BUILDING A WORLD OF DIFFERENCE

5 November 2014

WASTE-TO-ENERGY ROAD MAPPING WORKSHOP

PATRICIA SCANLAN DIRECTOR, RESIDUALS TREATMENT

BLACK & VEATCH
Building a world of difference.®

WHY ARE WE HERE?

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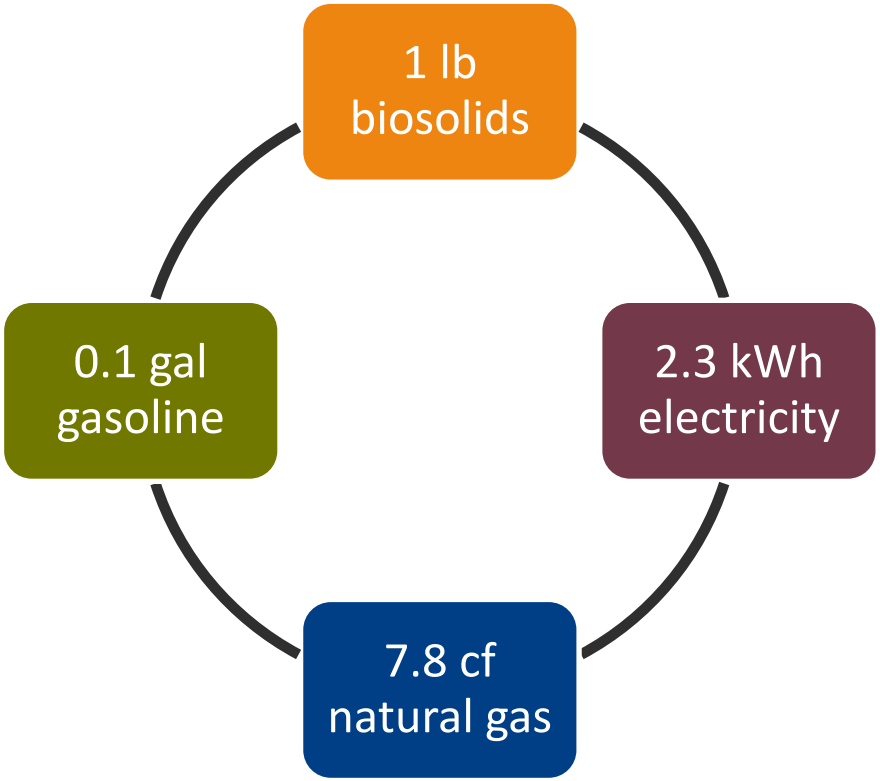
- **Transportation use by the numbers:**
  - 30% of energy use for transportation (people and goods)
  - 60% of transportation energy for personal vehicles
  - US has ~ 5% of world population, with 30% of world's vehicles
  - More than 80% of the vehicle fuel from fossil fuel

National Academies Press, 2009

How do we increase our use of biomass-based transportation fuels?

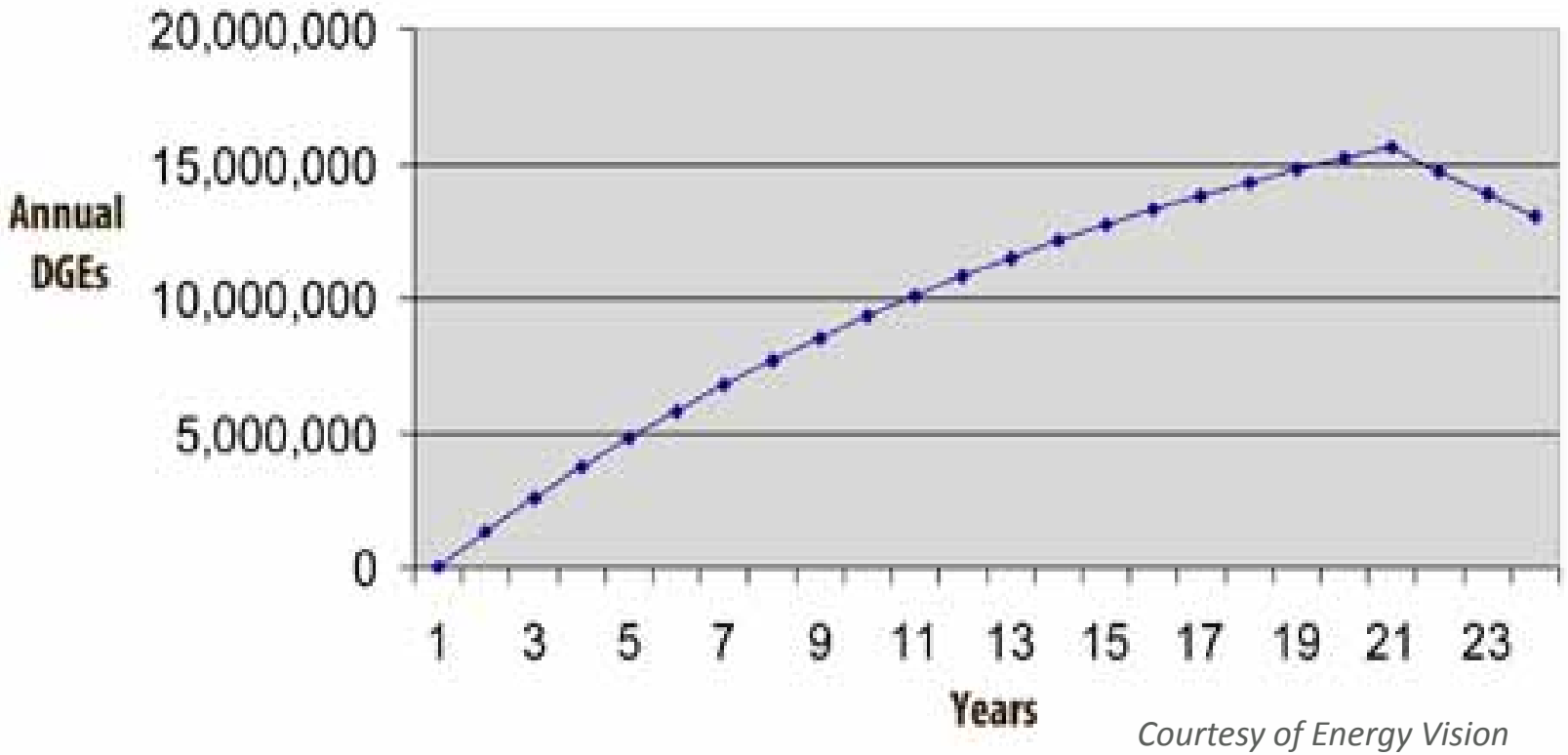
WHY ARE WE INTERESTED IN ENERGY RECOVERY FROM BIOSOLIDS?

