Future Energy & Waste

→ Waste is energy
fuel
circular

SWANA Northern Lights February 2021
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Contents of Presentation

- Introduction: Waste-to-Energy Overview and Markets
- Organic Waste-to-Energy:
  - Greening the Grid with RNG and H2
  - LFG-to-Energy
  - Biogas-to-Energy
  - Methanation of Biogas
- Thermal Conversation of Waste
  - Conventional Incineration
  - Advanced Thermal Conversation Technologies
  - Fuel Cells in Waste Management
- Research and Development

Introduction

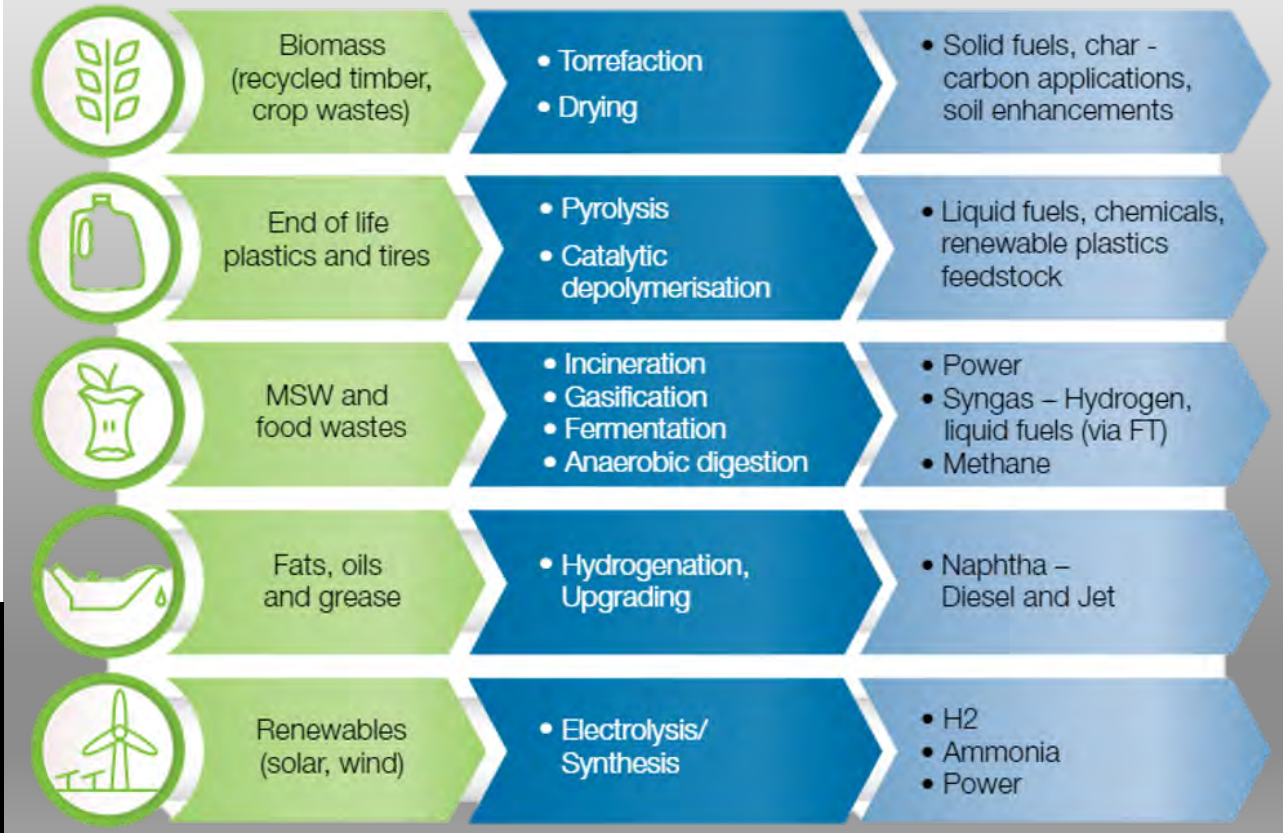
- What is Future Energy?
- Waste to Energy Overview
- WTE in North America and Europe
- Market Drivers for Waste-Derived Fuels

Waste to Energy Overview

→ In a transitioning energy system, waste is increasingly being viewed as a valuable resource.

