle or more) to sustain digesters (Fig. 9).[54]

By multiplying the number of these larger farms by their average herd size, there are approximately 197,220 dairy cows on Washington farms eligible for digesters. Equated with Informa Economic's

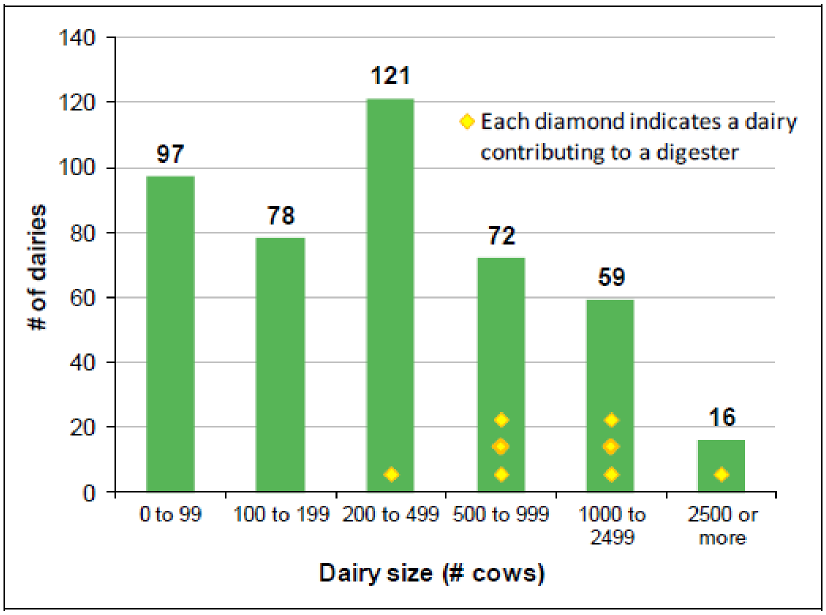

Figure 9: Washington Dairies by Size, Noting Dairies Contributing to a Digester (Source: WA Dairies and Digesters, WSDA 2011)

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[53] "National Market Value of Anaerobic Digester Products. Informa Economics"
[54] "Washington Dairies and Digesters, WSDA."

value of $715 per cow (197,220 x $715), we can estimate a potential total value for AD biogas and co-products from Washington dairy digesters to be $141,012,300 per year. This estimate excludes two-thirds of Washington's dairy cows (roughly 53,000 head of cattle) as they are on farms too small to support their own digester. If able to contribute their manure to a community digester, this could add $42 million a year of net value.

Based on the current rate of development, WSDA gives a conservative estimate that six to nine additional dairy digesters will likely come on-line by 2020.[55] If a biomethane market was to develop and nutrient recovery goals were attained, this number could be much higher and include significant community digesters to process the waste of Washington's smaller dairy operations that account for two-thirds of the state total.

Feasibility Studies: As exhibited in the preceding overview of current AD facilities and feedstock availability, it is apparent that Washington has significant potential for further AD development. Economic analyses, however, show that primary financing through biogas-generated electricity is insufficient for Washington, where received electrical sale prices are historically low.[56] Looking back at the market analysis conducted by Informa Economics, it is evident that value-added byproducts and ecosystem markets can triple the revenue stream for AD, compared to energy generation alone (Fig. 10).[57]

Two Washington-based feasibility studies conducted for WSU have shown that diary digesters need the development of new value-added co-products to be financially viable in the long term. The studies analyzed available financing mechanisms of specific digesters along with their construction and operation expenses derived from each dairy's

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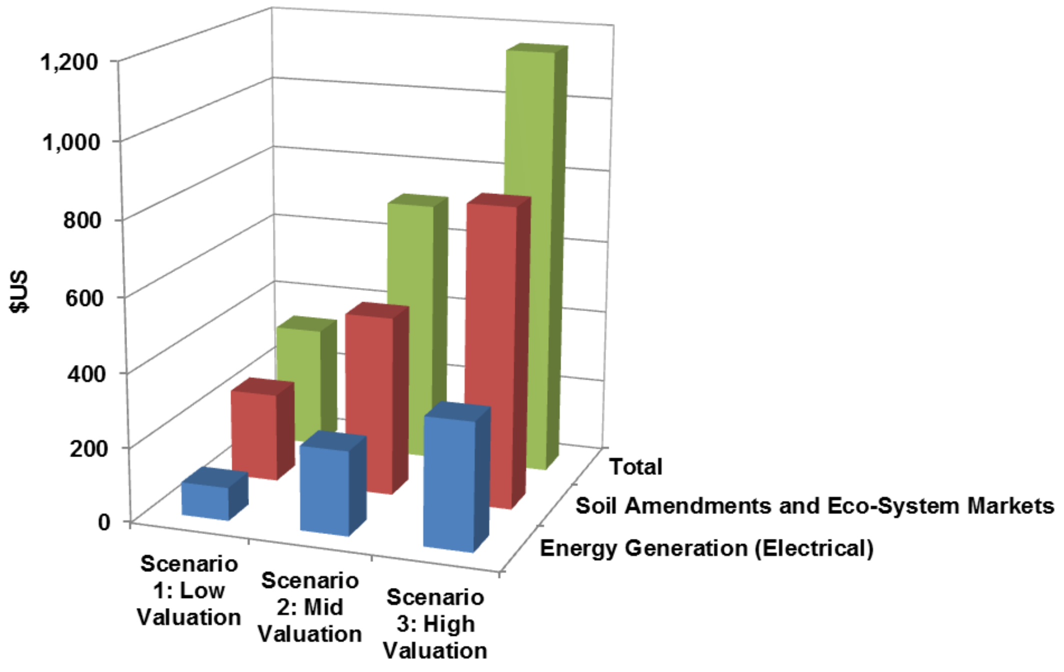
[55] Ibid.
[56] *Renewable Natural Gas and Nutrient Recovery Feasibility for Deruyter Dairy, 2012*.
[57] "National Market Value of Anaerobic Digester Products."

financial records. Analysts used common indicators to gauge economic performance with numerous byproduct marketing scenarios.

A 2009 study commissioned by the WA Department of Commerce, *The Economics of Dairy Anaerobic Digestion with Co-product Marketing*, used the VanderHaak Dairy digester in Whatcom County as a case study to evaluate the economic returns of marketing electricity, digested fiber, tipping fees and carbon trading. Value-added products such as struvite (attained through nutrient recovery), waste heat and biomethane/RNG were not assessed in their evaluation.



	Scenario 1: Low Valuation	Scenario 2: Mid Valuation	Scenario 3: High Valuation
Energy Generation (Electrical)	$90	$228	$343
Soil Amendments and Eco-System Markets	$241	$487	$811
Total	$331	$715	$1,155

🟦 Energy Generation (Electrical) 🟥 Soil Amendments and Eco-System Markets 🟩 Total

Figure 10: Fiber, Nutrient and Eco-system Market Potential (Source: Informa Economics)

Another feasibility study commissioned by the WA Department of Commerce was conducted in the Yakima Valley in 2012 and titled *Renewable Natural Gas and Nutrient Recovery Feasibility for DeRuyter Dairy*. This study projected digester revenues with several potential scenarios involving combined heat and power (CHP) generation, biogas refinement, co-digestion and the sale of digested fiber as a peat moss substitute and phosphorus-rich fine solids as fertilizer. The study concluded that the addition of biomethane/RNG and advanced nutrient recovery were necessary to uphold profits with the anticipated decline in power purchase agreement prices and RECs. Both studies concluded that AD has significant potential as a “holistic, sustainable conservation technology and energy source,” as stated in the VanderHaak study, yet “the development of new product markets must emerge.”

Summary: Unlike many waste management and energy production technologies, AD has relatively few drawbacks. The greatest obstacle for AD is economic, whereby the initial construction of a digester is capital intensive. The development of value-added co-products and incentives such as *green credits* can not only finance projects but has the potential of making them quite profitable. While there are social concerns of having digesters near residential areas, biogas power is essentially very clean and safe.

The energy and environmental benefits of AD are overwhelming, yet legitimate concerns exist. The feedstock choice for digesters is a main determinant for the overall carbon balance of AD. Depending on production methods, purpose grown crops can negate the positive environmental attributes of AD, yet this advantage can be maintained by exclusively using organic waste that would otherwise release methane upon natural decomposition. AD’s containment of nutrients and destruction of pathogens are environmental benefits with great import to the health of our nation's aquatic ecosystems. The practice of co-digestion of industrial waste in farm digesters is increasing revenue and biogas production, but also exacerbating the danger of nutrient over-loading for farms. Nutrient recovery is a viable solution for this issue, as discussed in following chapters.

3.2 PRODUCTION CAPACITY: On a national level, there are just over 2,000 biogas capture systems operating in the United States, with roughly 10% on dairy farms, 30% at landfills and 60% at wastewater treatment plants. These figures are derived from the American Biogas Council which projects that the U.S. has the potential to sustain roughly 12,000 biogas capture systems across the country (Fig. 11). Although exact figures could not be attained by this research, it should be noted that many of these biogas capture facilities simply burn off (flare) their methane instead of using it as a fuel source.

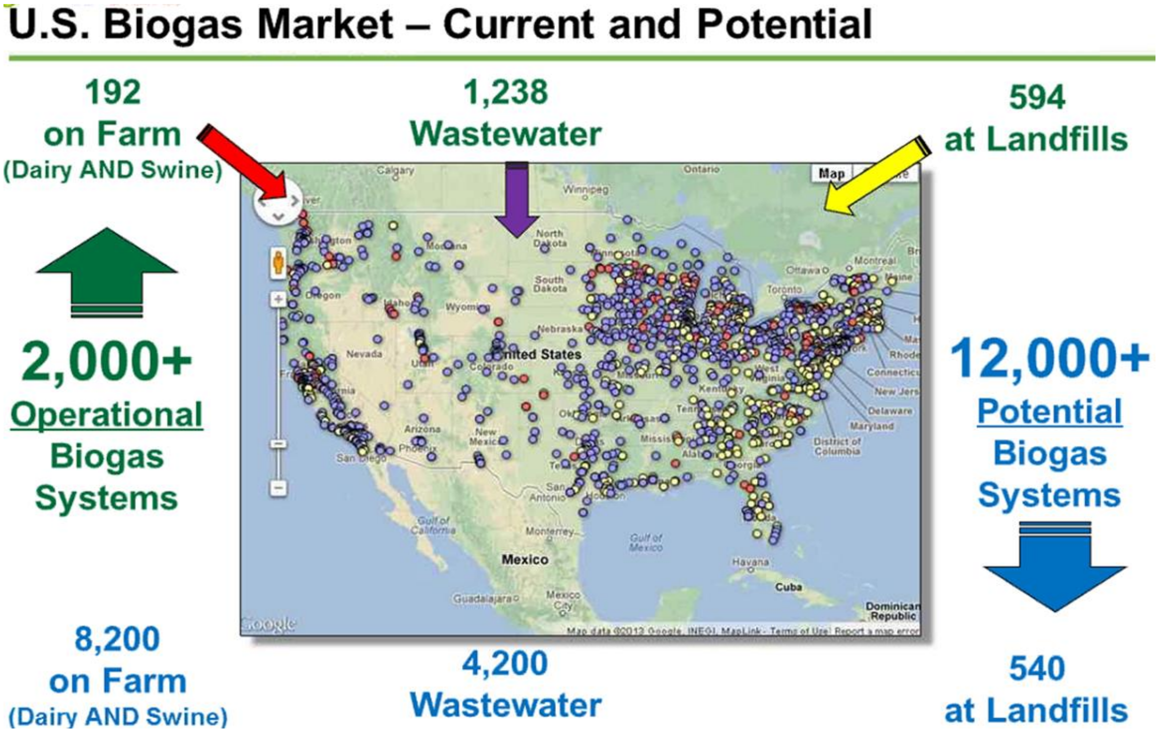
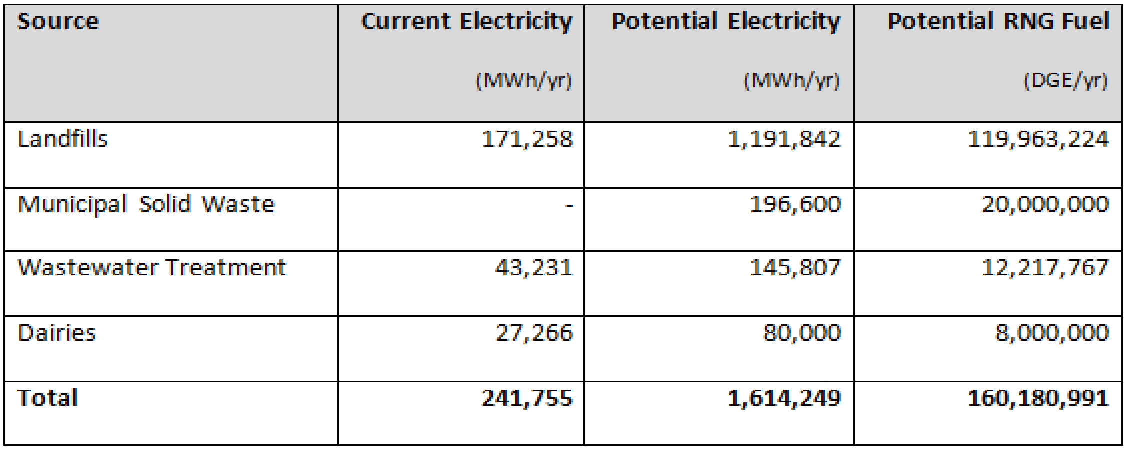


Figure 11: U.S. Biogas Production Facilities
Perimeter Data: Existing (green); Potential (blue) **Icons:** Farms (Red); WWTP (Purple); Landfills (Yellow)
(Source: American Biogas Council)

Estimates for Washington State's biogas production potential were calculated for this study in conjunction with Peter Moulton, WA Bioenergy Team Coordinator, by quantifying available feedstock amounts attained from state reports and biomass inventories. Capacity factors were assigned to each category, as the different composition (i.e., carbohydrates, proteins, fats, cellulose) of feedstock determines the quantity of biogas it will release through AD and the percentage of methane in the gas itself, ranging from 50% to 70%. Calculations were then converted into megawatt hours per year (MWh/yr) and diesel gallon equivalent (DGE/yr). The analysis shows that the state is only producing 15% of its total biogas potential from all sources, with a potential six-fold increase to 1,614,249 MWh/yr, or 160,180,991 DGE/yr, as shown below in Table II. For reference, Washington produces roughly 20 million MWh/yr of electricity from non-renewable sources, of which 7 million comes from natural gas.[58]

Table II: Current/Potential Electrical Power and RNG Production from Biogas Sources
(Source: Peter Moulton, WA Dept. of Commerce)



Source	Current Electricity (MWh/yr)	Potential Electricity (MWh/yr)	Potential RNG Fuel (DGE/yr)
Landfills	171,258	1,191,842	119,963,224
Municipal Solid Waste	-	196,600	20,000,000
Wastewater Treatment	43,231	145,807	12,217,767
Dairies	27,266	80,000	8,000,000
Total	**241,755**	**1,614,249**	**160,180,991**

MWh/yr = Megawatt hour/year **DGE/yr = Diesel Gallon Equivalent**

Data for the estimates presented in Table II were derived from available feedstock amounts from landfills, separated organics, wastewater treatment and dairies, yet do not

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[58] "2013 Biennial Energy Report - 2013-Biennial-Energy-Report.pdf."

include those from industrial organic waste which could significantly increase overall biogas production. WSU researcher Craig Frear determined that supplementing manure with 30% off-farm substrates (co-digestion) that are high in sugars, fats and oils can double biogas production.[59] This chapter offers an examination of Washington's current and potential biogas production capacities, presented in four categories: landfills, separated organics/municipal solid waste, wastewater treatment and dairies. In most instances, the metric used to quantify production capacity is in biogas units.