- Significant renewable energy source



ENERGY POTENTIAL FROM LANDFILL GAS

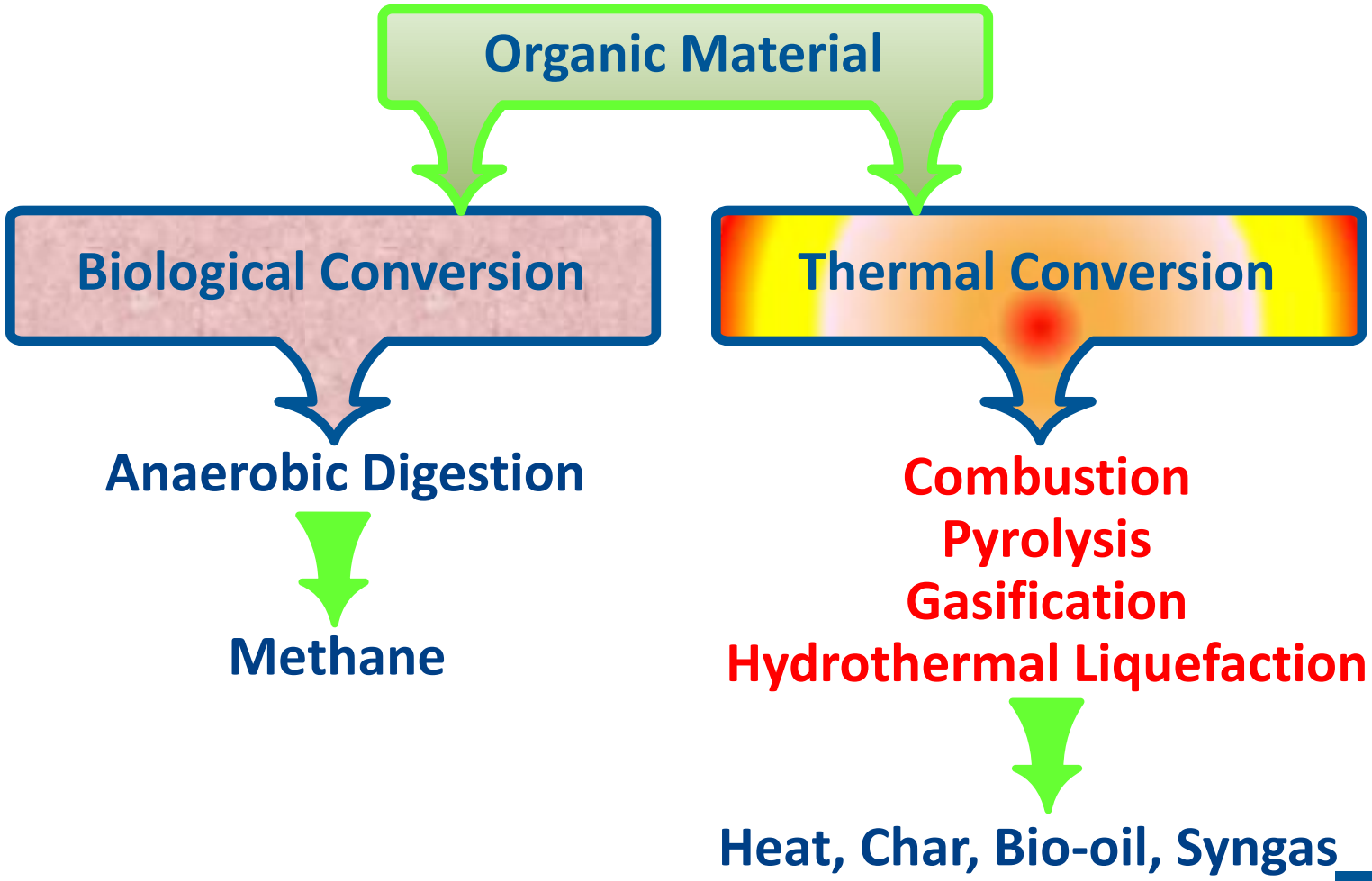
- If we converted all landfill gas to diesel fuel, we could meet ~ 16% of total demand



Courtesy of Energy Vision

Gas production from a single mid-sized landfill will fuel ~ 2,000 refuse trucks

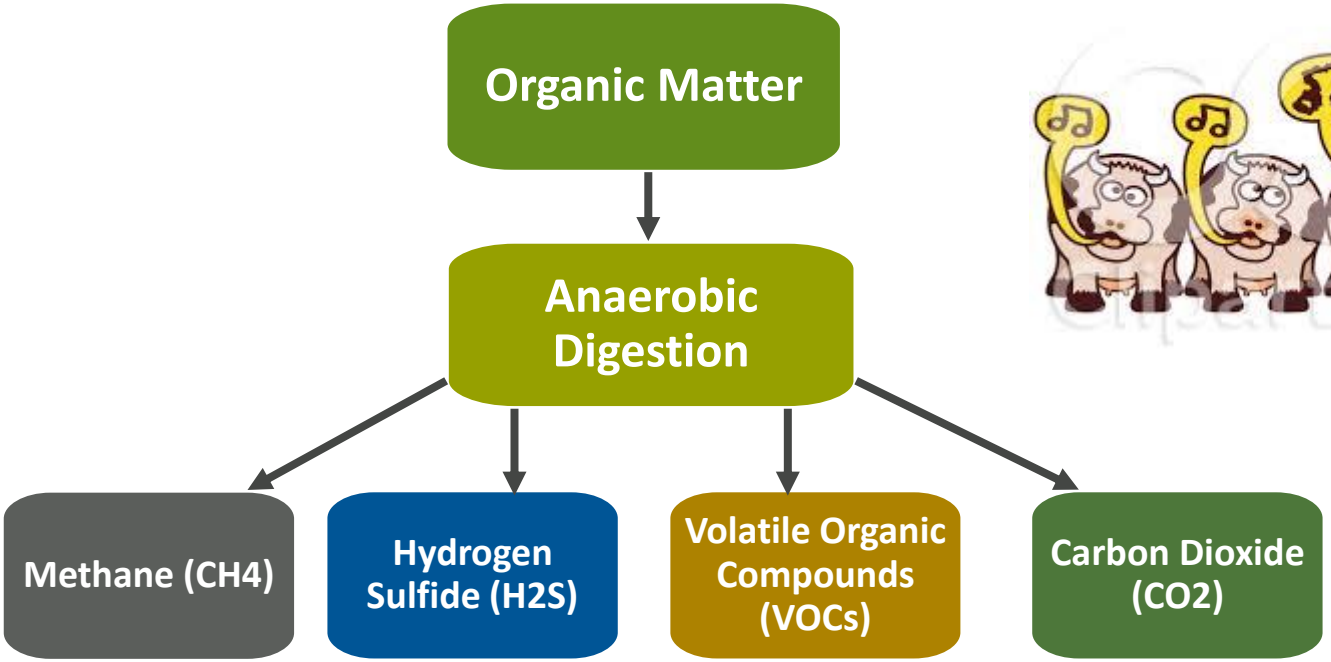
RENEWABLE ENERGY GENERATION – 2 PATHWAYS



ANAEROBIC DIGESTION AND BIOGAS

ANAEROBIC DIGESTION PROCESS

- Biological, naturally occurring



ANAEROBIC DIGESTER BIOGAS

- **Typically 40% to 60% methane**
- **Majority of the remainder is carbon dioxide**
- **Small amounts of other contaminants – cause odors and require removal prior to beneficial use**
  - Water
  - Hydrogen sulfide
  - Nitrogen
  - Volatile organics

WHERE IS ANAEROBIC DIGESTION USED?