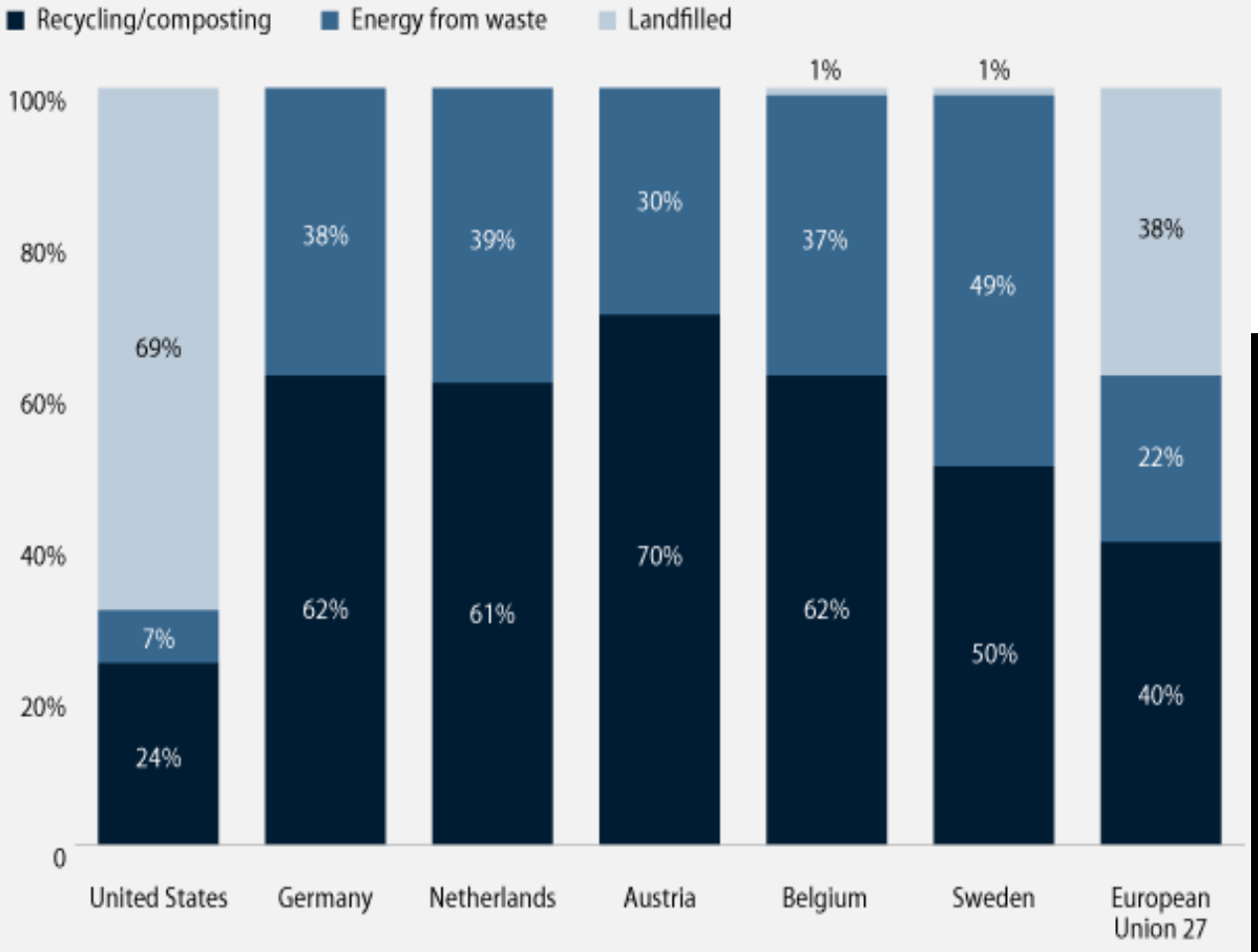
Generally, waste contains:

- **Biogenic content** – food waste, wood waste, paper, cardboard, manure, etc.
- **Non-biogenic combustible materials** – plastics, rubbers, hydrocarbons, and other petroleum-based synthetic materials
- **Non-combustible materials** – glass, ceramics, metals