3.2.1 Landfills: Biogas is produced in landfills through anaerobic decomposition of organic waste such as food scraps and yard debris found in the under-layers of landfills that are void of oxygen. The American Biogas Council reports that 594 landfills in the U.S. are capturing biogas, yet most simply flare the gas to destroy the methane.

Washington has 20 active or recently closed landfills that are candidates for AD with projected yields of at least 4 million cubic meters of biogas per year over the next 10-15 years. These facilities are detailed in Appendix A. The combined energy production potential of all 20 landfills is estimated to be 1,191,842 MWh/yr – enough to meet the annual electrical demand of 105,000 average homes. If refined into RNG, this potential gas has the energy equivalent of 119,963,224 gallons of diesel (DGE). While most Washington landfills have some degree of methane capture, only four use the biogas for power production, with one refining it into biomethane, as shown below.

- Roosevelt Landfill: Power production (10.5 MW)
- Tacoma Landfill: Power production (1.9 MW)
- Hidden Valley Landfill: Power production (1.6 MW)
- Cedar Hills Landfill: Power production (4.7 MW) and pipeline injection (10,000 scfm)

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[59] "Biomethane from Dairy Waste. 2005."

Case Study: The Cedar Hills Landfill has an estimated 33 million tons of waste in place and injects about 10,000 scfm[60] of refined methane into the nearby natural gas pipeline while producing an additional 4.7 MW of electrical power (Fig. 12). Processing efficiency varies between 80-92 percent based on the volume of gas collected. Once the commissioning stage is completed and the facility is operating at full capacity, it is expected to deliver about 5.5 million cubic feet of gas per day, which is enough to power about 24,000 homes. Proceeds from the sale of the gas will help keep solid waste disposal rates low and will provide approximately $1 million annually to the Solid Waste Division.[61]

Figure 12: Cedar Hills Gas Processing Center (Source: Ingenco)

The LRI 304th Street Landfill will soon begin a three-phase project to generate power and produce RNG for their truck fleet. Projected biogas amounts are expected to produce 4.8 MW of power and over 6.6 million DGE of RNG, or enough to operate roughly 1,170 trucks driving 25,000 miles per year.[62] Power generation from biogas is also planned for the Greater Wenatchee Landfill.[63]

The majority of landfills that qualify for large-scale methane capture projects are located near major natural gas pipelines, as illustrated in Appendix D. This proximity would allow biogas to be cleaned and injected into the existing pipeline infrastructure with minimal delivery costs. Yet a unique obstacle exists for landfill gas in that Washington is making considerable efforts to divert organic waste from landfills. A

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[60] scfm = standard cubic feet per minute
[61] "Cedar Hills Regional Landfill - King County Solid Waste Division."
[62] "Landfill Gas-to-CNG Development Project at the LRI Landfill. 2012."
[63] "Greater Wenatchee Regional Landfill and Recycling Center."

generator technician for a Washington landfill, who wished to remain anonymous, stated in an interview, “The trash we’re getting has less and less organic waste since the state has promoted composting and is collecting stuff like yard debris. I suppose this is good for them but it doesn’t help us out with producing biogas here at the landfill.”

3.2.2 Separated Organics/Municipal Solid Waste: A more efficient method of capturing biogas from our waste stream lies in the diversion of organics from landfills for dedicated anaerobic digestion. The *National Market Value of Anaerobic Digester Products* report estimates that 18.8 million tons of organic substrates could be diverted to digesters in the U.S. if collection systems were in place. The report states that if separated organics were used in co-digestion this would provide the single largest environmental benefit of AD, with an estimated 13 million metric tons of CO_2e (carbon dioxide equivalent) gas not being emitted into the atmosphere - the same as removing 3.2 million automobiles from the road (Fig. 13).[64] A report prepared by New York City found that AD and thermal gasification were less costly on a commercial scale than traditional waste export practices and offered better environmental performance.[65]

To encourage the separate collection of organic waste from Washington residences, many municipalities provide free curb-side pickup of such material, as shown in Figure 14. The WA Department of Ecology’s Waste-to-Fuels Technology Project, in partnership with WSU’s Biological Systems Engineering Department, is developing a municipal organics high-solids anaerobic digester (HSAD) that is expected to reduce transportation and landfill costs, while producing more biogas. This development would

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[64] “National Market Value of Anaerobic Digester Products.”

[65] “Evaluation of New and Emerging Solid Waste Management Technologies.”

directly support the state's Beyond Waste Initiative and help fulfill challenging climate policy goals established by the legislature.

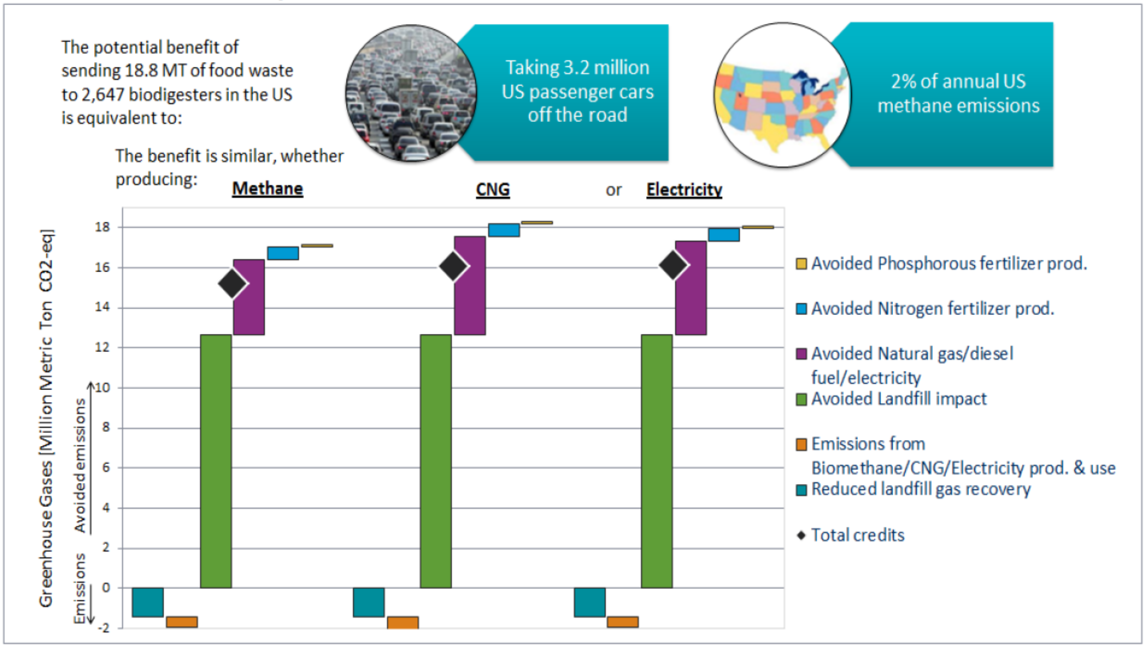


Figure 13: Benefits of Organic Waste Diversion in Digesters
(Source: Analysis and graphic provided by Quantis, Sept. 2012)

ORGANICS RECYCLING

Yard Waste • Food Scraps • Food-Soiled Paper

Place these items in your organics recycling bin

Breads & Grains
Baked goods, beans, bread, pasta, pizza, rolls

Fruits & Vegetables
All fruit and vegetables

Meats & Dairy
Bones, cheese, dairy items, egg shells, meat scraps, seafood

Food-Soiled Paper
Food cartons, pizza boxes, paper towels, paper napkins, paper plates & cups, paper grocery & lunch bags, paper take-out containers, produce boxes, waxed cardboard boxes, gable-top milk & juice cartons

Plant & Yard Waste
Brush, floral & tree trimmings, grass, leaves, weeds, wooden crates

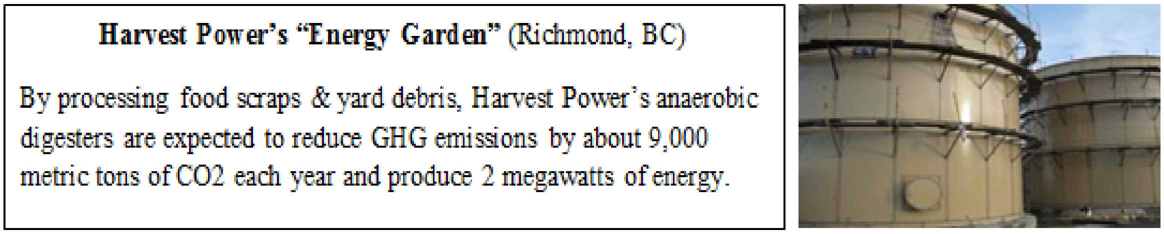
No plastic bags

Questions?
Call your LeMay Enterprise hauler or go to www.lemayinc.com.

Not accepted: No plastics of any kind, including plastic bags. No Styrofoam, cellophane, foil, foil juice pouches, fruit stickers, glass, grease, liquids, metal, or oil. No rocks, sod, treated or painted wood. No feminine hygiene products, toilet tissue, cigarettes or animal waste.

Figure 14: Separated Organics Curbside Collection - Olympia, WA

While an HSAD facility being developed by the WA Department of Ecology and WSU will be the first of its kind in the state, a successful model is in operation just over the border in Richland, Canada (Figure 15). Project developers have been working with Seattle, Tacoma, Everett and Spokane to explore HSAD technologies as a new waste management strategy for their metropolitan areas.



Harvest Power's "Energy Garden" (Richmond, BC)

By processing food scraps & yard debris, Harvest Power's anaerobic digesters are expected to reduce GHG emissions by about 9,000 metric tons of CO2 each year and produce 2 megawatts of energy.

Figure 15: HSAD Digester in Richmond, BC (Source: Harvest Power)

A statewide study by the WA Department of Ecology found that over 35% of the state's waste stream was organic material such as food waste, paper products, and yard debris.[66] Capturing biogas from these materials through HSAD can be a valuable addition to existing composting practices. Burned for power generation, the biogas would generate an estimated 196,600 MWh of energy – enough to meet the annual electrical demand of 15,000 homes in Washington State – or close to 20 million DGE of RNG.[67]

3.2.3 Wastewater Treatment Plants: Anaerobic digestion has been used to manage sewage since its first application in the 19th century. In many parts of the world, AD is the primary treatment given to municipal wastewater.[68] Nationally, 1,238 wastewater treatment plants (WWTP) produce biogas and 837 of them use its energy in

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[66] "Organic Materials Management - WA State Department of Ecology."
[67] "Peter Moulton, WA Dept. of Commerce Bioenergy Coordinator."
[68] Dr. Arthur Wellinger, *Biogas Production and Utilisation*.

one form or another.[69] A total of 292 WWTP generate electricity from biogas, of which 74 deliver surplus power to the grid and 25 refine it into biomethane for pipeline injection.[70]

In Washington, about 50 of the 330 municipal WWTP use AD to produce biogas. Appendix E shows the location and status of WWTP in the state and their favorable proximity to NG pipelines for RNG injection. Most WWTP flare their biogas, or use it for on-site facility heating or to dry biosolids. Only three use the biogas to produce electricity. West Point Seattle generates 4.6 MW and supplies one-third of its on-site power needs. LOTT Alliance WWTP in Olympia generates 335 kW for its on-site power needs and uses waste-heat from the digestion process to heat a local children's museum and government buildings. South Renton generates 8 MW and refines 80% of its biogas for pipeline injection, pictured in Figure 16.

Figure 16: One-MW generator at King County South Treatment Plant (Source: King County Dept. of Water)

A 2011 report from the EPA titled *Opportunities for Combined Heat and Power at Wastewater Treatment Facilities* indicates that WWTPs with inflows of five million gallons or more have sufficient source material to economically pursue combined heat and power. Appendix B provides further detail on each candidate facility. The 26 WWTPs in Washington that process at least five million gallons a day (MGD) of wastewater have a combined energy production potential of 145,807 MWh/yr, or 12,217,767 DGE/yr of RNG. This energy/fuel potential could be tripled through co-digestion if energy-dense food and beverage waste is added. Furthermore, The EPA has

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[69] "Operational Landfill Biogas Facilities, American Biogas Council."
[70] "Http://www.biogasdata.org/."

since revised this threshold downward to include WWTP with inflow as low as one million gallons, allowing even more plants to consider AD.

Figure 17: J.R. Simplot Digester (Source: J.R. Simplot)

Industrial Waste Treatment: Energy-rich industrial waste, especially that which is discarded from food and beverage processing, has considerable biogas potential. Food waste substrates can produce up to 15 times the methane as cattle manure can due to its high levels of sugars, fats and oils, yet few industrial AD projects have been established in Washington.[71] Agri-Beef in Toppenish and the J.R. Simplot potato processing plant in Moses Lake (Fig. 17) provide good examples of the services an AD system can provide to the industrial sector. Simplot's twenty million-gallon digester treats wastewater on-site, producing biogas used to heat the facility's process water. Methane captured by Simplot's system generates about 38,000 carbon credits a year and is equivalent to removing 7,300 cars from the road.[72]

3.2.4 Dairy Operations: Agriculture generates a variety of organic waste that may be suitable for AD, but manure from dairy operations has been the primary focus of farm-based digesters due to the pressing need to safely manage manure. Dairy digesters provide an opportunity to produce a significant amount of renewable energy while managing nutrients, protecting water quality, and bringing economic benefits to dairies, digester owners, and a variety of associated businesses, as previously shown in Table 1 (page 16). The USDA and the national dairy industry have agreed to reduce carbon

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[71] "The Benefits of Anaerobic Digestion of Food Waste At Wastewater Treatment Facilities, USEPA."
[72] "J.R. Simplot 2011 Sustainability Report.pdf."

emissions twenty five percent from dairies by 2020, with a goal of having 1,300 ADs operating across the country by 2020.[73]

Washington State has approximately 450 dairies, 147 of which are considered large enough by WSDA criteria (at least 500 cows) to consider AD. These dairies house about three-quarters of the state's 250,000 dairy cows, yet only 6% of the cattle have their manure processed by AD.[74] At a production rate of roughly 27 tons of manure per cow, per year, Washington's dairy cows produce about seven million tons of manure annually. According to the USDA, the manure from an average milking cow can produce 47 cubic feet of biogas a day.

Washington currently has eight dairy digesters (192 nationwide) with the electrical generation capacity of 4,150 kW, for which details are shown in Appendix C. This equates to 36,378 MWh/yr, yet only 27,266 MWh/yr is produced due to regulatory obstacles such as those discussed herein. Most of Washington's digesters produce enough electricity with on-site generators for their own use and sell excess power to their local utility. Residual heat is used to support digester operation.