- **Wastewater treatment plants (typically medium to large facilities)**
  - Approximately 65% of wastewater treated through anaerobic digestion
- **Landfills**
- **Animal manure facilities**
- **Commercial organic waste conversion facilities**

Most common use of the biogas from anaerobic digestion has been power generation…but things are changing

ANAEROBIC DIGESTION: COST TO IMPLEMENT

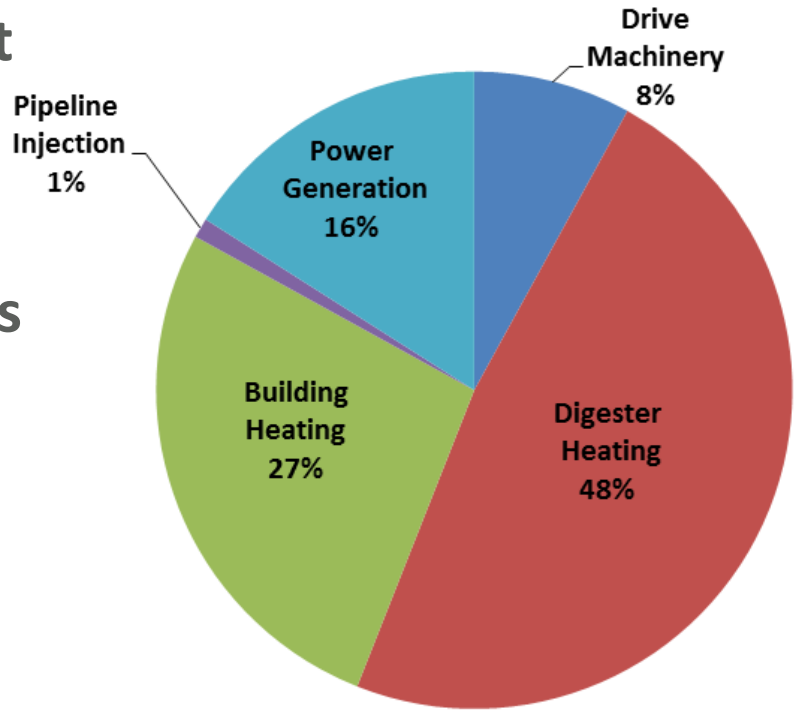
- **Expect ~ $4 to $8/gallon for digestion process facility**
  - ~ $100k/cfm of biogas
  - ~ $1/gallon of fuel equivalent (capital costs only)

Reading STW, UK

Courtesy of Hoosier Ag Today

OPTIONS FOR BIOGAS USE

- On-site heat/use in treatment process
- On-site power generation
- Clean-up to “near” natural gas quality
  - Pipeline injection
  - Use as vehicle fuel
- Use typically based on economics



From WEF Biogas Production and Use at Water Resource Recovery Facilities in the United States

We could fuel 550,000 vehicles using current municipal biogas production

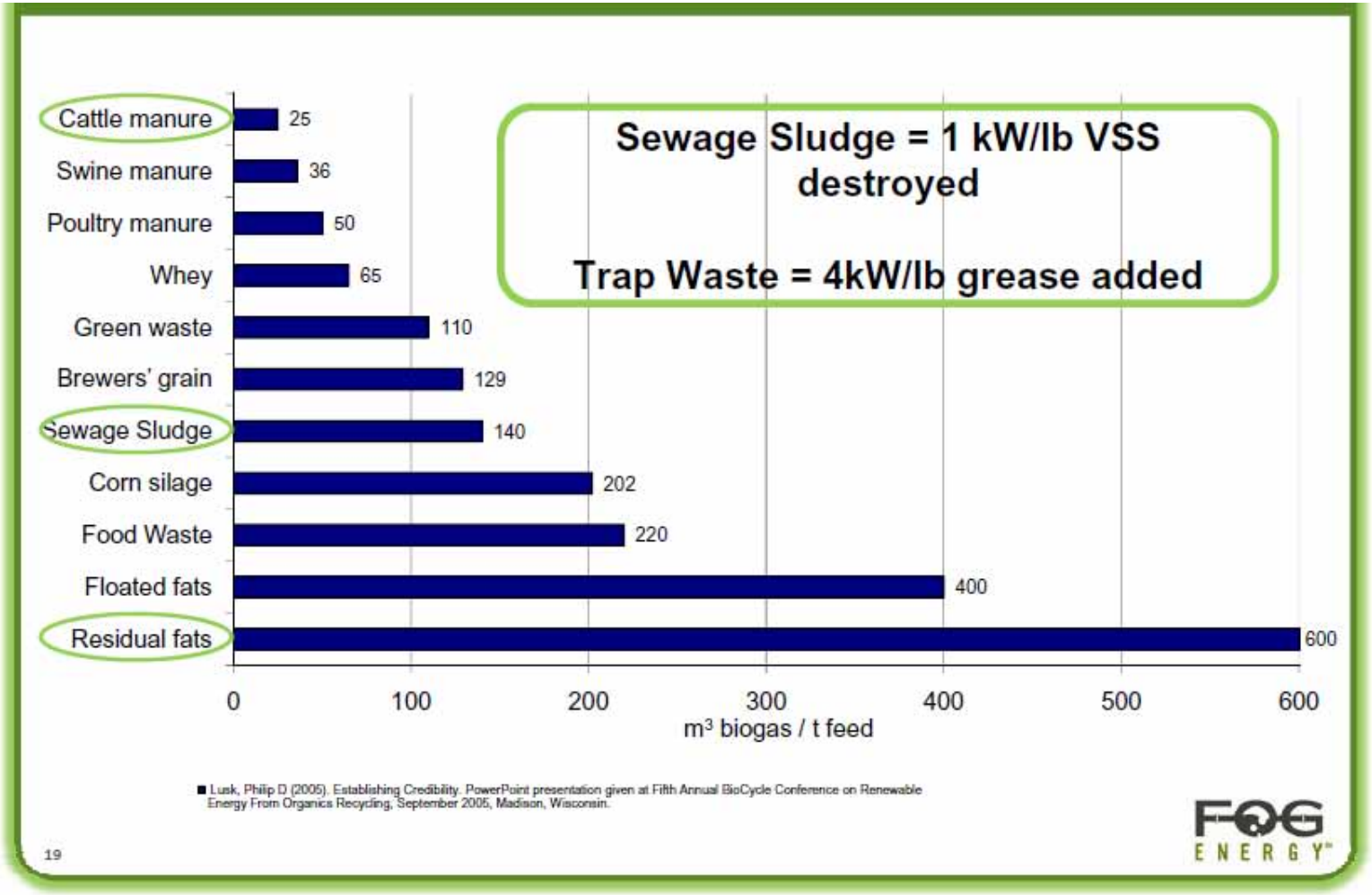
HIGH STRENGTH WASTES AND OTHER SUBSTRATES

WHAT CAN WE DIGEST?