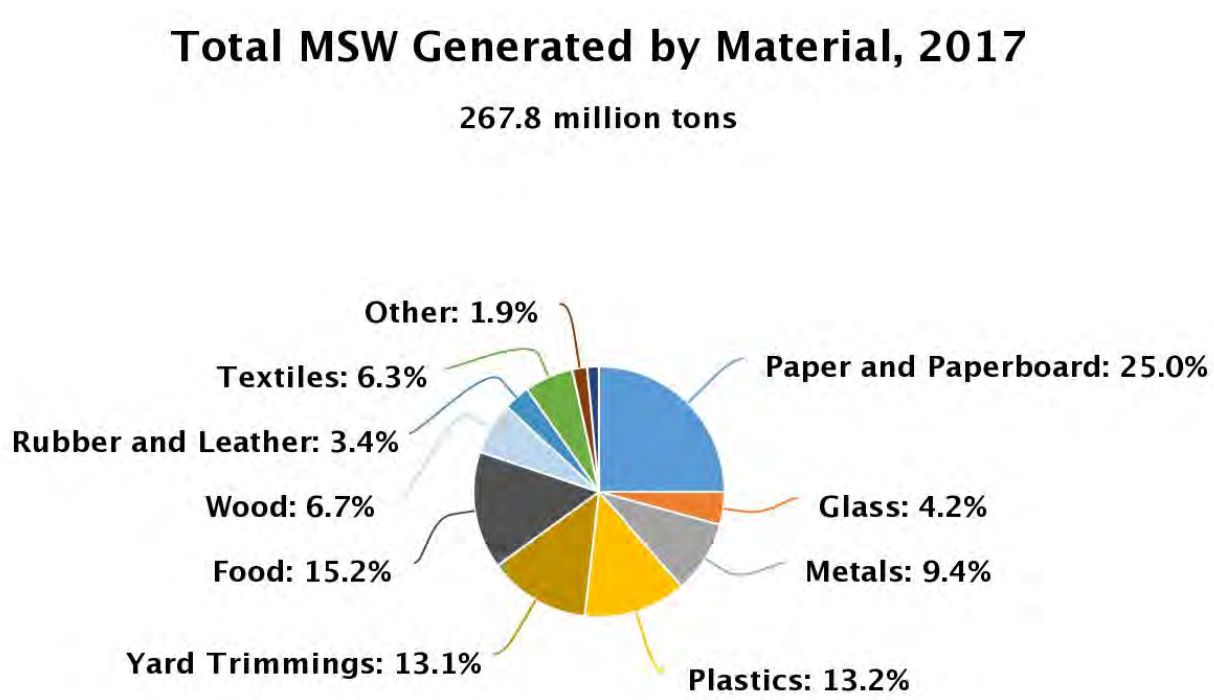


Recycling, composting, and waste-to-energy are complementary to achieve lower landfill rates.

European nations a model for waste management



Sources: BioCycle and the Earth Engineering Center of Columbia University; Confederation of European Waste-to-Energy Plants.



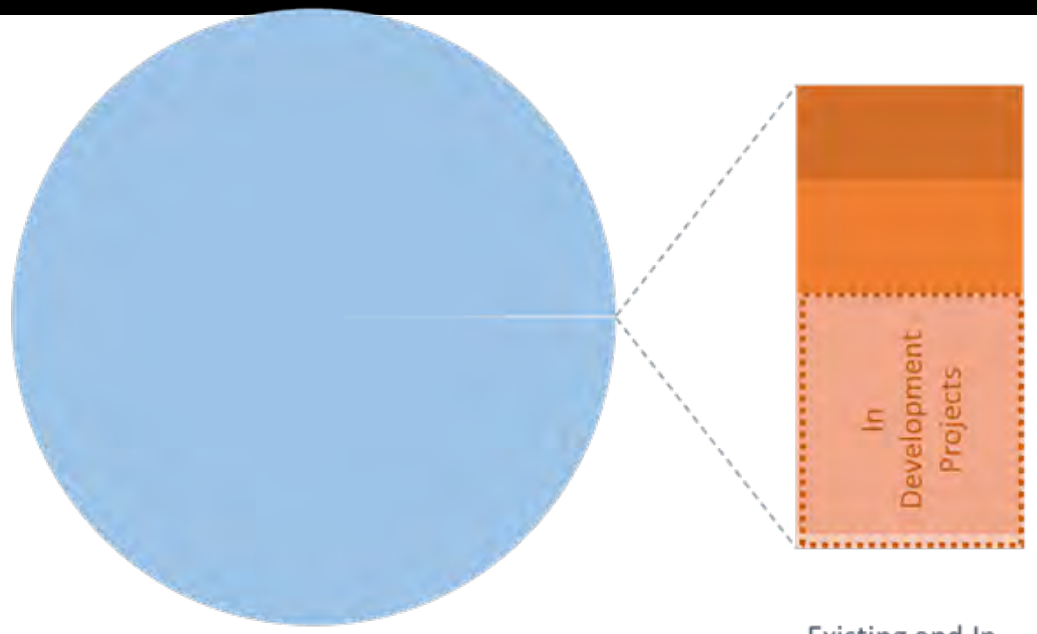
- Organics waste-to-energy (anaerobic digestion) has taken off in Canada, with major projects across the country
- Thermal conversion of waste less common in North America, widespread in Europe. Large-scale modern incineration facilities with proven operational success, several advanced conversion facilities also in operation or demonstration (gasification, pyrolysis, plasma arc)

Market Drivers

- Rising demand for renewable natural gas, biofuels, low-carbon hydrogen

Waste-to-energy provides a low-carbon method for producing fuels and energy. Where industries cannot electrify, they can turn to low-carbon fuels to meet decarbonization targets.