As one of the nation's top ten dairy states, Washington is considered a prime market for dairy digesters. Appendix F shows the location and size of the state's dairy operations. Researchers at Washington State University (WSU) estimate that approximately half a million metric tons of CO_2e could be captured each year if the state's 147 largest farms were to implement AD. The total GHG offset would rise to 2.5 million metric tons CO_2e each year if manure was co-digested with 30% suitable

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[73] "Agriculture Secretary Vilsack, Dairy Producers Sign Historic Agreement to Cut Greenhouse Gas Emissions by 25% by 2020 | USDA Newsroom."
[74] "Washington Dairies and Digesters, WSDA."

municipal solid waste and the displacement of fossil fuels through biogas power was accounted for, as determined by this research. This offset is equivalent to the annual emissions of 520,000 passenger vehicles, or the complete energy needs of 128,000 average homes.[75]

Co-digestion: Biogas yields at dairy digesters can be significantly enhanced with the addition of high energy feedstock such as food and beverage processing waste. Washington regulations allow for up to 30% off-farm source materials without additional permits. Biogas production typically doubles when manure is mixed with 20-30% organic solids. When off-farm organics are from local sources, GHG mitigation can occur by eliminating long distance hauling to landfills.

Laboratory and field trials led by WSU researcher Craig Frear showed that co-digestion, as compared to manure-only digestion, allowed for more preferred levels of key micronutrients, neutral pH, and additional alkalinity.[76] A significant benefit of co-digestion for digester owners is the addition of 'tipping fees' charged to receive off-farm waste. Contracts to receive and process supplemental waste from facilities such as food and beverage processing plants can triple digester revenue. As stated by Frear, "Results showed a 110% increase in biogas production and a tripling of gross receipts with 72% of all receipts being directly due to substrate supplementation."

An obstacle encountered by co-digestion is that this addition of nutrient-rich substrates leads to a significant increases in total nitrogen and phosphorous loading to the

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[75] "Greenhouse Gas Equivalencies Calculator | Clean Energy | US EPA."

[76] Frear et al., "Evaluation of Co-Digestion at a Commercial Dairy Anaerobic Digester."

farm.[77] The development of nutrient recovery technology would help resolve this issue of exacerbated nutrient overloading issues and further increase potential revenue from co-digestion, as discussed in Section 4.2.1 (page 48).

Summary: An analysis of current conditions shows that digesters are being successfully used in all major sectors and that adequate technology and plentiful feedstock is available. An assessment of feedstock and viable facilities shows that Washington is only using 15% of its readily accessible feedstock with a potential six-fold increase to 1,614,249 MWh/yr, or 160,180,991 DGE/yr. Another analysis performed for this thesis estimated that AD products from Washington's dairy digesters have a potential annual value of over 140 million dollars if one-third of the state's digesters used AD and were able to market its products. If the remaining smaller farms were able to contribute their manure to a community digester, this could add another 42 million dollars a year of net value.

A review of feasibility studies reveals that the main hindrance to AD development is the state's low electricity prices, which inhibits the conventional financing model for digesters of selling biogas-generated power. The following chapter presents avenues that can assist in the development of AD through supportive policies, marketable products and monetization of AD's environmental value.

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[77] Ibid.

4. DISCUSSION & RECOMMENDATIONS

This chapter offers pathways that would help promote AD as an environmental mitigation strategy, renewable energy/fuel source, and robust sector of Washington's *green* economy. These recommendations are based on an extensive review of the current AD market, ongoing research, policies, incentive programs and existing models that have already demonstrated success. Recommendations are presented in four categories; biomethane, research/development priorities, development models, and funding/policy.

4.1 BIOMETHANE: Biogas from AD has the unique ability to be used not only to produce heat and electricity but as a portable transportation fuel and stand-in replacement for natural gas. Once biogas has been "scrubbed" of carbon dioxide and other impurities to natural gas standards (around 97% pure methane) it is referred to as biomethane or renewable natural gas (RNG). RNG can be injected into natural gas pipelines or compressed for use as a transportation fuel. The later gives it a particularly valuable asset of being able to serve as a renewable transportation fuel. Figure 18 illustrates a potential production and market pathway for RNG.

The Energy Independence and Security Act of 2007 established the Renewable Fuel Standard (RFS) program which mandates that 36 billion gallons of renewable transportation fuels must be a mix of our overall use by 2022 with 21 billion gallons coming from advanced biofuels such as biomethane, as shown in Figure 19.

Peter Moulton, Coordinator of the Washington Bioenergy Team, recognizes the current obstacles for RNG in stating, "Although recent technological advances have reduced costs and improve efficiencies, scrubbing remains an expensive process. Until natural gas prices increase, direct marketplace competition won't favor an investment in biogas scrubbing. The challenge for RNG developers is to find markets that monetize the environmental attributes of their product."[78]

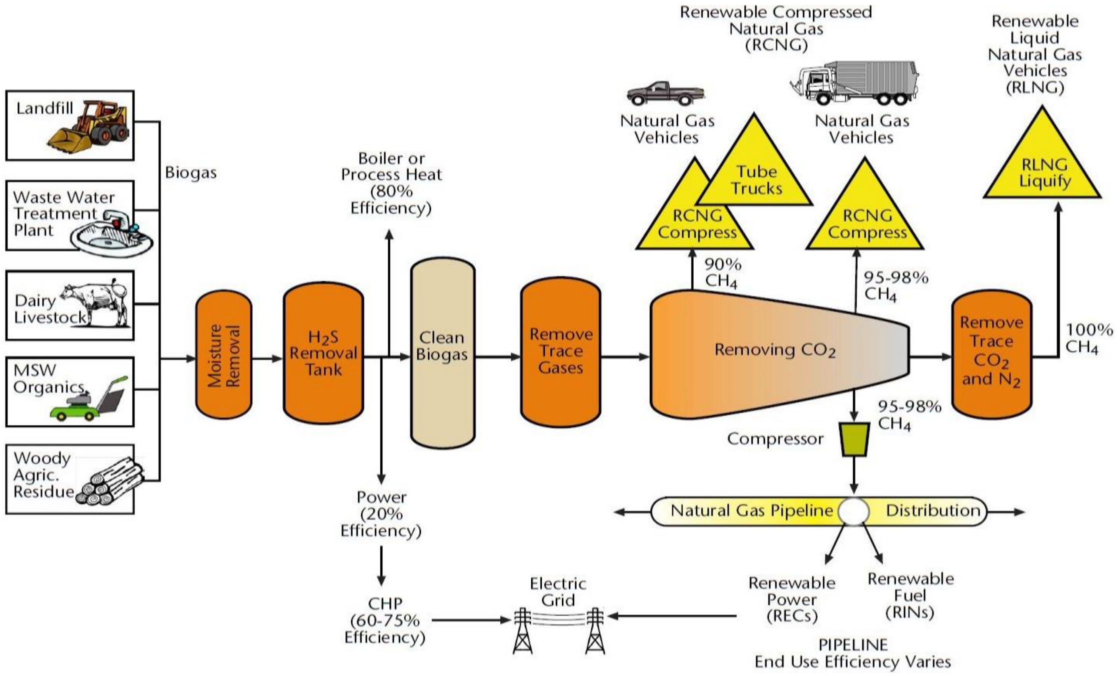

Figure 18: Biogas Upgrading and End-Use Pathways
(Source: Biomethane for Transportation, WSU Ext. Energy Prog. 2011)

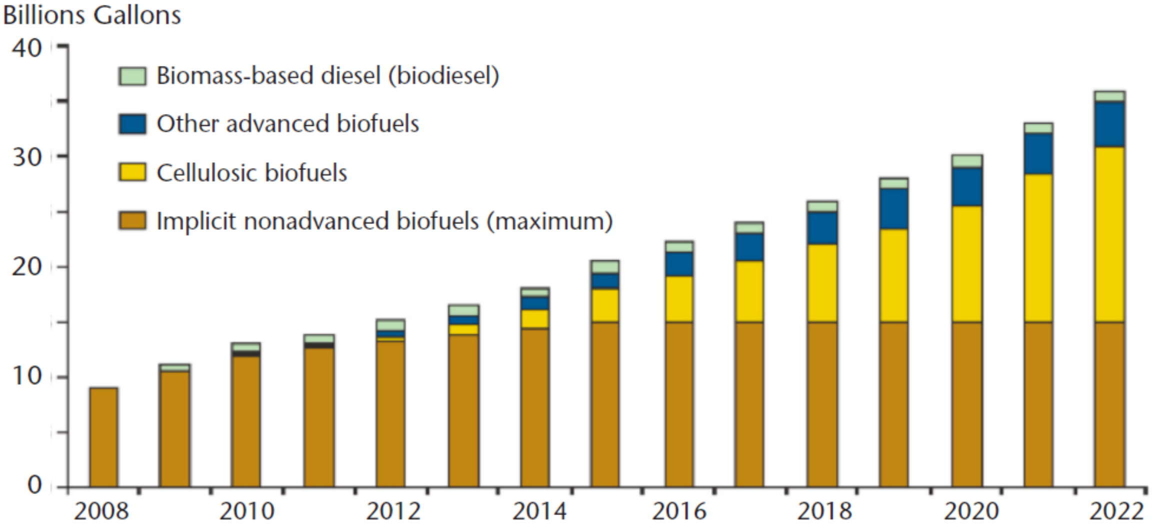

Figure 19: Renewable Fuel Standard Mandates, by Type
(Source: Biomethane for Transportation, WSU Ext. Energy Prog. 2011)

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[78] Peter Moulton. 11 Mar. 2013, interview.

Although biomethane remains a very small part of the overall gas market (20,381 vehicles in 2012), relegated mostly to specific fleets such as garbage trucks, the expanding natural gas market is creating a distribution infrastructure that can also serve biomethane.[79] As shown by the maps in Figure 20, and detailed in the appendix, the majority of feedstock sources are within close proximity to NG pipelines. This proximity allows for delivery of RNG with minimized investment in new infrastructure.

Peter Moulton adds that the use of compressed natural gas vehicles has been growing as public and private fleet operators seek clean and affordable transportation fuels. As RNG derived from AD of waste material can qualify as an advanced biofuel under RFS, additional benefits can be attained through RINs associated with RNG. Used to track RFS compliance, RINs remain a separate commodity from the fuel itself and are afforded similar benefits to that of renewable electricity production.

Wholesale distribution of RNG requires pipeline delivery to customers in various locations on the natural gas pipeline grid. RNG values are set by the applicable index price for natural gas (e.g., Sumas Index), plus any green premium such as RINs or RECs, minus a negotiated share for the reseller. As noted by Peter Moulton, “The logistics needed to access these markets are capital intensive and, although they offer profitable scenarios, the debt, unreliability of green credits, and operational risk can impede adoption.”

To envision the potential future for RNG in America, we can look at its current development status in Europe, which leads the world in large-scale AD installations and biomethane powered vehicles. Sweden has the strongest RNG market, with over half of

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[79] “Biomethane Shows Market Promise, at Least in Europe. Navigant Research.”

their natural gas enabled vehicles running on biomethane. Italy sells roughly 160,000 natural gas vehicles each year, many of which are fueled in part by RNG.[80]

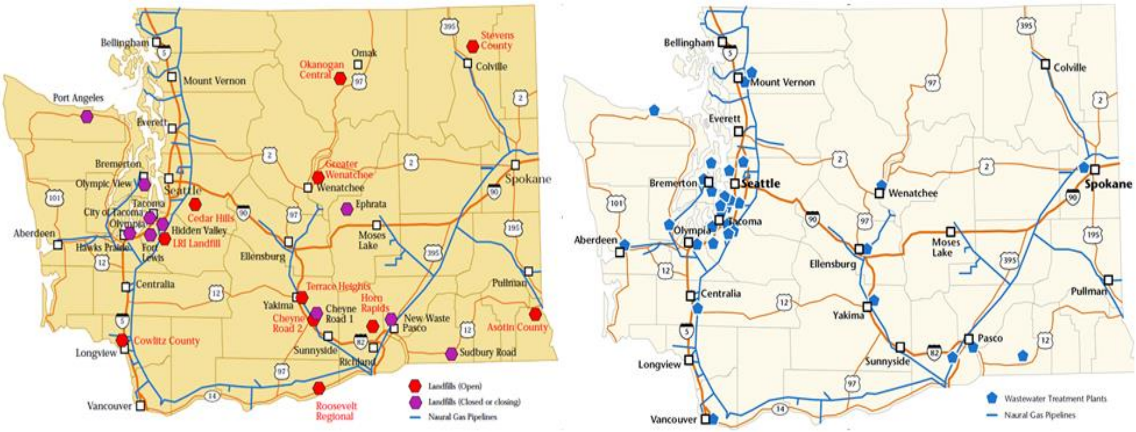

Figure 20: WA State Maps Showing Proximity of AD Feedstock (icons) to Major NG Pipelines (blue lines). Landfills on Left, Wastewater Treatment Plants on Right

(Source: Biomethane for Transportation, WSU Ext. Energy Prog. 2011)

4.2 RESEARCH & DEVELOPMENT PRIORITIES: Extensive research and collaboration between industry and government are producing major andances in value-added co-product development, including WSU-patented processes for the production of a peat moss substitute and concentrated fertilizer. These efforts are largely driven by public investment in state and national research institutions and resource agencies. Increased support is needed to further this research and promote market opportunities for new co-products.

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[80] Ibid.

4.2.1 Nutrient Recovery: Nationally, 36% and 55% of large feedlots dairies are in a state of nitrogen (N) and phosphorous (P) overload, respectively.[81] Meanwhile, much of the world's farmland is nutrient-deficient, and largely reliant on a fossil fuel-intensive form of nitrogen, anhydrous ammonia, when manure is insufficient as a soil amendment.[82] Over one hundred million tons of nitrogen fertilizer is applied worldwide each year and the costs, economic and environmental, are rising. The market for renewable, economical and biologically-sourced fertilizer, such as that possible through nutrient recovery, will only grow with time.

Raw manure fertilizer contains an abundance of organic elements such as N and P that take more time to be absorbed by plants than they are given. The runoff of excessive nutrients into waterways and groundwater create severe effects such as the Gulf of Mexico "Dead Zone" and Blue Baby Syndrone. The use of AD effluent by farmers is preferred over raw manure since the AD process removes carbon from nutrients such as nitrogen and phosphorus, creating an inorganic form of the elements that is more readily absorbed by plants. [83] Due to the digestion process, AD effluent is relatively odorless and pathogen-free. However, the levels of nutrients present in both the digested and non-digested versions are often too high for the limited acres of land to which dairies can apply their liquid, putting dairy operators at risk of exceeding their nutrient management plans.

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[81] "Nutrient Management and the U.S. Dairy Industry in 2002. USDA."

[82] Davidson, "The Contribution of Manure and Fertilizer Nitrogen to Atmospheric Nitrous Oxide since 1860."

[83] "Commercial Demonstration of Nutrient Recovery of Ammonium Sulfate and Phosphorus Rich Fines from AD Effluent (S. Dvorak, PE and C. Frear, PHD)."

Digester owners are starting to accept more and more off-farm waste as co-digestion can significantly increase biogas production and bring in additional revenue through tipping fees. This only exacerbates the problem of managing on-farm nutrients as they are retained throughout the AD process. Nutrient recovery is the process of extracting nitrogen and phosphorus from AD byproducts to allow for the efficient transport and profitable sale of these concentrated nutrients to other farms in need of these elements.