- Municipal substrates can be increased through co-digestion with other organic wastes
- Municipal solid waste (landfill waste) typically not included in co-digestion concept

Co-Digestion of Dairy Manure/Food Processing Waste and Biosolids/Food Processing Wastes to Energy, California Energy Commission Report, 500-2007-15, March 2008

SIGNIFICANT BIOGAS POTENTIAL IN HIGH STRENGTH WASTES



CO-DIGESTION BENEFITS AND DRAWBACKS

- **Benefits**
  - Take advantage of unused digester capacity
  - Increase biogas production
  - Increase revenue/decrease expenses
  - Stabilize C:N ratio in digesters
- **Drawbacks**
  - Characteristics vary – difficult to provide stable digester feed
  - Potential for contamination
  - Increased competition from other industries
  - Mixing and handling challenges
  - Pretreatment requirements and costs

BIOGAS CLEANING FOR VEHICLE FUEL

BIOGAS CLEANING

- **Cleaning is required for biogas to remove contaminants that damage downstream equipment**
- **Basic gas cleaning:**
  - Moisture removal
  - Hydrogen sulfide removal
  - Siloxanes removal
- **To achieve “near” natural gas quality for CNG:**
  - Carbon dioxide removal
  - Compression

GAS COMPOSITION REQUIREMENTS

Raw and Clean Digester Gas Compositions			
Parameter	**Unit**	**Digester Gas**	**Pipeline Gas**
Heating Value	Btu/scf	600	990-1,150
Water Content	ppm	70,000	150
Hydrogen Sulfide	ppm	1,000-2,000	4
Carbon Dioxide	vol%	31	3
Siloxanes	ppb	0-11,000	70
Pressure	psig	0.3	600

Carbon dioxide removal costs ~ equal to other cleaning costs

CARBON DIOXIDE REMOVAL

- **Physical and Chemical Solvents**
  - Amines
  - Water
  - Selexol
  - Cryogenic CO2
- **Pressure Swing Adsorption (PSA)**
- **Membranes**
- **Costly for small to medium plants**
  - Typically becomes economically viable ~ 2 million scfd

SOLVENT REMOVAL

- **Solvents somewhat selectively absorb CO2**
  - Solvents typically also remove other compounds (H2S)
  - Include water, amines , glycols
- **Packed tower technology**
- **Usually at pressures > 100 psi**
- **Solvent is regenerated by reducing pressure (sometimes at high temperatures)**
  - Tailgas includes CO2, H2S, and CH4
  - Requires combustion in flare, scrubbing, or venting

Fair Oaks IN (Greenlane) Courtesy of USEPA

PRESSURE SWING ADSORPTION

- **Biogas compressed to 100 – 150 psig and flows through adsorbent filled packed bed**
  - Adsorbent selected for CO2 removal, CH4 passes through
- **Spent bed regenerated by depressurizing the vessel and using dry regeneration gas**
  - Small amount of CH4 released in tailgas
- **May be able to remove H2S and siloxanes**
  - Additional H2S treatment may be necessary to meet SOx emissions

San Antonio, TX (SAWS) Courtesy of Molecular Gate

MEMBRANE CO_2 REMOVAL

- **Semi-permeable barriers**
  - Uses differential partial pressure to drive separation process
  - Requires biogas compression to >150 psig
- **Usually requires 2-stage process to match PSA capture efficiency**
  - Waste gas from the first stage is recompressed and treated through second stage
  - May have higher losses than PSA
- **Membranes damaged by VOCs, H2S, and particulates**
- **Modular – good for systems expected to scale**
- **Low capture, lower cost systems available for vehicle fuel**

Membrane Biogas Cleaning
Courtesy of Air Liquide

TURN-KEY SYSTEMS

- **Packaged systems available with cleaning and vehicle fueling**
  - BioCNG (Cornerstone and Unison)
  - Up to 200 cfm
  - Compress to 3,000 -3,600 psi
- **Use membrane technology**
  - Low CH4 capture rates – 60% to 70%

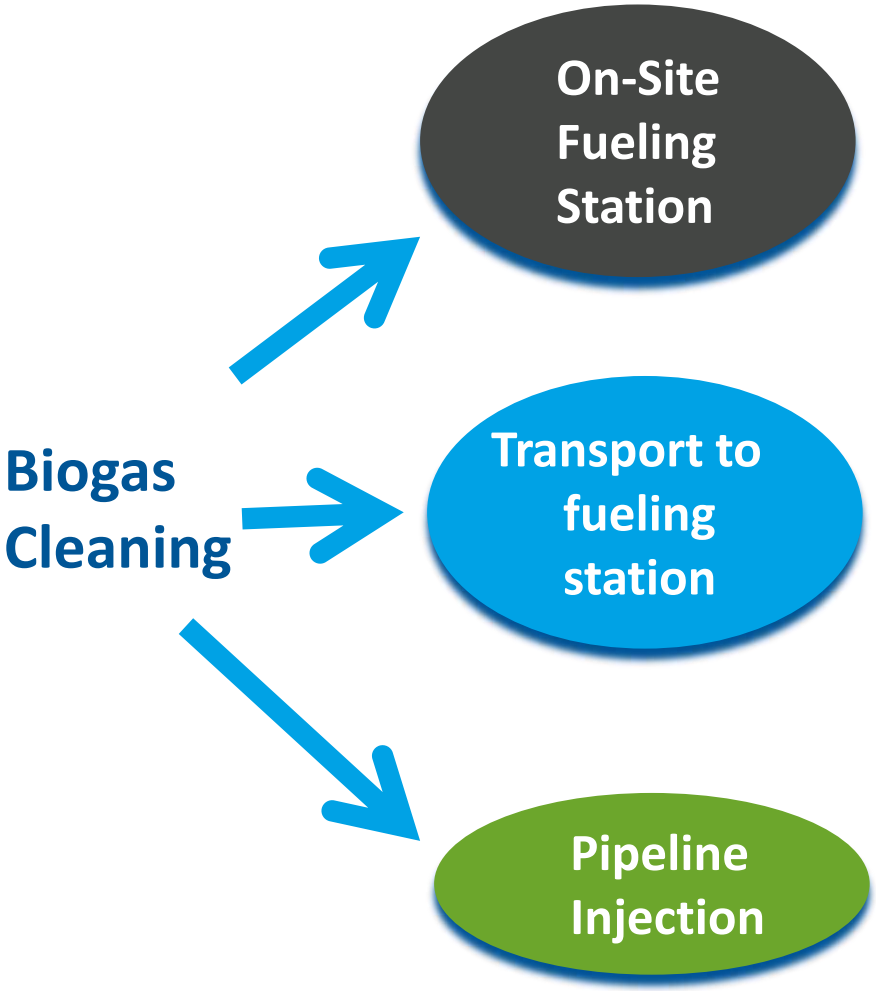
Riverview, MI Landfill
(Courtesy of Energy Vision)

HOW MUCH DOES GAS CLEANING COST?