Ontario RNG Supply as a Fraction of a 2% RNG Target



Remaining RNG Capacity: 528,642,500 GJ/yr

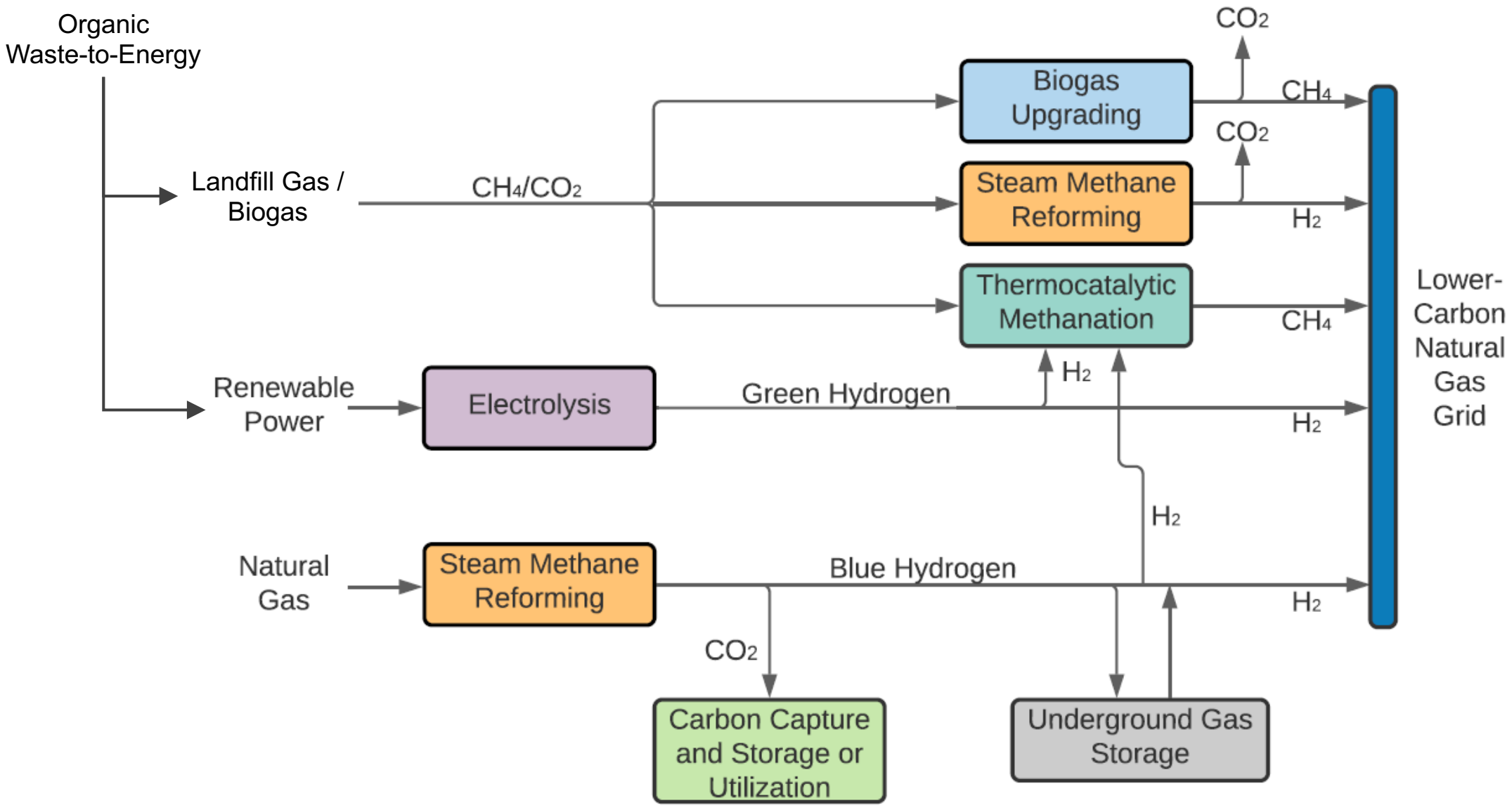
Existing and In Development Projects: 346,500 GJ/yr

- "RNG's plug and play nature make it ideal, and we believe RNG could grow to account for ~7-11% of natural gas supply by 2040, consistent with most industry analyses" – RBC, 2020
- "RNG from a range of existing sources has the potential to meet ten percent of natural gas demand." – M.J. Bradley & Associates
- Low-carbon hydrogen and RNG can be blended into local natural gas networks, reducing emissions for heating and industry.
- Biofuels demand supported by Clean Fuel Standard. WTE facilities can produce ethanol, biodiesel, jet fuel (kerosene) for fuel blending.

Organic Waste-to-Energy

- Greening Natural Gas with RNG and Hydrogen
- Landfill Gas to Energy Case Study
- Biogas to Energy (Anaerobic Digestion) Case Study
- Catalytic Methanation