Researchers at WSU are leading the development of AD nutrient recovery processes that actively recover large fractions of N and P in the form of ammonia-based solids. The first nutrient recovery system in Washington was established in 2009 at Vander Haak Dairy near Lynden by FPE Renewables. Figure 21 shows trial studies, an experimental digester and phosphorus solids. The system, patented by WSU, can recover up to 80% of phosphorus and nitrogen from the digestion process.[84] A similar digester, also based on WSU research, was recently installed at Rainier Biogas near Enumclaw, Washington.

Phosphorus recovery from livestock wastewater in the form of struvite has been demonstrated at the Qualco Energy digester, reducing total phosphorus in the effluent by 60-80%.[85] Current collaborative research efforts by WSU and Multiform Harvest include process refinements to reduce costs, improve struvite particle size, and further tailor effective performance with dairy manure. State support for research and development is needed to ensure that Washington continues to lead the way.

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[84] S. Dvorak, PE1 and C. Frear, PHD, *Commercial Demonstration of Nutrient Recovery of Ammonium Sulfate and Phosphorus Rich Fines from AD Effluent*.

[85] “Commercial Demonstration of Nutrient Recovery of Ammonium Sulfate and Phosphorus Rich Fines from AD Effluent (S. Dvorak, PE and C. Frear, PHD).”

Figure 21: Nutrient Recovery Trial Studies, VDH Experimental Digester & Phosphorous Solids End-Product (Source: Washington State University)

4.2.2 Bio-Based Commodity Chemicals: The AD process can be adjusted to produce high concentrations of acids, alcohols, ketones, polymers and other unique products that can displace equivalent commodity chemicals derived from fossil fuels. These biorefining processes are similar to petroleum refining, except that renewable biomass feedstock is used in lieu of crude oil. Such “green chemistry” applications have the potential to increase the economic viability of AD while providing manufacturers a means of addressing environmental and safety issues posed by conventional chemicals.

The Washington State Department of Ecology recently released their *Roadmap for Advancing Green Chemistry in Washington State*, highlighting the importance of bio-based chemical innovations for the state’s *green jobs* market and environmental mitigation efforts. The report states that better research coordination and capacity building are needed to integrate green chemistry into Washington State’s efforts to transition to a greener and more sustainable economy. Strong links between technical and business interests and collaborative training are key to the adoption and implementation of green chemistry.[86]

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[86] “A Roadmap for Advancing Green Chemistry in Washington State - 1204009.pdf.”

4.2.3 Pyrolysis of AD Solids: Ongoing research is being conducted into the benefits of processing residual AD solids through pyrolysis. Pyrolysis is the process of heating organic material in an oxygen-limited environment. Due to the lack of oxygen, the material does not combust and the chemical compounds (i.e. cellulose, hemicellulose and lignin) thermally decompose into oils, gases and a charcoal-like substance referred to as biochar.[87] The byproducts have potential for use as a soil amendment and to sequester carbon, while capturing additional energy potential through gasification. University of Illinois researcher, Dr. Wei Zheng, explains, "Bio-oil and syngas can be captured and used as energy carriers. Also, bio-oil can be used at petroleum refineries as a feedstock that is greenhouse gas-neutral and renewable."[88]

Researcher and product developer, John Miedema (BioLogical Carbon LLC), has pioneered a process to create biochar from AD solids (Fig. 22). Miedema states the following regarding the multiple benefits of the process:

Figure 22: Biochar from AD Solids (Source: michiganbiochar.com)

> Biochar production, in conjunction with agricultural systems, provides the opportunity to use byproducts such as AD solids in an economic and environmentally beneficial manner. Biochar production technologies utilize about one-third of the biomass to power the system, whereby the rest is converted to marketable products. Biochar carbon compounds are very stable in soil as compared to the carbon compounds present in fresh organic matter. Biochar contributes to carbon sequestration, long-term soil fertility, and it can assist in the remediation of contaminated soils and ground water. Current research is looking at producing biochar from AD solids and allowing it to absorb AD liquid effluent as an efficient transport medium for nutrients to cropland.[89]

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[87] "Sustainable Biofuels and Co-Products : What Is Pyrolysis?".

[88] "Biochar and Carbon Sequestration - Illinois Sustainable Technology Center - University of Illinois."

[89] John Miedema. 28 Jan. 2013, interview.

As a soil amendment, biochar has shown the ability to regulate soil moisture, reduce erosion and help reestablish mycorrhizal layers; the latter of which is vital when converting to no-till farming. Studies have shown that biochar can also enhance nutrient cycling, lower soil density and reduce leaching of pesticides and nutrients to waterways.[90] While having the potential of improving agricultural productivity and reducing runoff, biochar has a global benefit of fixing carbon for long periods. Carbon-dating of biochar has found some samples to be over 1,500 years old with their carbon structures intact.

Compounding benefits may be attained when biochar through pyrolysis is combined with nutrient-rich AD effluent, as mentioned by Miedema. A limiting factor in the use of AD nutrients is the expense of transporting the heavy liquid slurry, yet if the nutrients were to be absorbed in biochar granules, a multi-purpose soil amendment could be extremely valuable. Furthermore, trial studies have shown that biochar can recover upwards of 32% of the phosphorus in AD effluent, potentially helping to minimize nutrient overloading issues for dairies.[91]

While biochar production from AD solids may have compelling benefits, rigorous research needs to quantify the full range of its effects. A recent scientific review has brought to light concerns that biochar from waste material may introduce undesired contaminants into soils, increase weed growth and negatively affect the pH and electrical conductivity of agricultural soils.[92]

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[90] Laird, "The Charcoal Vision."

[91] "Biochar Produced from Anaerobically Digested Fiber Reduces Phosphorus in Dairy Lagoons [J Environ Qual. 2012 Jul-Aug] - PubMed - NCBI."

[92] *Biochar Application to Soil: Agronomic and Environmental Benefits and Unintended Consequences, Kookana et Al. Advances in Agronomy 112*.

4.3 PROJECT DEVELOPMENT MODELS: The need for new AD development models is evident in the fact that only six percent of dairy farms have digesters in operation despite their multitude of benefits. When developing AD projects, both individualized and collective approaches are needed to maximize the profitability and end-use of byproducts. This may involve the integration of facilities, partnerships between stakeholders or innovative financing mechanisms. This section offers recommendations based on successful development models encountered while researching this topic.

4.3.1 Partnerships*:* Alliances between stakeholders can help share costs of AD projects, strengthen political representation and foster integrative approaches to environmental stewardship, agriculture and distributed energy/fuel production. For these purposes, there is currently an effort to form a partnership between the Roza Irrigation District and local dairies. Their hope is to advance AD in the Yakima Valley by combining resources and bolstering political representation.

One such partnership that already exists was formed over a decade ago between the Sno/Sky Agricultural Alliance, Tulalip Tribe, and Northwest Chinook Recovery in the Snohomish Valley just north of Seattle. The project has successfully bridged cultural values, environmental issues and economic interests. Property and funds were contributed by the aforementioned partners to construct an anaerobic digester to convert the waste from 1,300 cows into renewable energy produced from the biogas. Qualco Energy was formed through this effort to run the digester's power production while helping to mitigate water pollution and assist dairies in fulfilling their nutrient management plans.

Qualco's facility currently produces 450KW of electricity but has the capacity to produce 1.2MW. The disparity between actual and potential power production is symptomatic of policies and regulations that have hindered AD development. Many of the policy recommendations offered herein would support the development of collaborative projects such as Qualco's.

Another partnership approach is to collectively invest in larger centralized digesters built to serve multiple farms at once. Appendix F shows how Washington's dairies are generally clustered, favoring the use of community digesters. Around 70% of Washington's largest dairies are located in the Yakima Valley and Columbia Basin, while small to medium sized dairies are typically found in western Washington. As discussed on page 29 (Section 3.1.3), if smaller dairies were able to contribute to community digesters this could add another 42 million dollars of net economic benefit to the projected value of 141 million dollars for the larger dairies.

Rainier Biogas, near Enumclaw, is an example of a community digester in Washington that serves multiple dairies. With feedstock input from three farms, the digester has a power generation capacity of 1 MW and prevents approximately 9,000 tons CO_2e of methane from entering the atmosphere each year.[93] Several farms in the Yakima Valley are in the development stages of creating a similar enterprise. Plans involve transporting manure in pipelines from each farm to the digester so as to mitigate concerns of pathogen transfer otherwise possible with on-site pickup by tractor trailers. This project is also looking into refining biogas into RNG for pipeline injection.

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[93] "Rainier Biogas Dairy Digester Breaks Ground — Harvesting Clean Energy."

4.3.2 Co-location: A common obstacle in realizing the full value of AD byproducts is the expense and logistics in delivering the product itself. Shipping nutrient-rich liquid effluent becomes cost-prohibitive after a relatively short distance due to its weight while valuable excess heat from the digestion process dissipates quickly. The co-location of symbiotic facilities near digesters is a way to efficiently use byproducts and create new AD-related industries. Examples of co-location facilities include greenhouses and fish farms that can use the excess heat for season extension and liquid nutrients for feed. Additionally, carbon dioxide extracted from biogas and injected into greenhouses can benefit plant growth, as demonstrated at the U.S. Water Conservation Laboratory.[94] A digester in Lynden, Washington, was the first in the country to co-locate a commercial greenhouse with a dairy digester (Fig. 24 & 25).

Figure 23: 750 kWh Generator with Heat Recovery Unit (Source: FarmPower)

Figure 24: Greenhouse at Lynden Digester Heated by AD Waste Heat (Source: FarmPower)

The use of ‘waste’ heat from digesters is also being implemented at a wastewater treatment plant in Olympia, Washington. Liquid is heated by the digester/generator and

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[94] Idso and Kimball, “Growth Response of Carrot and Radish to Atmospheric CO_2 Enrichment.”

circulated in a closed-loop piping system to provide water and space heating to nearby municipal buildings and a children's museum.

4.4 FUNDING: Innovative efforts to advance AD have been largely driven by public investment in state and national research institutions and resource agencies. Ongoing financial support is needed to further this research and promote market opportunities for new co-products. Co-owner of Farm Power Northwest, Daryl Maas, offered his view regarding the need for equitable funding for digesters:

> "While all the state's dairy digesters received the majority of their funding from owner equity or loans, most other current and potential biogas projects are government-owned and can spread their costs over millions of ratepayers; the financing model for wastewater treatment plants or municipal solid waste projects is thus much different than the investor-driven approach Farm Power has taken, and with much less connection between those deciding to take project risk and those responsible for paying if the projections turn out to be wrong. Our preference would be for the State to continue to make relatively small grants from 10-20% available to private projects that have to measure up to bank and investor scrutiny, rather than let government entities take the lead with ratepayer funds"[95]

4.4.1 State & Federal Funding: The continuation and support of state and federal funding programs, as well as market incentive expansion, will play a crucial role in the success of digester development in Washington State. In addition, alternative market incentives are needed, such as the expansion of Washington State's Renewable Energy Portfolio, the introduction of RNG incentives and carbon trading. Appendix H provides a

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[95] Daryl Maas. 11 Dec. 2012, interview.

list of state and federal funding sources that have been identified in this study as providing important incentives for AD projects and deserving increased funding.

4.4.2 Innovative Financing Mechanisms: Innovative financing mechanisms have had success in promoting green technologies through incentives and market approaches. Following are those that have specific application to advancing biogas power and RNG as a renewable transportation fuel. As identified by this research and presented herein, they are as follows: green vehicle credits, compliance/voluntary markets and unbundled renewable energy credits.

<u>Green Vehicle Credits:</u> The market for NG/biomethane vehicles has yet to develop in the U.S. yet new state mandates, such as those in California, provide needed incentives. In an effort to ensure that fifteen percent of vehicles emit minimal emissions by 2025, the California Air Resources Board requires that all automobile makers produce a certain number of zero-emission vehicles each year. With a shortage of these vehicles in production, manufacturers can buy "green credits" from the few companies that are ahead of the game.

Tesla Motors, maker of luxury high-mileage electric cars, offers a good example of the potential for RNG vehicles. The company has been in the red since it opened a decade ago and sustained a $90 million quarterly loss in 2012. Total revenue has since increased to $562 million, in part due to their new business model of selling $68 million worth of zero-emission vehicle credits to other automakers.[96] Tesla produced more than its necessary share of zero-emissions cars and was able to sell their credits at a premium to other automakers who failed to meet California's mandates. As stated in a recent Los

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[96] "How Tesla Finally Turned a Profit - The Week. 5/9/2013."

Angeles Times article, "The credits, coupled with state and federal incentives to buyers, can add as much as $45,000 (profit) to each Tesla Model S sold. No other automaker in the country enjoys such an advantage."[97] The article cited a Wall Street analyst in projecting that Tesla could soon gain as much as $250 million a year from selling green credits due to the new federal fuel-efficiency standards. These federal standards now mandate that automakers double their average fuel-efficiency for passenger vehicles to 54.5 miles per gallon by 2025.[98] Although this economic prospect is appealing for the development of RNG vehicles, a more extensive fueling infrastructure must first be established - similar to that which is being developed for electric vehicles.

RNG vehicles have been slow in the making in Washington, and the U.S. as a whole. Washington's Department of Commerce Bioenergy Coordinator, Peter Moulton, mentioned in an interview that the State's ferry fleet is considering running their boats on RNG, yet a decision is forthcoming.[99] Dan Evans from Promus Energy said in another interview that the private sector is starting to take a leading role in the establishment of a NG/RNG infrastructure with the construction of filling stations along major trucking routes. Evans also mentioned that semi-truck manufacturer, Cummins, is producing a line of nine-liter (9 L) engines that will run on NG and RNG.[100]

Compliance & Voluntary Markets**:** The purchase decision for electricity by utility companies is a main determinant for renewable energy demand. Obligatory and voluntary programs that encourage renewable energy have been a major driver in supporting biogas power. Compliance markets involve state mandates such as Washington's I-937 that

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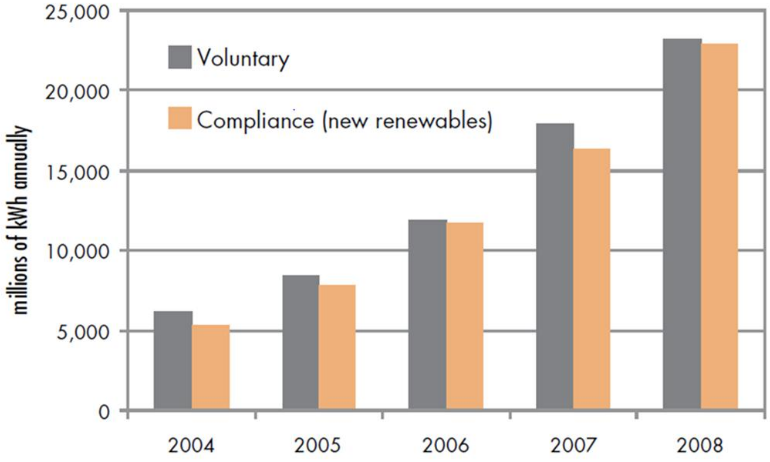
[97] "Tesla Drives California Environmental Credits - L.A. Times. 5/5/2013."
[98] "Obama Admin. Finalizes 54.5 MPG Fuel Efficiency Standards | The White House."
[99] Peter Moulton. 11 Mar. 2013, interview.
[100] Dan Evans. 15 Apr. 2013, interview.

require utilities to source a certain portion of their energy from renewable sources without the need for customer input. I-937 has helped spur investment in biogas production in the sense that it's encouraged the promotion of voluntary programs to enlist the support of rate payers.