- **Less than you might think**
  - Full cleaning costs ~$5- $10/mmBtu
    - Equivalent to ~ $0.60 - $1.20/gal GGE
  - Compare to natural gas cost ~ $4.00/mmBtu
- **Helpful drivers**
  - Incentive for renewables
  - Low electricity costs
  - GHG credits
  - Low SOx limits
  - Publicity value
  - Available end users

Costs based on 114,000 Btu/GGE

MARKET CONSIDERATIONS FOR DISTRIBUTION



Users must purchase fuel at generation site – Wholesale or retail pricing, limited market

Users can purchase fuel at convenient site – Maximum retail pricing

Users can purchase fuel at convenient site; Requires dedicated pipelines or agreement with gas utility – wholesale pricing with gas utility

VEHICLE FUELING

Fueling Station (Courtesy Clean Energy)

- **Retail outlets should be similar in look and use to gasoline filling stations**
- **Fast fill vs. slow fill**
  - Retail outlets require fast fill systems for user convenience
  - Storage required for fast fill systems

St. Landry Parish, LA Landfill Gas System (Courtesy St. Landry Parish)

TRANSPORTATION TO FUELING LOCATION

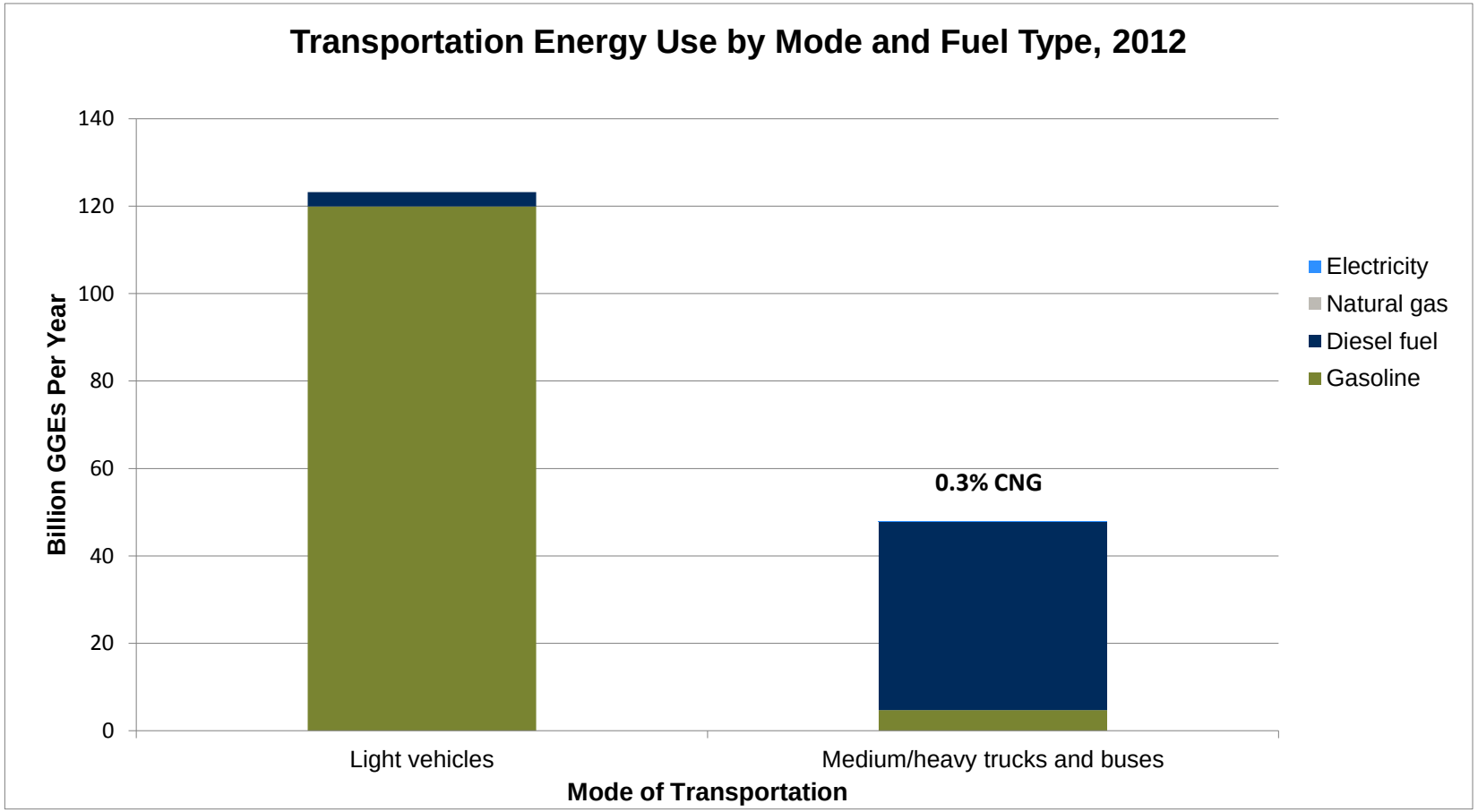
- Variety of options

Tube Trailer
(Courtesy of Keen Gas)

Fuel Mule (includes fueling equipment)
(Courtesy Fuel Mule)