Greening Natural Gas with RNG and Hydrogen



LFG to Energy

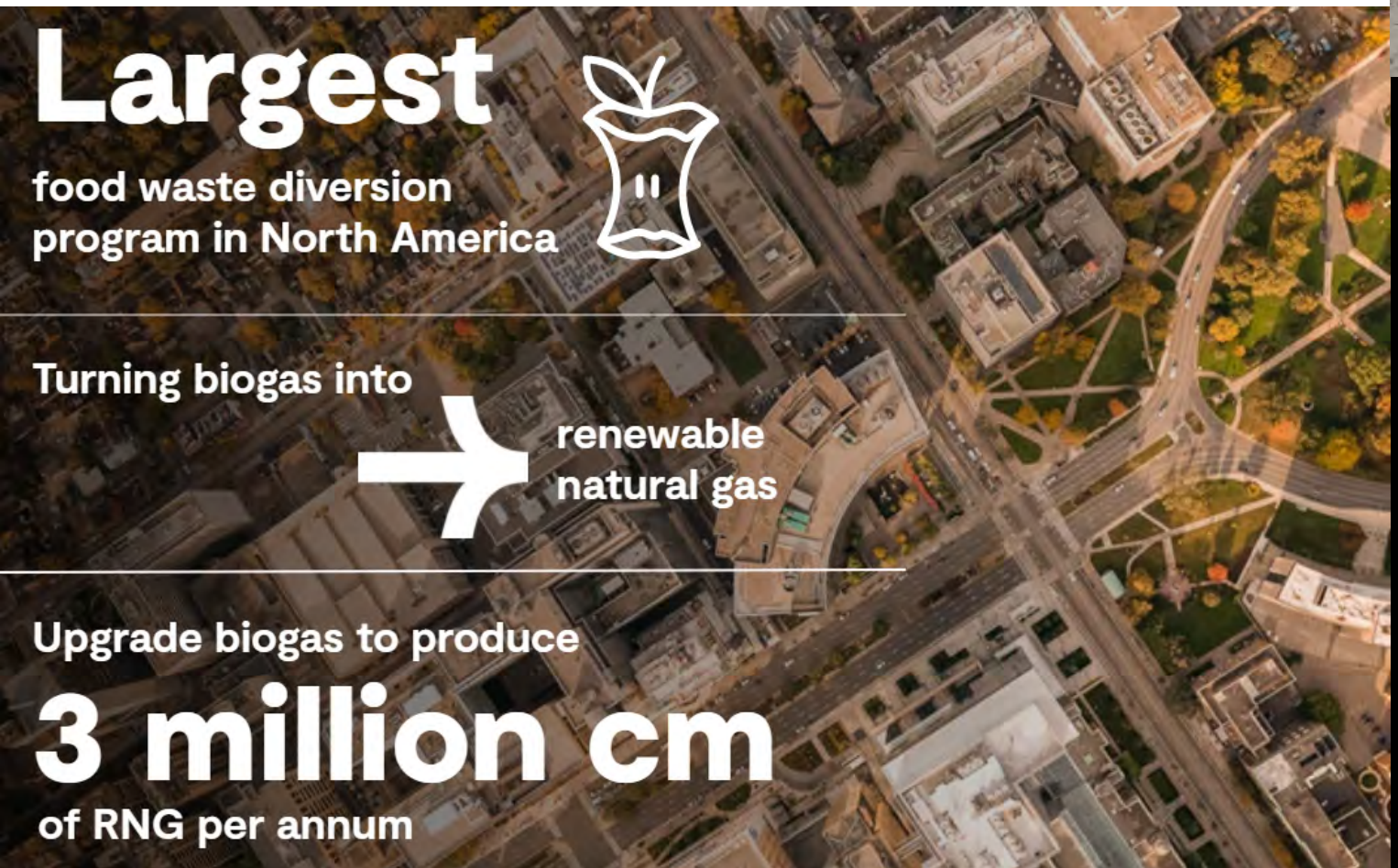
- Landfill gas is mainly CO_2 + CH_4
- LFG to energy options include:
  - Power generation
  - Combined heat and power
  - Upgrade to renewable natural gas

Cache Creek Landfill Gas to Energy Facility

4.8 MW of clean power generation, delivered to the local utility in BC

Organic Waste to Energy

Organic waste (kitchen scraps, yard waste, pet waste) produces methane when broken down in anaerobic conditions. In anaerobic digestion facilities, produced biogas can be utilized for power generation or upgraded to RNG.



City of Toronto x Enbridge Dufferin Waste Management Facility RNG Project

Not only will organics collection trucks use the RNG for fuel, the RNG will also be blended with the City's entire 50 million cm annual consumption – further reducing its carbon footprint and working towards the City's Transform TO targets.

Methanation of Biogas or Captured CO2 for RNG Production

Greenfield Global and H2yGen JV
Varennes, Quebec

- Currently, biogas → RNG focuses on *scrubbing out* CO2, leaving behind a highly pure CH4 stream.
- Methanation of biogas reacts H2 with the CO2, using catalysts and controlled conditions, to increase CH4 output and utilize the CO2.
- Waste CO2 can also be converted to biomethane/RNG using this process.