Voluntary green power purchases give customers the option of paying a small premium on their bill to support the development and delivery of renewable energy. While the average citizen cannot finance a multi-million dollar anaerobic digester, some are willing to contribute a small monthly amount to collectively support such efforts. Figure 26 illustrates the U.S. EPA statement that, "Voluntary green power purchases have played an important role in driving development of the market and are expected to be an important part of the market for the foreseeable future."[101] Currently, over 850 utilities offer green pricing programs in the United States, or about a quarter of all large utilities delivering over 35 million MWh of renewable energy annually.[102] Washington State has the sixth highest green power sales in the



Note: "New" renewable resources generally refer to renewable facilities that began operation in 1997 or later.

Figure 25: Comparison of Voluntary & Compliance Markets for Renewable Energy, 2004–2008 (Source: NREL)

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[101] "Guide to Purchasing Green Power - USEPA."

[102] "Market Brief: Status of the Voluntary Renewable Energy Certificate Market (2011)."

country with just over half a million MWh of annual production. Currently, 16 utilities in Washington State offer voluntary green power to their customers.

Puget Sound Energy (PSE) has the largest utility-based renewable energy program in the state, called *Green Power*, with over 30,000 participants and about 330,000 kWh of annual sales. PSE's *Green Power* program currently sources 20% of its power from landfill biogas and 8% from dairy digesters. Participants can enroll by contributing as little as $4 per month, while PSE claims that a contribution of $10-12 will offset all of an average home's usage. PSE states that this program does not make a profit, whereby all revenue goes to support renewable energy projects. PSE currently purchases biogas power from seven dairy digesters, with the recent addition of Rainier Biogas and Edaleen Cow Power.[103]

Unbundled Renewable Energy Credits: Another expanding voluntary customer market for renewable energy is in the form of renewable energy credits. Whether or not customers have access to green power from their utility, they can offset their fossil fuel use through the purchase of *unbundled* RECs. About 25 companies offer this service to retail customers, while other avenues are available to commercial and wholesale customers. RECs represent the environmental attributes of an energy source and *unbundled* RECs are those that can be sold directly to consumers, regardless of their utility provider. The majority of these credits are sold to businesses, and the renewable energy associated with these sales increased from 83,400 MWh in 2003 to over 13 million MWh in 2009.[104]

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[103] "Puget Sound Energy Green Power Report. Fall 2012."
[104] "Voluntary Green Power Market Forecast through 2015 - NREL."

4.5 POLICY: Awareness of the benefits afforded by AD is growing among state legislators and several supportive legislative actions were passed at the outset of the 2013 legislative session. The most significant of which was the separation of carbon credits and renewable energy credits, allowing AD projects to claim the dual benefits of preventing greenhouse gas emissions and producing renewable energy. Additionally, property tax exemptions for digester sites were extended for another six years. Below are policy issues that this study has identified as deserving priority consideration if we are to pave the way for AD projects. The following recommendations are largely informed by the 2012 draft report titled *Washington State Thermal Energy Efficiency Opportunities*, prepared by the WSU-Extension Energy Program.

4.5.1 Power Issues: While Washington's low electric rates hinder the economics of AD projects, there are specific policies that would help encourage power production from biogas and reduce the pay-back period for digester developers and owners. The three main issues needing revision are power purchase agreements, interconnection standards and net metering. Additional considerations exist in regards to Washington's Ballot Initiative 937 (I-937) and on a federal level, the Public Utilities Regulatory Policies Act.

Power Purchase Agreements: A power purchase agreement (PPA) is a contract between a power producer and power purchaser (typically a utility) to exchange power at an agreed price, location and time period. PPAs are a powerful tool for developing distributed and thermal resources and accessing these resources is an important step to improve the overall efficiency of energy generation in Washington State. Foremost, digesters should be recognized as part of the regional power supply rather than specific to the utility in whose territory the capability is located. There are several issues in Washington State regarding PPAs that are inhibiting the growth of digesters. These issues fall into the following three categories: the length of contract terms, the negotiated contract price and the size of qualifying projects.

Length of Contract: Each utility in Washington has unique contract terms which can create a wide range of uncertainty and disparity from the developer's perspective. For smaller projects, the use of Standardized Offer Contracts (SOC) would alleviate much of that uncertainty for digester development. An SOC is essentially a simplified form of a PPA that contains standardized language and can greatly reduce transaction costs for the buyer and seller, accelerating the development of smaller digester systems. It is suggested that the SOC apply to systems 2 MW or smaller to encompass current digester potential.

Additionally, AD power projects would benefit if contracts offered fixed prices for at least 20 years to provide enough stability for producers to receive financing. Long contract periods are especially important for obtaining financing for smaller size digester operations.

Contract Price: When biogas power can be used close to the point of generation delivery costs (for both heat and power) are avoided. Therefore, the value of these systems should include avoided transmission and distribution losses, climate benefits, ancillary support, dispatch-ability, firming capabilities and the value of deferring the cost to upgrade energy delivery infrastructure. Biogas power also offers valuable voltage support during peak demand and this value should be fairly reflected in PPAs and SOCs.

Washington's public utility districts (PUDs) have studied the costs and benefits of various approaches to interconnection, considering line loss calculations. Their findings show that pricing transmission at a more granular level can provide a stronger economic signal to digester development, while offering greater value to the transmission system.

Given these PUD conclusions, pricing should recognize the value of power and voltage support, efficiency factors and the ability to store energy during times of surplus generation. Electricity produced from digesters can be profitable for the utility, the host, the developer and the public. Simplifying the process and offering fair contract prices will help improve the project finances as well as speed up project development.

Size of Projects: Utilities in Washington State are required to offer PPAs to generators up to varying sizes depending on site and utility. Many of these utility rates only apply to qualified projects of up to 2 MW, and in some cases only up to 1MW. PPAs should be offered to projects up to 10 MW, while projects under 2 MW should be allowed SOC.

Interconnection Standards**:** Current interconnection standards in Washington State, while being adopted as recently as 2007, have not resulted in facilitating digester development, but have instead hindered the interconnection process from application to installation. Technical requirements for interconnection and the jurisdiction of the Washington State Utilities and Transportation Commission (UTC) are defined by WAC 480-108 (Electric companies – interconnection with electric generators).[105] WAC 480-108 has created electrical safety redundancy, high insurance requirements, and a lack of uniform utility procedures and agreements – all of which are preventing projects from moving forward.

1. Structure breaking points in a way to allow projects of various sizes to have relative interconnection standards. Proposed rulemaking would create 3 tiers for projects: tier 1 - 25kW or less, tier 2 - 500kW or less, and tier 3 – 20 MW or less.

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[105] "WAC: ELECTRIC COMPANIES — INTERCONNECTION WITH ELECTRIC GENERATORS. WA State Legislature Website. Chapter 480-108."

Relative interconnection standards are identified in the revised WAC 480-108

2. Remove the redundant requirement for external disconnect switches on UL 1741 listed inverters. Proposed rulemaking would remove this requirement for tier 1 customers under certain agreements with the interconnection customer.
3. Adopt a model interconnection application and screening process framework for interconnection rules. Proposed rulemaking would simplify the application process, and provide tier based application fees and screening.
4. Investigate potential jurisdictional issues and consider a queue process to ensure fair access to the grid as well as an opportunity to review the impact of the projects on the grid system. Proposed changes do not yet address this.
5. Adopt maximum values of insurance that the utility can require of customer generators. A cap on the amount of insurance a utility may require, would ensure that any insurance requirements placed on customer generators are reasonable and not cost prohibitive for digester resource interconnection. Proposed changes do not yet address this.
6. Support and encourage the UTC's changes to interconnection standards – The UTC has proposed rulemakings that will assist smaller power providers. Support for these changes, as well as the encouragement of further changes to interconnection standards that facilitate digester development.

Net Metering: Net metering is an electricity policy that allows an on-site generation system to run the electric meter backwards during periods when on-site electricity production exceeds load. The value to the on-site generator is two-fold; it values any excess electricity production at retail rates and removes the need for on-site electricity storage. Although net metering can be applied to any type of electricity generation including fossil fuels, most states, including Washington limit the policy to renewable sources. There are three policy areas where Washington State should consider making changes to the law in order to encourage digester development:

1. Increase the overall system size limit from the current 100 kW to at least 1 MW.
2. Increase the overall percentage of net-metered load required to be accommodated on a utility's existing system.
3. Allow net-metered systems to roll over excess generation credits beyond the current limit of one year, but do not require utilities to pay for excess credits.

PURPA Considerations**:** Due to the difficulty independent power producers had with selling renewable into monopoly-controlled markets, Congress enacted the Public Utilities Regulatory Policies Act (PURPA) in 1978. PURPA encouraged the development of alternative power, including renewable energy and cogeneration, by requiring utilities to purchase energy from qualifying facilities at their incremental, or avoided costs.

A review of PURPA found that many independent power producers are unable to fully capitalize on PURPA's benefits due to the complex nature of avoided cost ratemaking. Under PURPA, states have a broad discretion to set avoided cost rates. The following considerations would help PURPA better serve smaller energy producers such as digesters:

- Identify which avoided cost methodologies favor small power producers.
- Consider the full range of avoided cost options to include line losses, externalities and environmental costs associated with renewable energy production.
- Offer the option of 5, 10, and 15- year levelized rate contracts.

Emissions Regulations**:** The strict limits on generator emissions have hampered the deployment of biogas gen-sets for power production and added cost imposed by the permitting process and high-priced equipment guaranteeing minimal emissions. Co-owner of Farm Power Northwest, Daryl Maas, stated in an e-mail response to this study:

> "Despite the best efforts of stakeholders, the General Order defined *de minimis* emissions at such a low level that no current or proposed project (that is, beyond the concept stage) would qualify; a substantial amount of time and effort thus went into a rulemaking effort with no real resulting reforms."[106]

There is a growing argument for easing emissions standards for AD power generation, considering the multitude of environmental benefits afforded by the technology. Of primary consideration is the fact that AD generators reduce methane emissions by burning this potent GHG as a fuel source before it is released into the atmosphere. And as previously mentioned, the renewable energy produced from biogas averts pollution that would otherwise be created from fossil fuels used to create the same amount of power. This need to reconsider regulations for AD power production is expressed by Clark Gilman, Program Manager for Climate Solutions (Olympia, WA):

> "AD should foremost be considered an essential environmental mitigation strategy instead of primarily for power production. When considering regulations, the compounding benefits attained from biogas power from captured methane should be factored into the total allowable emissions for AD generators until more advanced technology becomes readily available and affordable for the run-of the-mill farmer. Until then, we should help, not

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[106] Daryl Maas. 11 Dec. 2012, interview.

> hinder, a farmer's efforts to manage waste and produce renewable energy for us all to use."[107]

Changes to emissions regulations that would acknowledge the net benefit of biogas power generation are currently under consideration in Washington. Removing environmental standards can be a difficult proposition in a time when our remaining natural resources are under increasing threat so the unique conditions of this issue need to be considered carefully.

4.5.2 I-937 Considerations*:* Ballot Initiative 937 (I-937), Washington State's Energy Independence Act, requires the state's largest electric utilities acquire both cost-effective energy efficiency and new renewable energy sources. The Act specifically recognizes the benefit of digesters by providing a double credit against utility renewable energy obligations for systems rated at five megawatts or less. As a result, I-937 has increased interest in and development of digesters.

While I-937 was intended to promote the growth of renewable fuels, there are several issues within the initiative that need to be addressed which would allow it to function more efficiently. These issues are mainly clarification issues and are outlined below.

- Improve the definition of cogeneration technologies to clarify what systems qualify under the Act. There is general agreement that the definition of cogeneration in the Act is not sufficiently detailed to include all types of cost-effective opportunities. For example, situations where electricity efficiency

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[107] Clark Gilman. 27 Feb. 2013, interview.

improvements may be small but overall energy efficiency increases, such as thermal energy savings, can be significant.

- Provide clarification on the five-megawatt limit for digester systems. As written, it is unclear if the five-megawatt limit applies to the capacity or the average annual output of a system, and whether it is for direct current or alternating current output of the system.

4.5.3 Biomethane Incentives: With the relatively low cost of natural gas at this time, incentives are needed to promote biomethane/RNG production and purchase. When used as an alternative vehicle fuel, biomethane may be a way to comply with both the State's I-937 and Federal RFS mandates. The following issues need to be addressed for the advancement of biomethane:

- Identify which avoided cost methodologies favor small power producers.
- Consider the full range of avoided cost options to include line losses, externalities and environmental costs associated with renewable energy production.
- Offer the option of 5, 10, and 15- year levelized rate contracts.
- Encourage federal subsidies for NG transportation infrastructure and vehicles.
- Consider 5-10% tax breaks for RNG fleets.
- Maintain support for the federal RFS to ensuring inclusion of biomethane.
- Support life-cycle assessments of biomethane.
- Partner with other agencies and advocates to move Washington State to adopt a low-carbon fuel standard and/or a carbon tax with equalization components
- Support valuation of the emission and greenhouse gas benefits of biomethane, such as carbon reduction mandates or carbon taxes.
- Support RNG infrastructure development.
- Support research, market development, and investment in waste-to-energy efforts.

Summary: This research shows great potential for new value-added AD byproducts and that there are significant actions we can take to advance their role in valuing the benefits of AD. These include consumer products such as concentrated fertilizer and intangibles such as carbon credits. Research concludes that biomethane holds tremendous potential to add value to AD, as it can use the existing (and expanding) natural gas infrastructure for distribution. The production of bio-based commodity chemicals and concentrated fertilizers from AD effluent are other promising additions to the AD market, as they can also serve as direct replacements for petrochemicals. Even more innovative ways to repurpose and add value to AD byproducts will emerge as the sector expands, such as the production of biochar through pyrolysis of AD solids.

Innovative approaches are needed to economize AD projects, such as the co-location of symbiotic facilities, co-generation (combined heat and power) and partnerships between stakeholders. Increased funding for research and development is paramount, along with the introduction of new incentive policies such as a Washington-based low-carbon fuel standard. Policy revisions are also critical, such as those concerning power purchase agreements. Investment and political action are essential to monetizing the environmental attributes of AD and bringing its valuable products to market.

5. CONCLUSION

Anaerobic digestion is a proven technology with a myriad of environmental, social and economic benefits that has significant opportunities for advancement in Washington. The state is spearheading efforts to develop new byproducts and models for AD in order to advance its development, independent of electric sales. Recommendations have been identified and presented herein that would benefit the prospects for AD. These include support for research and development of value-added co-products, development of a biomethane distribution infrastructure and cost-competitive market, revision and/or introduction of policies, and employment of innovative development models. Following are highlights of the recommendations presented in this study.