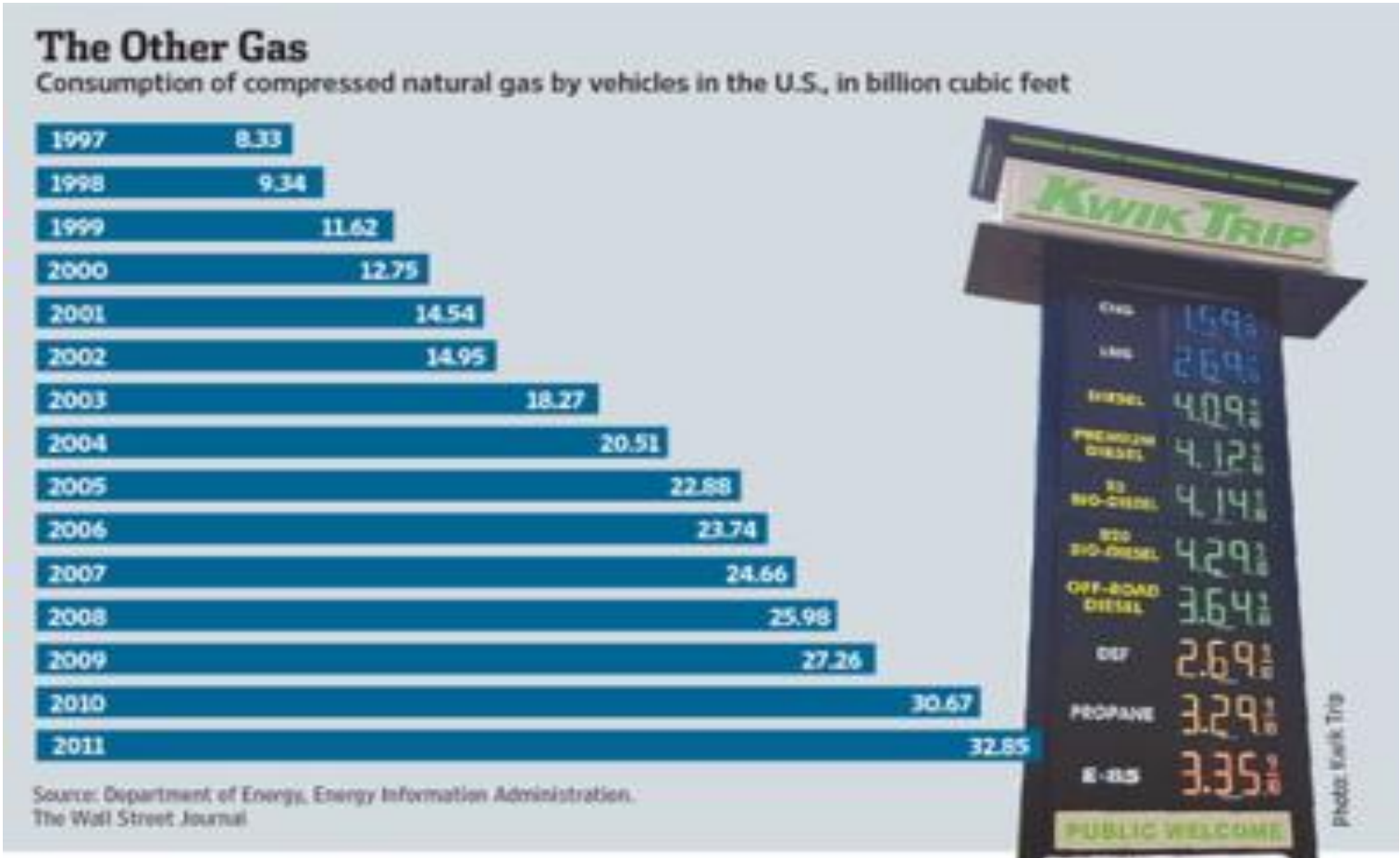
CNG FUEL MARKET AND INCENTIVES

THE BAD NEWS – THE CNG MARKET IS SMALL

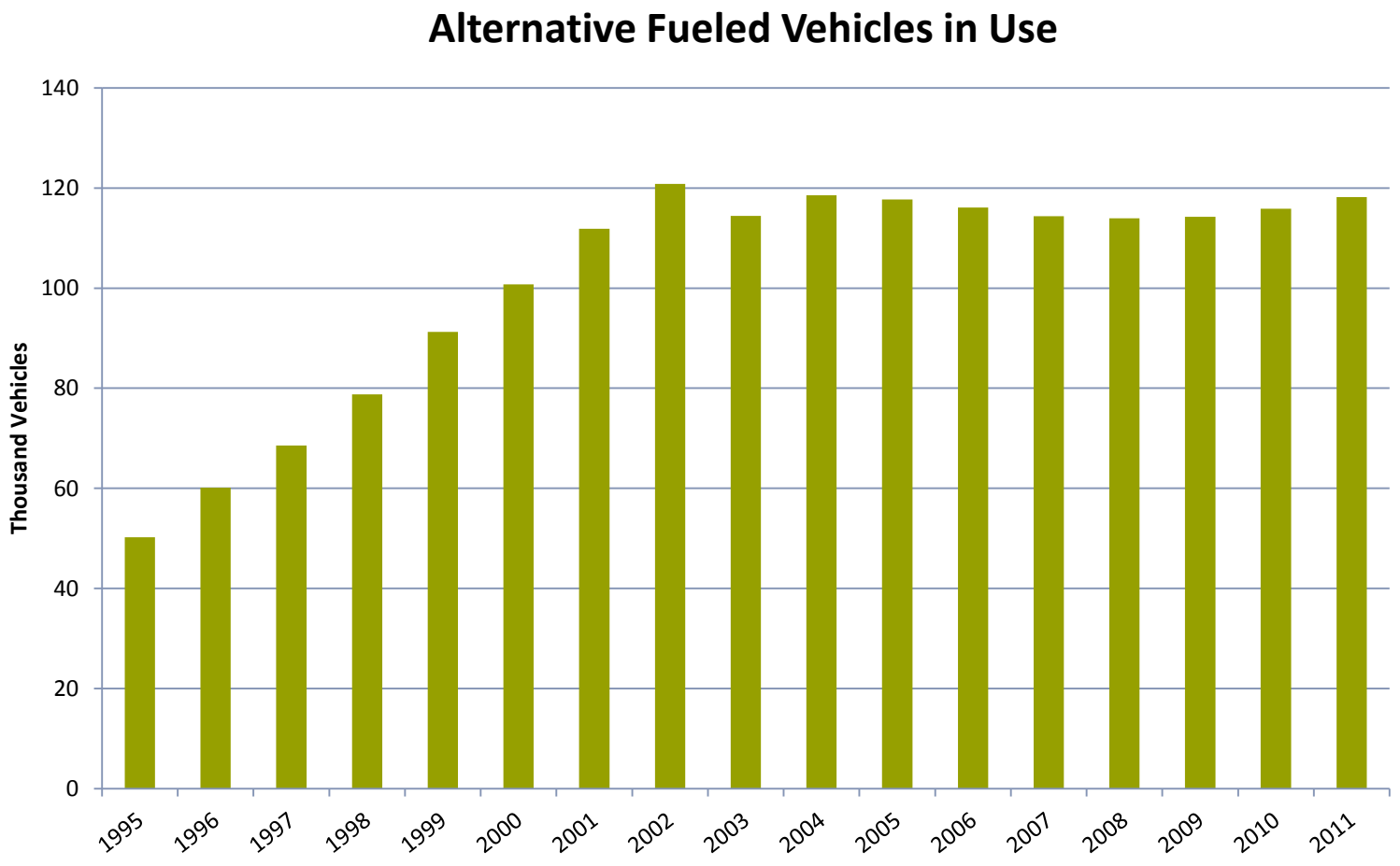


www.afdc.energy.gov/data

THE GOOD NEWS - THE CNG MARKET IS GROWING



THE RENEWABLE CNG MARKET HAS GREAT ROOM FOR GROWTH



CNG VEHICLE AVAILABILITY

- 10,000,000 CNG vehicles worldwide
- 20% of buses currently in the U.S.
- 60% of new U.S. refuse trucks