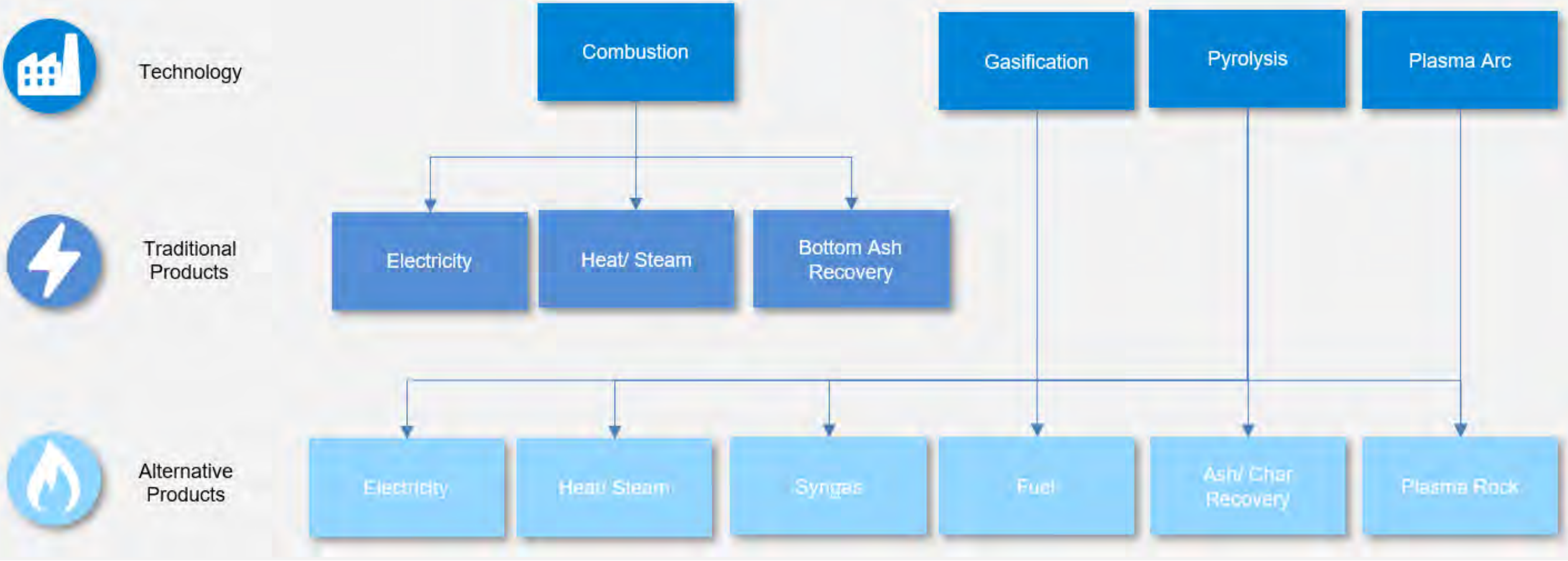
- Hydroelectric power will be used to produce green hydrogen
- Green H2 combined with waste CO2 from Greenfield's existing Biorefinery (pictured), producing **RNG and bioethanol**

Thermal Conversion of Waste

- **Combustion / Incineration**
- **Advanced Thermal Conversion**
  - → Gasification
  - → Pyrolysis
  - → Plasma Gasification

Waste to Energy using Thermal Conversion

- Feedstocks include MSW, plastics, tires, mixed commercial wastes, biomass, and more
- Advanced conversion technologies have incredible potential; face challenges with financing, proven-ness, pre-processing requirements



Advanced Thermal Treatment of Waste

→ Gasification
Plasma-Assisted Gasification
Pyrolysis

Produces Heat	Combustion:	800-1200°C Excess of oxygen
Produce Heat + Syngas	Gasification:	800-1200°C Oxygen-starved
	Plasma-Arc Gasification:	Very high temps can be achieved, >1500°C Greater feedstock variability than gasification
	Pyrolysis:	350-600°C Absence of oxygen Can treats difficult contaminants, i.e. PFAS