Biomethane/RNG: The recent influx of low-cost natural gas into our energy market presents challenges for marketing RNG, yet at the same time the extensive NG infrastructure can be used to the advantage of RNG. As noted in this study, the vast majority of AD feedstock sources suitable for RNG production are within close proximity to major NG pipelines, therefore minimizing the required infrastructure. Incentives such as purchase subsidies would help encourage RNG production while investment is needed to create its infrastructure.

The logistics needed to develop a robust RNG market are capital intensive and although they offer profitable scenarios, the debt, unreliability of green credits, and operational risk can impede adoption. The environmental attributes of RNG need to be monetized in order to gain the political support needed for incentives such as those afforded to ethanol and wind power.

Research and Development Priorities: The refinement and deployment of nutrient recovery technology is especially important to help resolve existing farm nutrient loading concerns. As the use of AD co-digestion on farms grows, so does the need to manage the extra nutrients that are associated with it. The extraction of nitrogen and phosphorus (nutrient recovery) could allow for the efficient transport and profitable sale of these concentrated nutrients to other farms in need of these elements. The market for biologically-sourced fertilizer will only grow with time and the State's support for research and development is needed to ensure that Washington continues to lead the way.

In addition, this study recommends expedited research into the conversion of AD digestate solids into biochar through pyrolysis. Preliminary studies suggest that biochar can help rebuild degraded soils while sequestering carbon for centuries, if not millennia. Additionally, studies are needed to examine the capacity of biochar to be an efficient carrier of nutrients when saturated in AD liquid effluent.

Project Development Models: In developing AD projects, creative approaches are needed to maximize the profitability and end-use of byproducts. This may involve the localized integration of facilities that can efficiently use AD byproducts or the construction of centralized digesters that can more efficiently serve numerous facilities.

In all of the projects studied in this research, partnerships between stakeholders have proven to be very beneficial. Unsuspecting alliances can have successful results, such as that brought together by Qualco Energy between the Tulalip Tribes, environmentalists and dairymen. Partnerships can also help increase political representation or simply make AD affordable to smaller farms by constructing community digesters.

Systems Approach: Looking at AD from a systems approach, WSU researcher Dr. Craig Frear states, “It is important that (anaerobic digester) systems are just that, systems—with the actual anaerobic digester only one component of multiple integrated units working together to eventually yield the desired results of waste treatment, energy production, and co-product development.” In this regard, we can view AD outputs as by-products of one activity that can be valuable inputs for others.

Funding Recommendations: With the current economic strain our country is under, funding requests for AD must appeal to our nation’s need for energy and environmental security. The unique ability of AD to turn ‘waste’ into renewable domestically-sourced power appeals to both of these national needs while helping meet our federal renewable fuel standards and state renewable portfolio standards.

Among the funding priorities offered herein, a few stand out as deserving the greatest attention. On a federal level, one of the more effective AD project financing mechanisms has been the Rural Energy for America Program (REAP) offered by the USDA. REAP and other sources such as the Environmental Quality Incentives Program (EQIP) are funded through the U.S. Farm Bill which, as of this time, is undergoing restructuring and is in need of supportive measures for sustainable biofuels such as AD.

On a state level, the Energy Freedom Program (EFP) provides loans and technical assistance for biomass energy projects such as digesters. Set to expire in 2016, EFP needs future funding allocation if it is to continue. Utility programs such as PSE’s *Green Power* should be promoted along with various grants offered for renewable energy. State tax incentives are also in jeopardy, which can greatly assist in AD development.

Perhaps the most effective use of state funds lies in the support of research and development efforts needed for AD co-products and their delivery to the marketplace. Funding the development of a biomethane delivery infrastructure in Washington State is equally crucial to the expansion of AD, as explained previously.

Policy Recommendations: This thesis identifies numerous policy recommendations yet the overriding need is for the compounding benefits of AD to be recognized in the value of its products. Avoided external costs represent a large factor that is not fully equated into the current value of AD. These include reductions in methane emissions and water pollution, mitigation of human health risks, assistance to farmers and benefits to our nation's overall energy security.

Although relatively small in scale, digesters are expensive investments and the financial burden can be greater for developers in relation to wind and hydropower projects. The multitude of benefits realized by AD, as mentioned above, should afford biogas a premium price so as to incentivize its development. More favorable power purchase agreement (PPA) contracts are essential to encourage power production while subsidizing biomethane is needed for its use as a transportation fuel.

Washington's typical PPA is insufficient in guaranteeing high enough prices for long enough periods that are needed to secure loans for their construction and pay back the investment in reasonable time. Most European countries, where AD is widely used, mandate that utilities pay a premium for power products such as biogas that have external benefits to society. This model, called feed-in-tariff (FIT), also guarantees the purchase of said energy for a long-enough duration to pay off the initial investment and insure investor confidence. It is the recommendation of this research that the FIT model be integrated into Washington's renewable portfolio standards, PPAs and throughout I-937 mandates.

A positive step has been taken in the valuation of AD's multiple benefits in that the Washington State Legislature recently approved the separation of carbon credits and renewable energy credits, hence allowing digester projects to receive payments for both energy production and environmental mitigation. Needing further consideration is the establishment of a low-carbon fuel standard and/or carbon tax. These measures would effectively increase the value for AD and its co-products and has been discussed as such in the Washington State Energy Strategy.

Suggestions for Further Research: In order to gain a more comprehensive assessment on Washington's biogas production potential, there is a need to quantify available feedstock from industrial facilities such as food and beverage processing plants. The co-digestion of such high-energy waste products could significantly increases biogas production and would likely increase the viability of AD projects.

Innovative development models for AD need further consideration and trial sites. Opportunities to use AD byproducts more efficiently on a local level would address one of the main obstacles of transportation and efficient usage of byproducts. A close examination of the natural gas industry and related opportunities for RNG could provide useful projections for understanding when and how RNG could become price competitive without subsidies. Lastly, attention should be paid to sourcing of AD feedstock to ensure its prolonged sustainability. Biogas has attained such value in other countries that food crops have been grown exclusively to feed digesters, therefore threatening its consideration as an advanced biofuel.

It is the conclusion of this research that anaerobic digestion has such overwhelming benefits to Washington's economy, environment and social welfare that aggressive action should be taken to advance its use in the state. Successful models, profitable new market opportunities, supportive policies and plentiful feedstock are all within reach. The unique ability for AD to convert waste products from a liability to an asset makes it a technology we cannot afford to dismiss.

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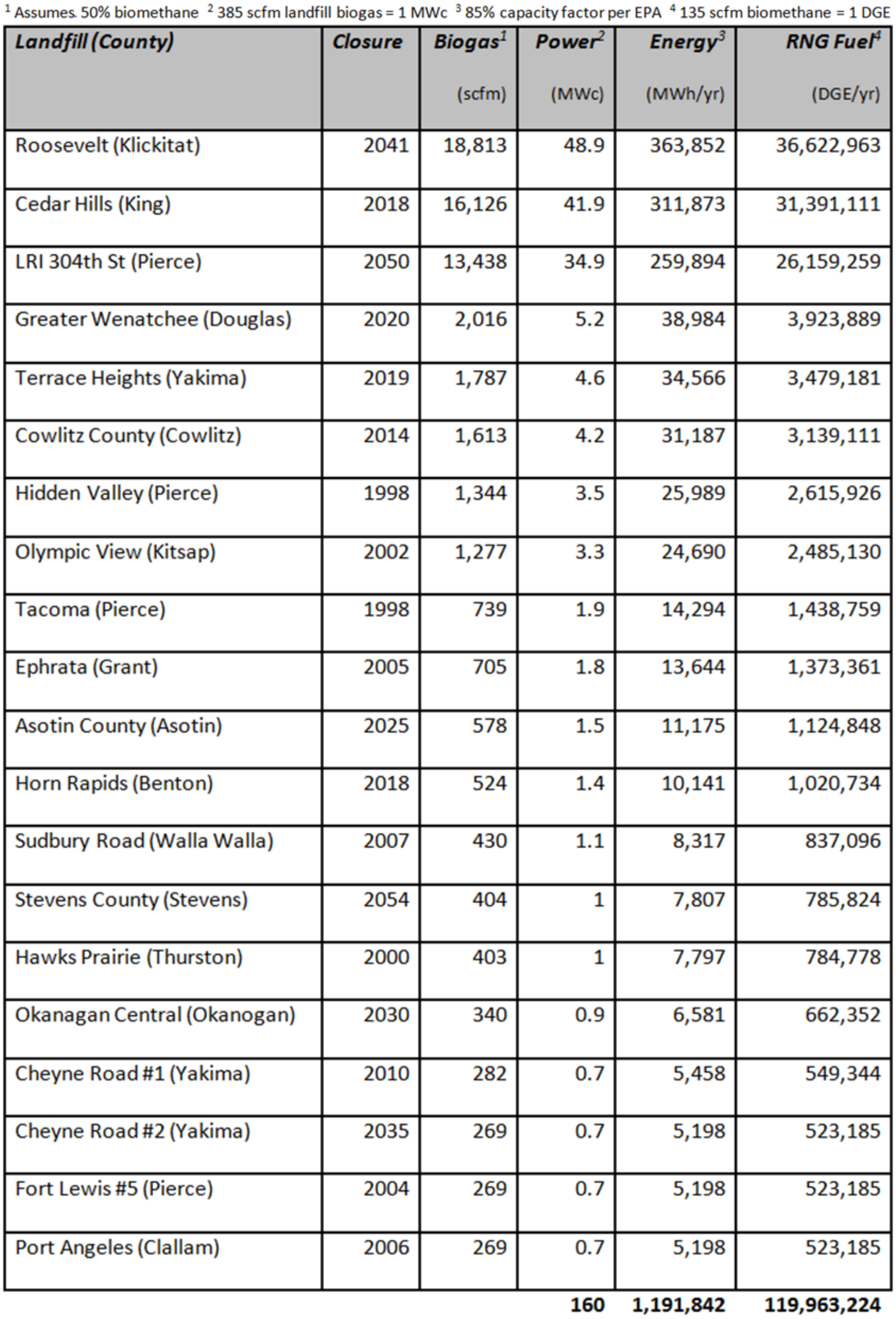
Appendix A: Candidate Landfills for Biogas Capture

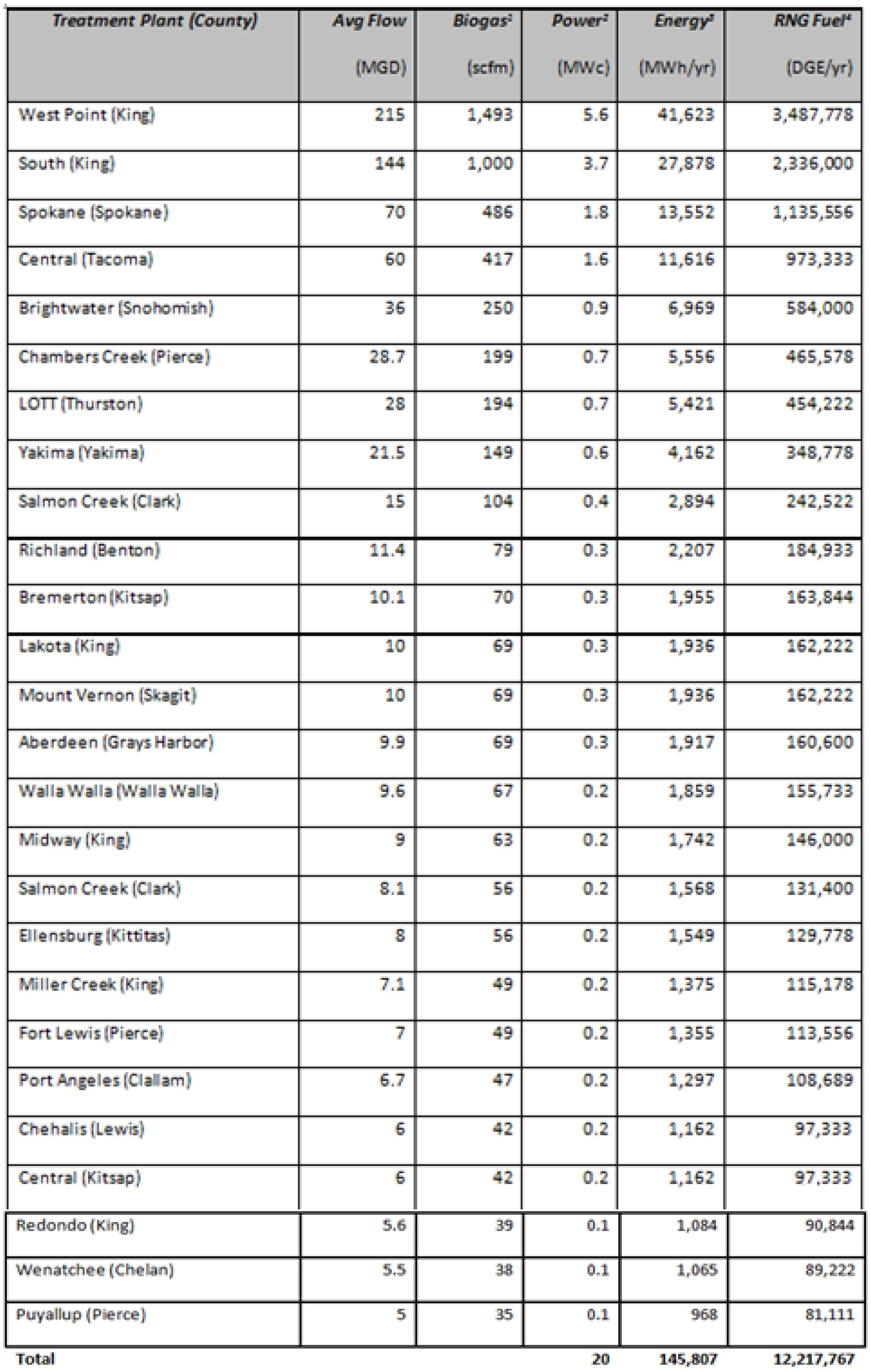
(Source: Peter Moulton, WA Dept. of Commerce, 2013)



[1] Assumes 50% biomethane [2] 385 scfm landfill biogas = 1 MWc [3] 85% capacity factor per EPA [4] 135 scfm biomethane = 1 DGE

Landfill (County)	***Closure***	***Biogas***[1] (scfm)	***Power***[2] (MWc)	***Energy***[3] (MWh/yr)	***RNG Fuel***[4] (DGE/yr)
Roosevelt (Klickitat)	2041	18,813	48.9	363,852	36,622,963
Cedar Hills (King)	2018	16,126	41.9	311,873	31,391,111
LRI 304th St (Pierce)	2050	13,438	34.9	259,894	26,159,259
Greater Wenatchee (Douglas)	2020	2,016	5.2	38,984	3,923,889
Terrace Heights (Yakima)	2019	1,787	4.6	34,566	3,479,181
Cowlitz County (Cowlitz)	2014	1,613	4.2	31,187	3,139,111
Hidden Valley (Pierce)	1998	1,344	3.5	25,989	2,615,926
Olympic View (Kitsap)	2002	1,277	3.3	24,690	2,485,130
Tacoma (Pierce)	1998	739	1.9	14,294	1,438,759
Ephrata (Grant)	2005	705	1.8	13,644	1,373,361
Asotin County (Asotin)	2025	578	1.5	11,175	1,124,848
Horn Rapids (Benton)	2018	524	1.4	10,141	1,020,734
Sudbury Road (Walla Walla)	2007	430	1.1	8,317	837,096
Stevens County (Stevens)	2054	404	1	7,807	785,824
Hawks Prairie (Thurston)	2000	403	1	7,797	784,778
Okanagan Central (Okanogan)	2030	340	0.9	6,581	662,352
Cheyne Road #1 (Yakima)	2010	282	0.7	5,458	549,344
Cheyne Road #2 (Yakima)	2035	269	0.7	5,198	523,185
Fort Lewis #5 (Pierce)	2004	269	0.7	5,198	523,185
Port Angeles (Clallam)	2006	269	0.7	5,198	523,185
			160	**1,191,842**	**119,963,224**