Honda Civic CNG Vehicle

Many mid- and heavy-duty vehicle choices available

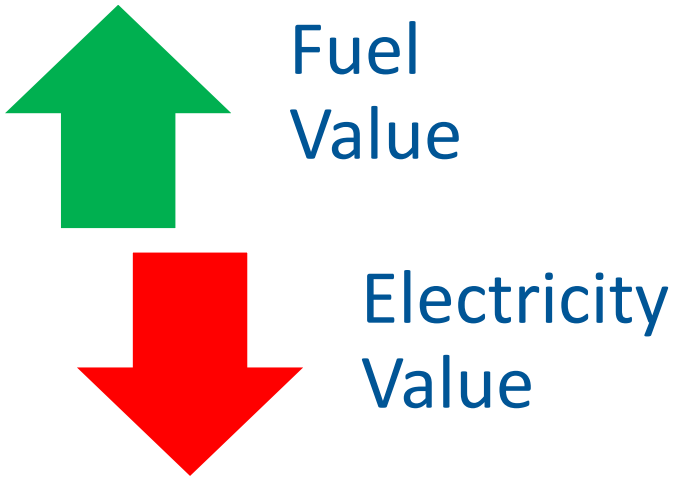
CNG MARKET COMPETITION

- Natural gas fueling station network (cities, utilities)

Courtesy of Clean Energy

WHEN DOES CLEANING TO PIPELINE QUALITY MAKE SENSE?

- **Large scale (economy advantage)**
- **Close to pipeline/CNG users**
- **Incentives for users over producers of gas**
  - RPS requirements
  - Efficiency advantage
- **High fuel prices**
- **Low electricity costs**
- **Want flexibility for end use (pipeline, vehicle fuel, cogeneration)**

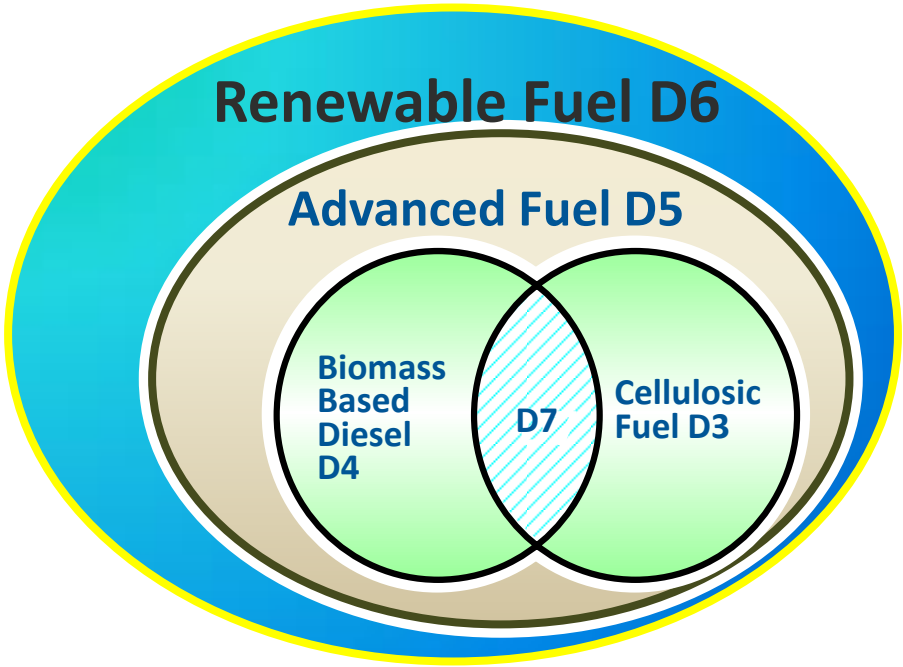


RINS (RENEWABLE IDENTIFICATION NUMBERS)

- **Part of the Renewable Fuel Standard (2) (2010)**
  - Targeted at reducing transportation emissions associated with climate change
  - Provides incentives for waste-derived fuels (4 different categories
- **RINS can be sold with or without the associated fuel**
- **Players in the market:**
  - Gasoline/diesel producers, importers, and blenders have RIN requirements
  - Renewable fuel producers and importers generate RINs

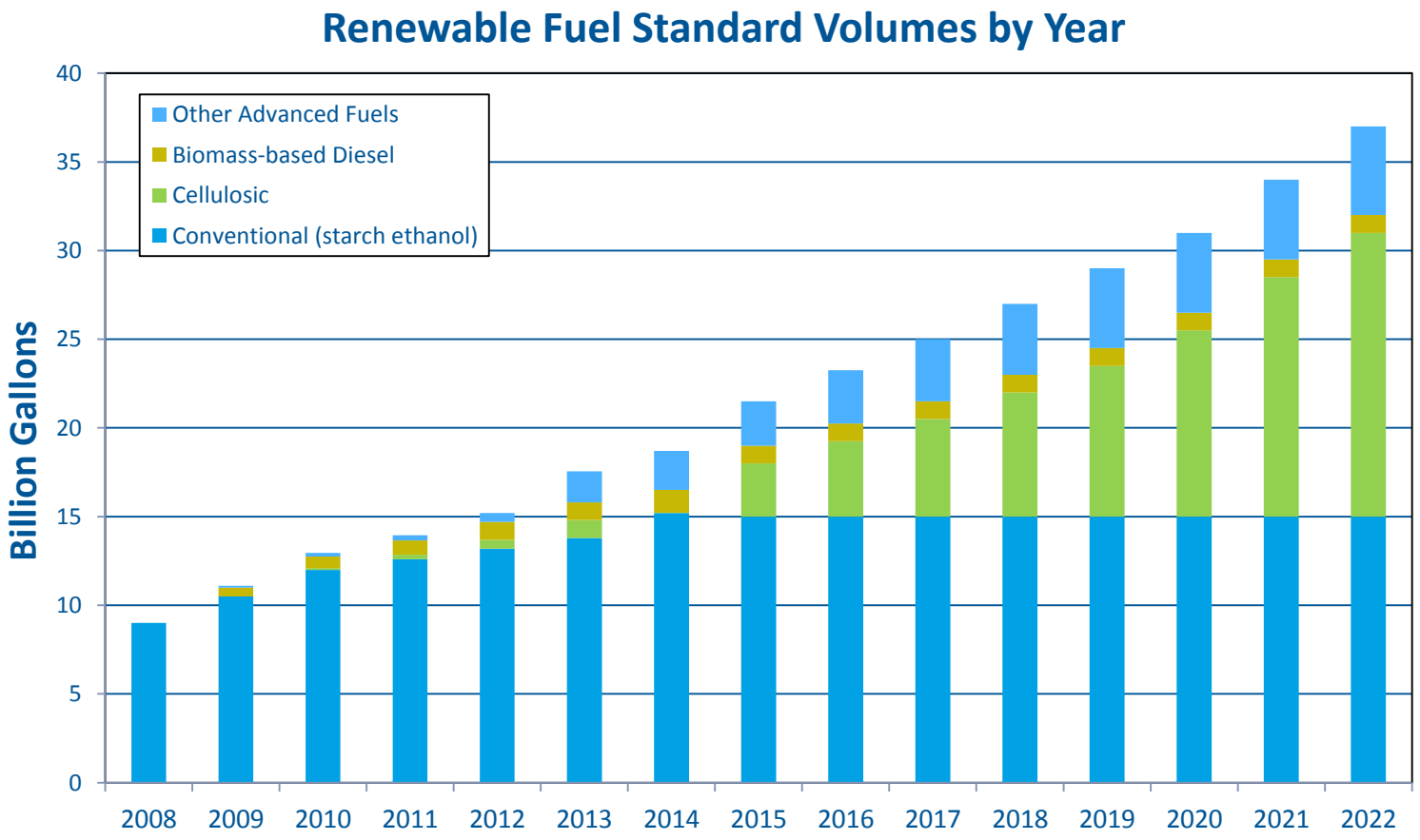
RINS (RENEWABLE IDENTIFICATION NUMBERS)