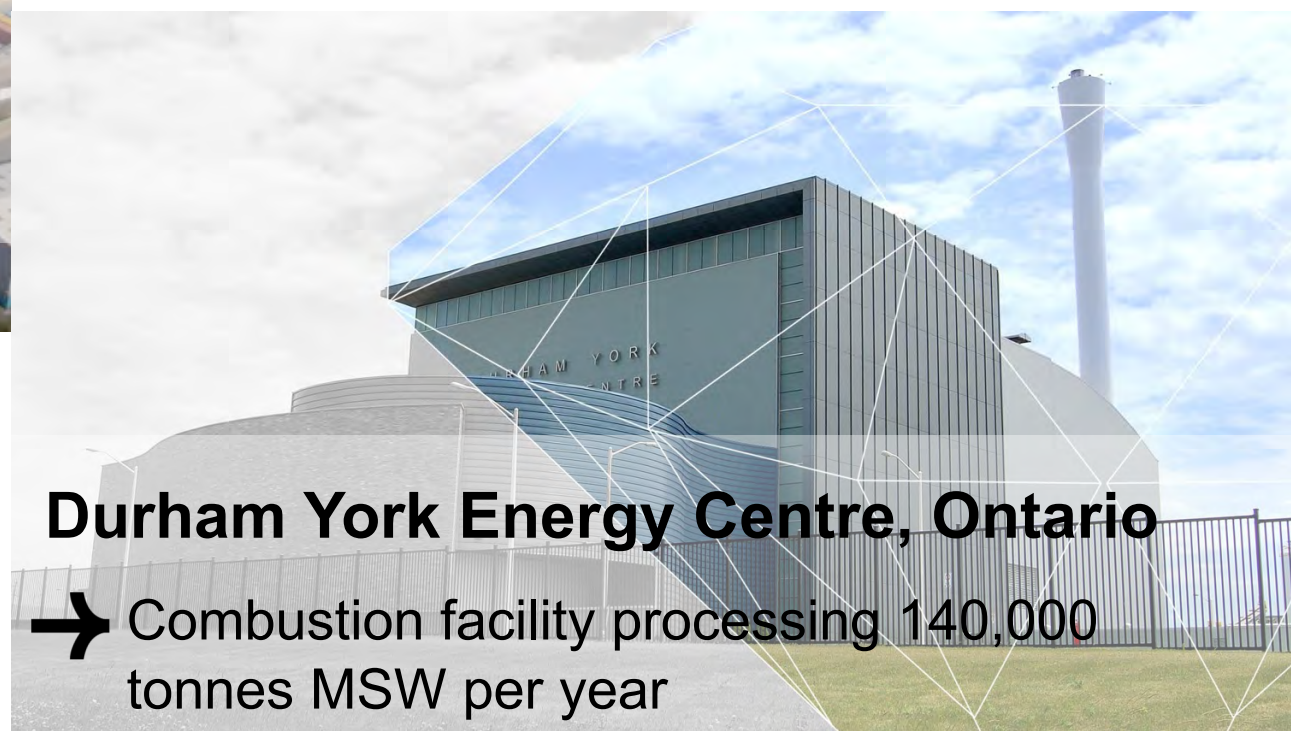
Combustion / Incineration

- Waste incineration facilities are commonplace in many countries with limited land for landfills.
- Established technology at large scales – facilities with long-standing operation treating up to 1.1 million tonnes of non-recyclable waste per year.
- Combustion produces electricity and heat.

Runcorn Energy Recovery Facility, UK

→ CHP facility treating pre-processed refuse derived fuel (RDF) from non-recyclable waste

- In Japan, a world-leading 71% of waste is incinerated.
- Denmark, Norway and Sweden all incinerate >50% of waste, while also having some of the highest rates of recycling in the world.
- In Canada, less than 5 percent of garbage is incinerated. ~72% of waste is landfilled.



Durham York Energy Centre, Ontario

→ Combustion facility processing 140,000 tonnes MSW per year

Plastic Waste-to-Energy

A challenge for recycling finds a solution in thermal conversation technologies

260 million tonnes of plastic waste is produced each year around the world, but only about 12 percent is currently being recycled.

The development of a new way to recycle/reuse holds huge potential for relieving the burden this waste places on our environment.

Peel Environmental and Waste2Tricity have got the planning green light for the UK's first waste plastic to hydrogen facility

The plant will process 35 tonnes of plastic waste and produce up to 2 tonnes of hydrogen per day, while generating 3.8 MW of electricity.

Energy-Neutral Pyrolysis of Biosolids

- Energy neutral, no fossil fuel demand after initial process warmup
- Biomass is reduced by 90%, the by-products are biochar and energy (heat)

Project Details

- New biodryer/pyrolysis system at an existing WWTP
- Replaces the existing thermophilic anaerobic digestion system with biodryers coupled with a pyrolysis reactor
- Reduces final product mass about 10-fold from current dewatered cake levels
- Produces biochar, a carbon-enriched end product, with potentially zero disposal costs and a small revenue stream
- No detectable PFAS compounds in the biochar