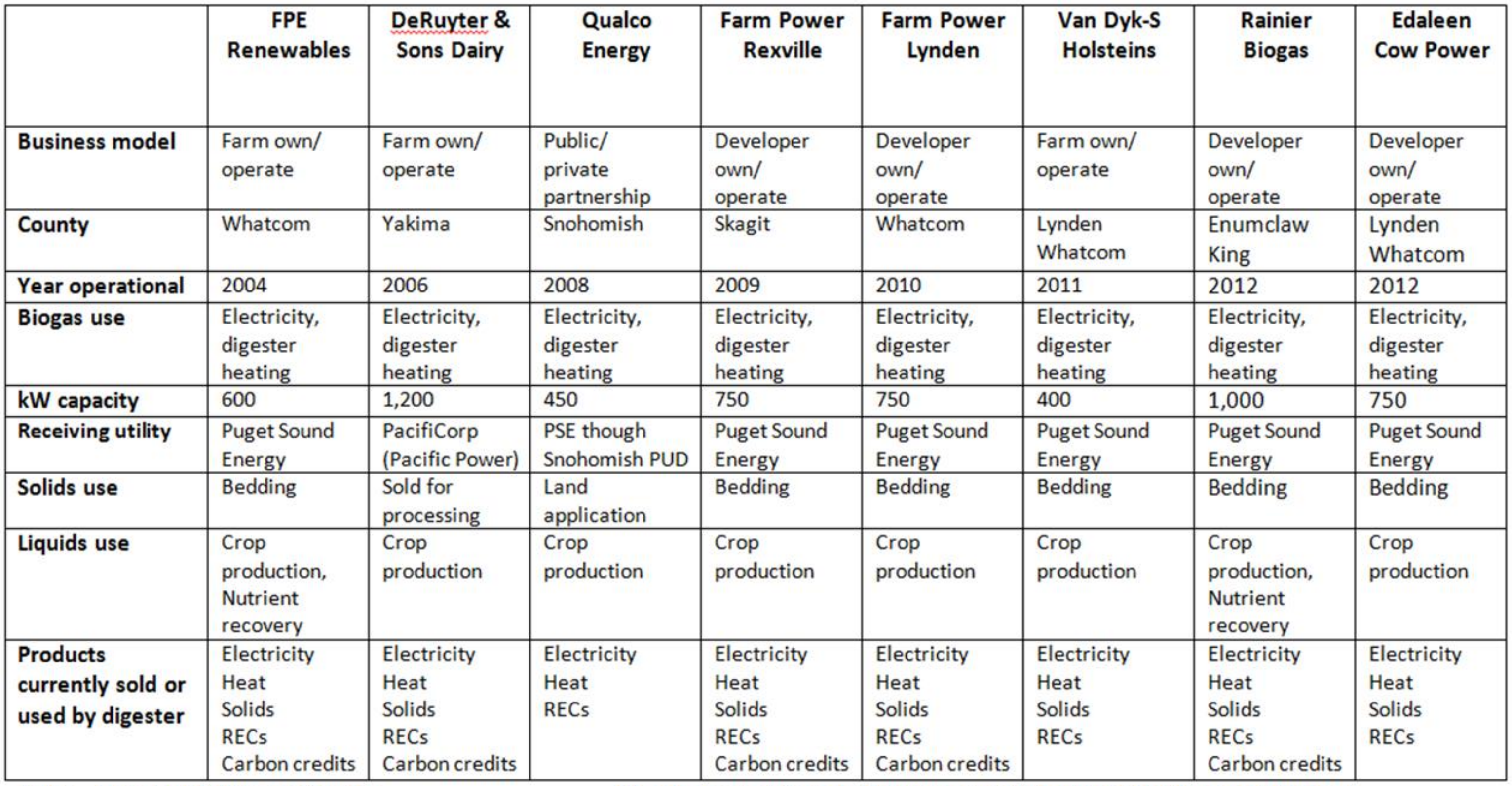
Appendix B: Candidate Wastewater Treatment Plants for Biogas Capture and Use (Source: Peter Moulton, WA Dept. of Commerce, 2013)



Treatment Plant (County)	*Avg Flow* (MGD)	*Biogas*[1] (scfm)	*Power*[2] (MWc)	*Energy*[3] (MWh/yr)	*RNG Fuel*[4] (DGE/yr)
West Point (King)	215	1,493	5.6	41,623	3,487,778
South (King)	144	1,000	3.7	27,878	2,336,000
Spokane (Spokane)	70	486	1.8	13,552	1,135,556
Central (Tacoma)	60	417	1.6	11,616	973,333
Brightwater (Snohomish)	36	250	0.9	6,969	584,000
Chambers Creek (Pierce)	28.7	199	0.7	5,556	465,578
LOTT (Thurston)	28	194	0.7	5,421	454,222
Yakima (Yakima)	21.5	149	0.6	4,162	348,778
Salmon Creek (Clark)	15	104	0.4	2,894	242,522
Richland (Benton)	11.4	79	0.3	2,207	184,933
Bremerton (Kitsap)	10.1	70	0.3	1,955	163,844
Lakota (King)	10	69	0.3	1,936	162,222
Mount Vernon (Skagit)	10	69	0.3	1,936	162,222
Aberdeen (Grays Harbor)	9.9	69	0.3	1,917	160,600
Walla Walla (Walla Walla)	9.6	67	0.2	1,859	155,733
Midway (King)	9	63	0.2	1,742	146,000
Salmon Creek (Clark)	8.1	56	0.2	1,568	131,400
Ellensburg (Kittitas)	8	56	0.2	1,549	129,778
Miller Creek (King)	7.1	49	0.2	1,375	115,178
Fort Lewis (Pierce)	7	49	0.2	1,355	113,556
Port Angeles (Clallam)	6.7	47	0.2	1,297	108,689
Chehalis (Lewis)	6	42	0.2	1,162	97,333
Central (Kitsap)	6	42	0.2	1,162	97,333
Redondo (King)	5.6	39	0.1	1,084	90,844
Wenatchee (Chelan)	5.5	38	0.1	1,065	89,222
Puyallup (Pierce)	5	35	0.1	968	81,111
Total			**20**	**145,807**	**12,217,767**

[1] 100 gal/day = 1 cf/day biogas, 60% methane [2] MGD = 26 kWc [3] 100% capacity factor [4] 135 scfm = 1 DGE

Appendix C: Key Characteristics of Washington State Dairy Digesters as of Jan. 2013 (Source: Adapted from *Washington Dairies and Digesters*, WSDA, 2011)



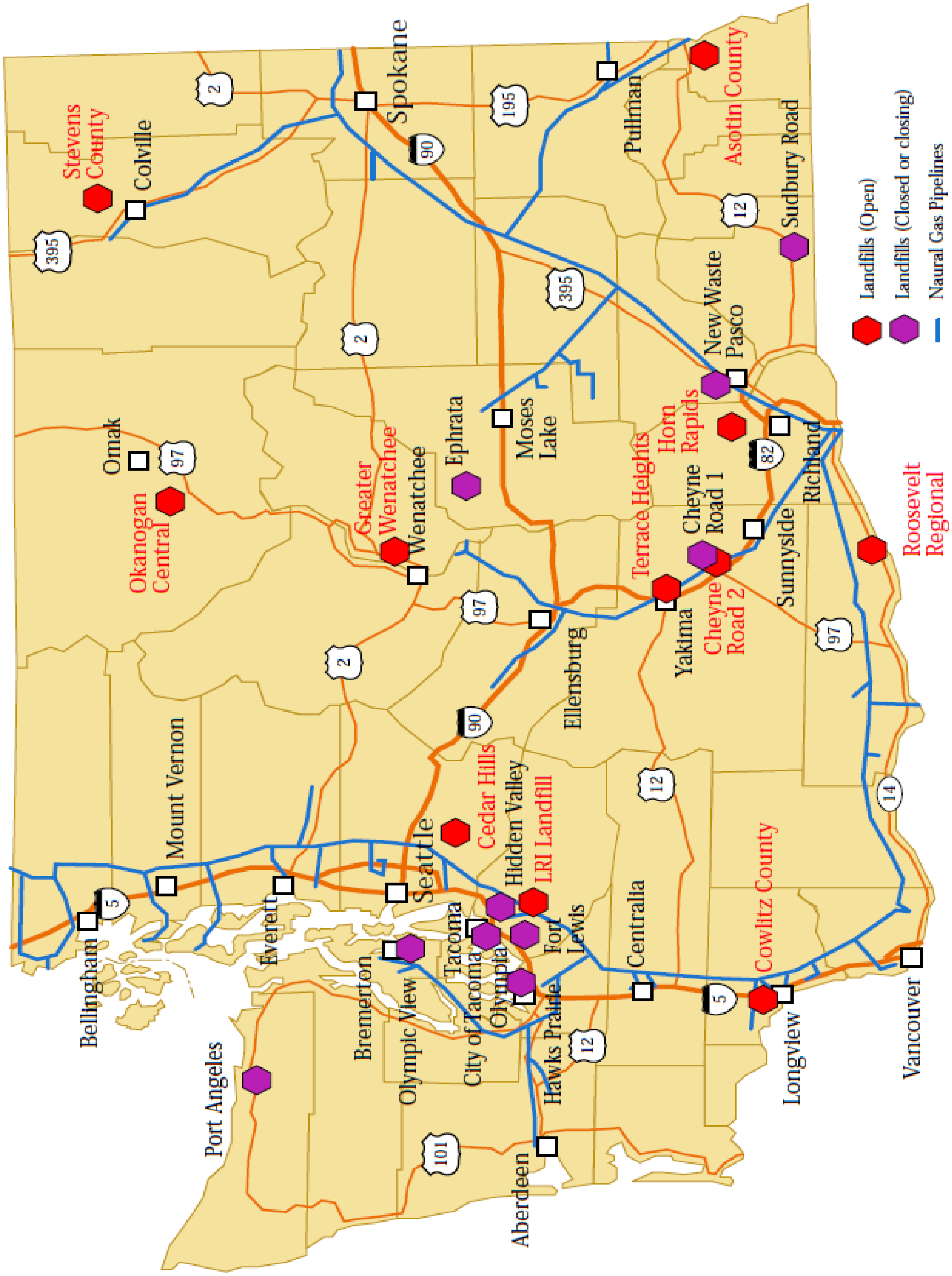
	FPE Renewables	**DeRuyter & Sons Dairy**	**Qualco Energy**	**Farm Power Rexville**	**Farm Power Lynden**	**Van Dyk-S Holsteins**	**Rainier Biogas**	**Edaleen Cow Power**
Business model	Farm own/ operate	Farm own/ operate	Public/ private partnership	Developer own/ operate	Developer own/ operate	Farm own/ operate	Developer own/ operate	Developer own/ operate
County	Whatcom	Yakima	Snohomish	Skagit	Whatcom	Lynden Whatcom	Enumclaw King	Lynden Whatcom
Year operational	2004	2006	2008	2009	2010	2011	2012	2012
Biogas use	Electricity, digester heating	Electricity, digester heating	Electricity, digester heating	Electricity, digester heating	Electricity, digester heating	Electricity, digester heating	Electricity, digester heating	Electricity, digester heating
kW capacity	600	1,200	450	750	750	400	1,000	750
Receiving utility	Puget Sound Energy	PacifiCorp (Pacific Power)	PSE though Snohomish PUD	Puget Sound Energy	Puget Sound Energy	Puget Sound Energy	Puget Sound Energy	Puget Sound Energy
Solids use	Bedding	Sold for processing	Land application	Bedding	Bedding	Bedding	Bedding	Bedding
Liquids use	Crop production, Nutrient recovery	Crop production	Crop production	Crop production	Crop production	Crop production	Crop production, Nutrient recovery	Crop production
Products currently sold or used by digester	Electricity Heat Solids RECs Carbon credits	Electricity Heat Solids RECs Carbon credits	Electricity Heat RECs	Electricity Heat Solids RECs Carbon credits	Electricity Heat Solids RECs Carbon credits	Electricity Heat Solids RECs	Electricity Heat Solids RECs Carbon credits	Electricity Heat Solids RECs

RECs = Renewable Energy Credits

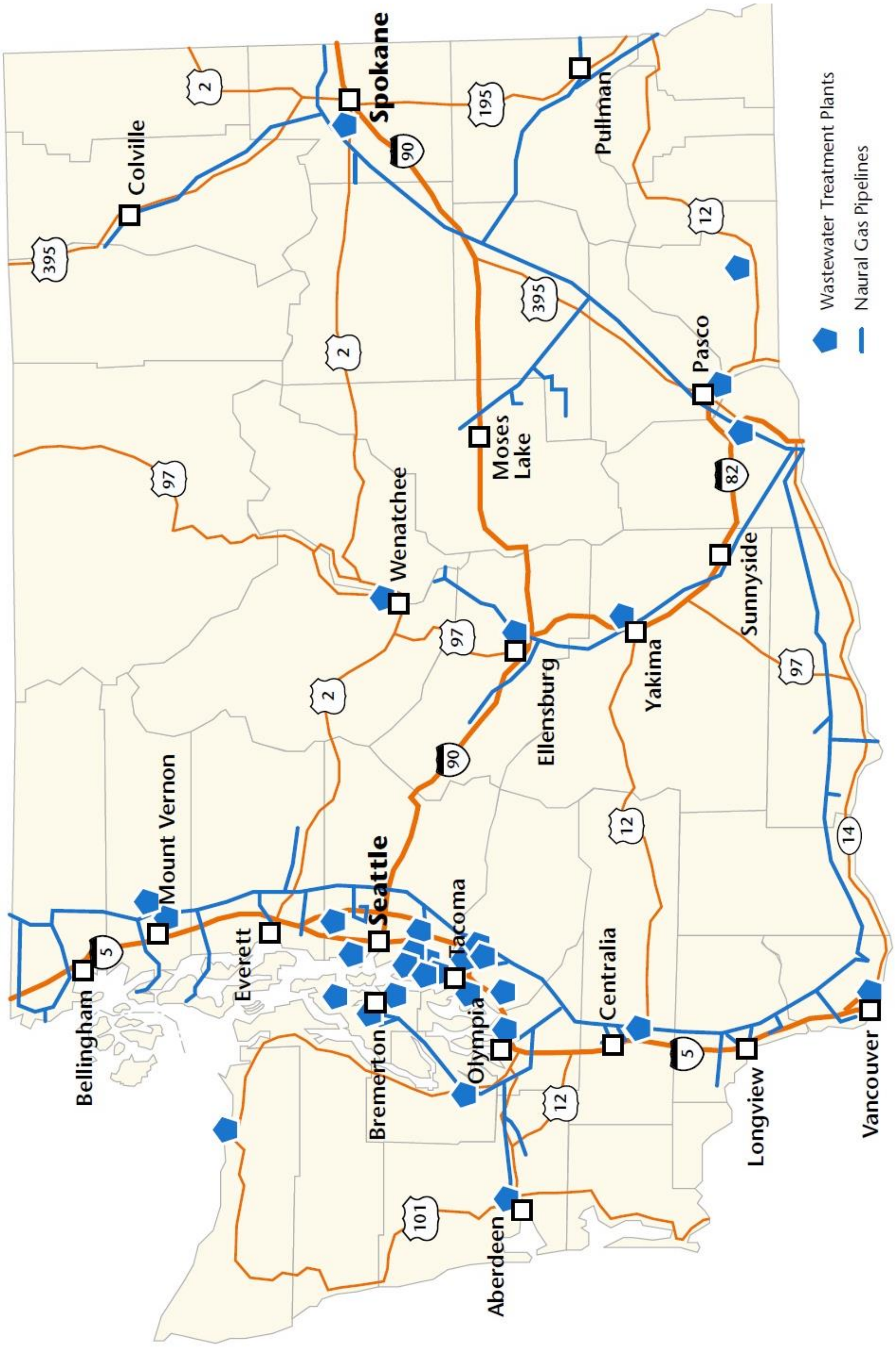
Chart adapted from WSDA report *Washington Dairies and Digesters*