- **77,000 Btu/RIN**
- **Categories based on GHG reduction from fossil fuel**
  - Ranges from 20% to 60%
  - Overlap of RIN categories
- **Biogas now counts as Cellulosic Fuel**



- **Volatile RIN price**
  - ~ $0.20 to $0.80/RIN
- **Renewable Volume Obligation (RVO) set annually by EPA**

PROJECTED RENEWABLE FUEL VOLUME REQUIREMENTS



EIA Monthly Energy Review

HURDLES TO RENEWABLE CNG PRODUCTION

- **Cost**
  - Low natural gas and gasoline costs reduce economic benefits
- **Competition**
  - Natural gas fueling station network is growing – how can renewable CNG tap into this market?
- **Pipeline requirements**
  - Vary by state and owner
- **Regulatory**
  - Few GHG emissions limits to drive production/demand
- **Demand**
  - Fueling facility location and consumer needs
- **Not "core business" of wastewater utilities/waste treatment**
  - 3rd Party vendors providing cleaning and compression

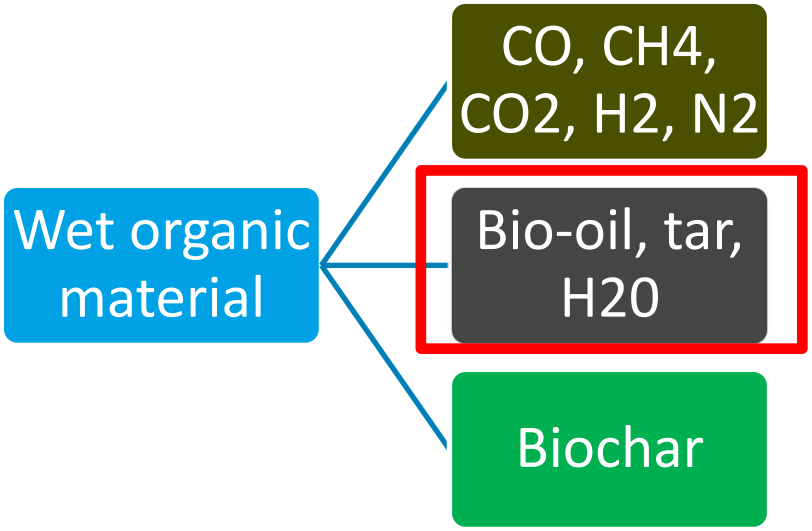
OPPORTUNITIES FOR CNG RESEARCH

- **Anaerobic digestion processes and HSW handling**
  - Reduced cost digestion and pretreatment
  - More complete information on co-digestion
- **Reduced cost cleaning technologies**
  - Increased effectiveness/lifespan
- **Reduced energy density engines (eliminates need for CO2 removal)**
- **Hydrogen conversion technologies**
  - Generate hydrogen for alternative fuel vehicles

HYDROTHERMAL LIQUEFACTION

HYDROTHERMAL LIQUEFACTION (HTL)

- **High temperatures and pressures to decompose organic matter**
  - Mimics natural processes that convert organic matter into oil
  - In the same family as pyrolysis and gasification



SUITABLE FEED MATERIALS

- Municipal biosolids
- Animal manure
- Algae
- Cellulosic biomass
- MSW

HYDROTHERMAL LIQUEFACTION – KEY DIFFERENCES

- Occurs at high pressure (725 to 2900 psi)
- Lower temperatures than gasification or pyrolysis (< 932 F)
- Performed on **WET** biomass (20 to 35% dry solids)
  - Water is critical (acts as a catalyst and reactant)

Dewatered biosolids ~ 15 to 30% dry solids

HTL PRODUCTS

- **Feedstock characteristics impact products**
  - High protein, high lipids → more oil
  - High fiber → more biochar
- **~ 100 GGE/acre wheat straw**

Biochar

Bio-oil

PRODUCT USES/MARKETS

- **Biochar**
  - Useful in agriculture
    - Soil amendment for improved water retention, pH adjustment, carbon sequestration
  - Replacement for coal
- **Bio-oil**
  - Organic liquid (corrosive)
  - Lower energy value than fossil fuel
  - Can further convert to bio-diesel (more established market for vehicles than biogas)

STATUS OF TECHNOLOGY

- **Potential high conversion rates of volatile material**
  - 70% or more, depending on substrate
- **Embryonic/emerging**
  - Significant research from the 1970's
  - Many substrates investigated
  - No full scale installations (?)

HURDLES

- **Low energy prices**
  - Research has been intermittent, interest fluctuating with energy prices
- **Few incentives**
- **Embryonic/emerging status of technology and equipment**
- **Cost of catalyst/process cost**
- **Outside of core business of generators**

RESEARCH NEEDS/OPPORTUNITIES

- **Well defined mass/energy balances for variety of substrates**
  - Optimum substrate mix and moisture
  - Temperature and pressure conditions
- **Catalyst research**
- **Equipment development and materials of construction**
- **Material handling issues**
- **Verifiable and repeatable costs for demonstration/ full scale installations**

SUMMING IT ALL UP…

- **Biogas to vehicle fuel**
  - Mature technologies
  - Limited current market
  - Economic hurdles
- **Hydrothermal liquefaction**
  - Significant research needs
  - Larger biodiesel market
  - Unknown costs/equipment requirements

QUESTIONS?

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