Appendix D: Location of Candidate Landfills and Primary Natural Gas Pipelines

(Source: *Biomethane for Transportation*, WSU-Extension Energy Program, 2011)

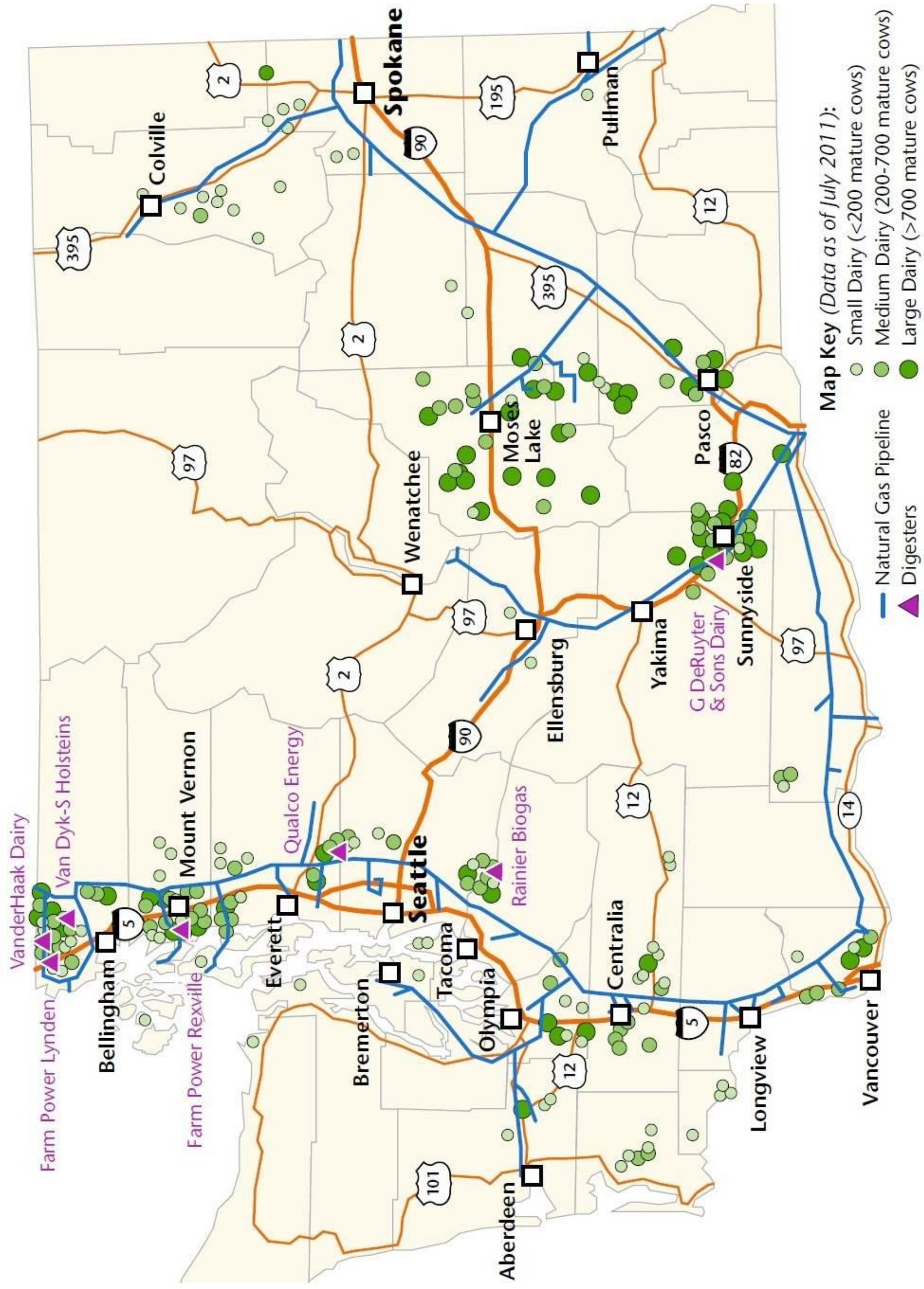


Appendix E: Location of Candidate Wastewater Treatment Plants and Primary Natural Gas Pipelines (Source: *Biomethane for Transportation*, WSU-Ext., 2011)



Appendix F: Washington State Dairies, Digesters and Natural Gas Pipelines

(Source: *Biomethane for Transportation*, WSU-Extension Energy Program, 2011)



Appendix G: US Market Values of AD Products (Source: Innovation Ctr for US Dairy)

ENERGY PRODUCTS (values for each are using entire gas production potential)

- Electricity: 11,701,222 megawatt hours (MWhs) per year, at an estimated current market value of $894 million. This can be sold to electrical utilities or it can used on farms to replace purchased electricity. For electricity sales, the contractual conditions for such arrangements can differ dramatically by state and utility.
- Pipeline Biomethane: The equivalent energy production to that used in electricity production could instead be used to generate 101.4 million MMBTUs per year, at an estimated market value of $413 million. This gas could be sold to utilities or distributors, or used in farm operations offsetting purchased gas energy.
- Compressed Natural Gas (CNG): 788 million diesel gallon equivalent CNG units at a current estimated market value of $733 million. CNG can be used as a transportation fuel to replace purchased diesel if vehicles have been modified to operate on CNG.

FERTILIZER NUTRIENTS (assuming continued development of nutrient recovery technologies)

- Nitrogen: 331,163 tons per year at a current market value of $467 million.
- Phosphorus: 108,782 tons per year, at a current market value of $324.6 million.

FIBER (from mixed plug flow digesters)

- Analysis suggests up to 30 million cubic yards of fiber may be produced at a likely market value of $217 million if sold as a peat moss replacement and on farm bedding material.

ECO-SYSTEM MARKETS

- *Greenhouse Gas Offset Credits*: 34.3 million metric tons of carbon dioxide equivalent offsets can be generated at a value of $10 per metric ton amounts to $343 million.
- *Renewable Energy Credits*: 11.7 million RECs, valued at $34.4 million. RECs are only available for electricity, thus increasing the value of electrical production produced by anaerobic digesters.
- *Renewable Identification Numbers*: 1.3 billion RINS per year could have a value of $1.01 billion for methane marketed as CNG for transportation fuel

Appendix H: Funding Sources Needing Continued and/or Enhanced Support

Federal Assistance:

USDA Rural Development Programs

- *Rural Energy for America Program (REAP)* – Section 9007 of the Farm Bill provides assistance in the form of grants and loans for agricultural producers to complete a variety of renewable energy projects such as AD development. The status and future of REAP is unclear given the tentative state of the Farm Bill.
- *Value-Added Producer Grants (VAPG)* – Grant program designed to help agricultural producers generate new products, expand market opportunities, and increase their income through activities related to the processing and/or marketing of bio-based products. Future funding estimates for this program are uncertain at this time.

- *Business and Industry Loan Guarantees (B&I)* – B&I's purpose is to improve, develop, or finance business, industry, and employment in rural communities. Guarantees for large loans, depending on size (80% up to $5 million), and can be combined with REAP.

USDA Natural Resources Conservation Service

- *Environmental Quality Incentives Program (EQIP)* – A voluntary program that proves financial and technical assistance to implement specific conservation practices that address environmental concerns; often helping producers meet Federal, State, Tribal and local environmental regulations. Future funding estimates are uncertain at this time.
- *Conservation Innovation Grants (CIG)* – A voluntary program that provides funds to stimulate development and adoption of innovative conservation approaches and technologies in conjunction with agricultural production. As a component of EQIP, future funding estimates are uncertain at this time.

USDA Farm Service Agency

- *Conservation Loan Program (CL)* – A program intended to provide access to credit for farmers interested in conservation efforts on their land. The CL program offers loans up to $300,000 and loan guarantees of up to $1.3 million.

IRS Tax Credits

- *Production Tax Credit (PTC)* - The federal renewable electricity production tax credit is a per-kilowatt-hour tax credit for electricity generated by qualified renewable energy. The PTC provides a 1.1¢/kWh credit for "open-loop biomass" of at least 150 kW.
- *Investment Tax Credit (ITC)* – The federal business energy investment tax credit is equal to 10% of CHP expenditures with no maximum limit for eligible systems placed in service before December 31, 2016, and can be used by utilities.
- New Market Tax Credit (NMTC) – A program created in 2000 to spur new or increased investments into operating businesses and real estate projects located in low-income communities. The program is expected to continue through 2013.

IRS Depreciation

- *Modified Accelerated Cost-Recovery System (MACRS)* - The federal MACRS allows eligible renewable energy technologies to recover investments in certain property through depreciation deductions. CHP projects can qualify for a five-year depreciation including 50% first-year bonus for 2012.

Appendix H: Funding Sources (continued)

IRS Bonds

- *Qualified Energy Conservation Bonds (QECB)* – QECBs may be used by state, local, and tribal governments to finance certain types of renewable energy projects. QECBs are qualified tax credit bonds where the borrower only pays back the principal and the bondholder receives tax credits in lieu of interest. Stimulus act provided $68 million to Washington State, of which 30% may be used to finance private projects.
- *Clean Renewable Energy Bonds (CREB)* – Provides bonds to public entities to be used to finance renewable energy projects similar those that are qualified for the PTC. Currently there is no appropriation for CREBs in the proposed budget at this time.
- *Exempt Facility Bonds (EFB)* – Common tool for tax-exempt funding of many public services including local power or gas production, limited to no more than two contiguous counties so best used for ADs intertied with public utilities.

US Department of Energy

- *Loan Guarantee Program (Section 1703)* – Supports projects that “avoid, reduce or sequester air pollutants or anthropogenic emissions of greenhouse gases; and employ new or significantly improved technologies as compared to commercial technologies in service in the United States at the time the guarantee is issued”. Only covers about 20% of loan. Future estimates on funding availability are currently unknown.
- *Tribal Energy Program* – Provides financial and technical assistance to tribes to evaluate and develop their renewable energy resources. Future estimates on funding availability are currently unknown.
- *Renewable Energy Production Incentive (REPI)* – Provides incentive payments for electricity generated from renewable energy facilities. Program pays ~2.2 cents per kWh for the first ten years for power sold. Facility must be placed in service before Oct 1 2016. Currently not in the federal budget for FY 2012.

Small Business Administration

- *Small Business Investment Corporations* – Privately owned and managed funds regulated by the Small Business Administration. Recently launched a $1 billion guaranteed bond initiative over the next five years to match private capital up to 2:1. Investments must be in companies located in distressed areas and/or in emerging sectors such as clean energy.

STATE ASSISTANCE:

Washington Department of Commerce Funding Options

- *Energy Freedom Program (EFP)* – Provides loans and technical assistance for bioenergy production, research, and market development, that converts farm products, organic wastes, cellulose and biogas into electricity, biofuel, and related co-products. No new funds have been appropriated for this program, and is set to expire after June 30, 2016. It is recommended this program be appropriated future funds, and be extended past 2016.
- *Community Economic Revitalization Board (CERB)* – Program finances public infrastructure to encourage new development and expansion in targeted areas. CERB board meets six times a year to consider projects, only $5 million available for current biennium. Since ADs are being developed to generate large amounts of electricity to the grid as a base load provider, it is recommended that the loan limit be extended to $50 million.
- *Rural Washington Loan Fund (RWLF)* - Gap financing to businesses that create or retain jobs, particularly for low-income persons. Loan amount is determined by the “gap” and competitive factors, cannot exceed 1/3 of total project costs. Maximum loan $1 million. No new appropriation for current biennium.

Appendix H: Funding Sources (continued)

- *Small Business Credit Initiative (SBCI)* – New program created by the federal Small Business Jobs Act to increase access to capital for small businesses. Washington received $20 million; about half of which will be available through the Enterprise Cascadia Fund for under-served and tribal communities. SBCI started this fall.

Public Utility Programs

- *RPS Renewable Energy Credits ("green tags")* – Under I-937, public utilities must purchase a certain percentage of renewable power – 3% by end of 2012, 9% by 2016, and 15% by 2020. Currently stagnant due to nearly all utilities having their 2012 percentage; projected to pick up in the next couple of years as they prepare to meet their 2016 targets.
- *Green Power Programs* – As of 2001, sixteen utilities in Washington are required to offer electricity generated from a qualified alternative energy source to their retail customers often referred to as "green power". The major programs that may be interested in purchasing green power from ADs for resale include: Avista Buck-A-Block, Clark County PUD Green Lights, PacifiCorp Blue Sky, Puget Sound Energy Green Power, Seattle City Light Green Up, Snohomish Co PUD Planet Power, and Tacoma Power EverGreen Options.
- *Grant Programs* – All three of the major Independently Operated Utilities (IOUs) offer grant programs. Currently only Pacific Power offers one open to ADs- the Blue Sky Renewable Energy Community Project Fund. They make annual awards, proposals usually due mid-summer for systems smaller than 10 MW, locally owned, commercial-scale in service territory.
- *Renewable Energy System Cost Recovery* – Utilities can provide payments 15 cents/kWh of up to $5,000/yr., which they deduct from their public utility tax.

State Tax Incentives

- *Sales and Use Taxes* – Equipment, labor, and associated services exempt from 75% of retail sales and use taxes until June 30, 2013. AD Construction and operation, and related services or components exempt from retail sales and use taxes as long as more than half of the feedstock is manure**.** It is recommended that this program be extended.

Other State Funding

- *Carbon Credits* – Establishing Washington carbon credit market to allow AD developers to sell carbon credits that represent the avoided greenhouse gas emissions.
- *Renewable Energy Credits* – AD developers can sell RECs, which represent the environmental benefits from renewable energy generation.
- *Small Securities Offering* – Allows for community investment independent of the Securities and Exchange Commission (SEC).