WWTP #1 Biosolids Processing and Handling Upgrade

Fuel Cells in Waste Management

- Fuel Cells that Run on Biogas
- Fuel Cell Garbage Trucks

Fuel Cell Garbage Trucks

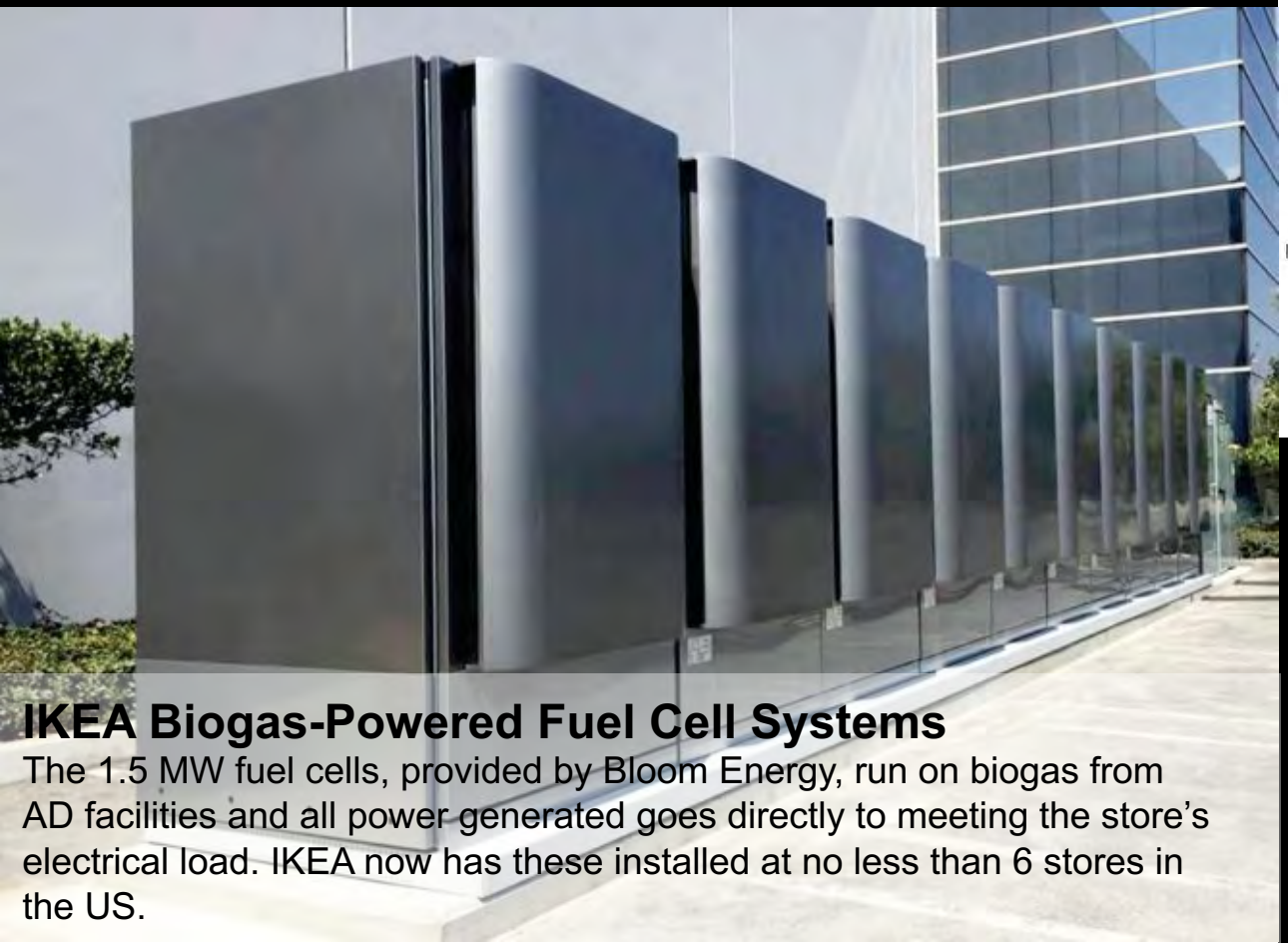
As of February 2021, REVIVE's fuel cell truck has hit the streets of Groningen, Netherlands, becoming part of the regular waste collection fleet.

Three projects leading the way in Europe

- REVIVE Project is developing and validating tech necessary for operating conditions of H2 fuel cell trucks
- LIFE 'N Grab HY Project is testing fuel cell garbage trucks under various operating conditions across Europe
- HECTOR Project is deploying 7 fuel cell garbage trucks to demonstrate effective emissions reductions

Biogas in Fuel Cells

- Biogas to electricity without combustion, using electrochemical processes instead and minimizing GHG emissions

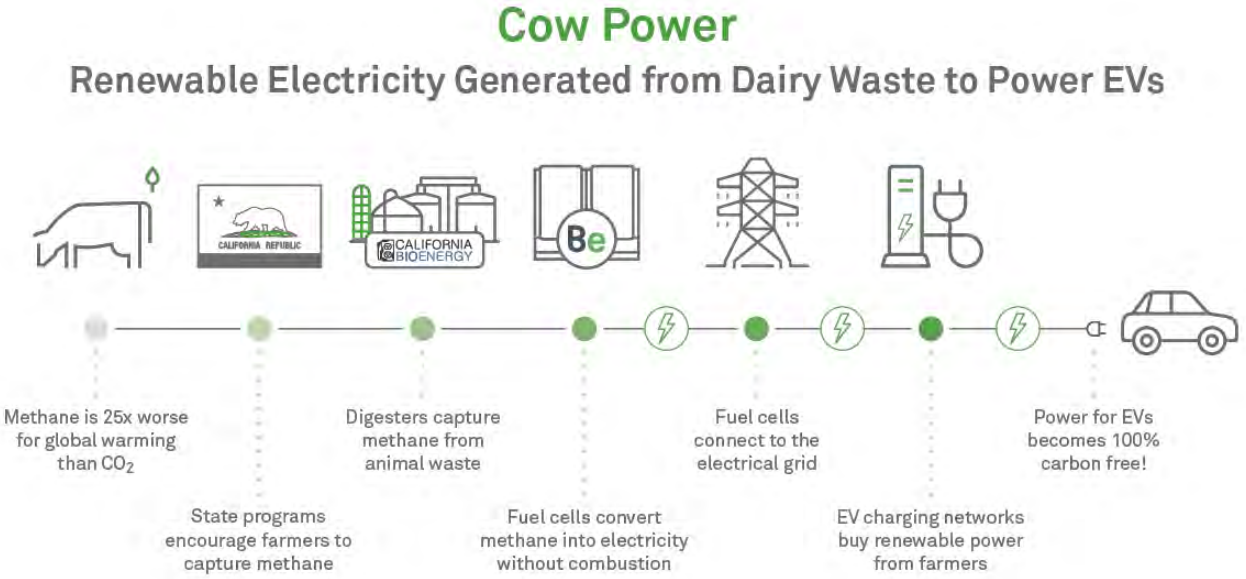


IKEA Biogas-Powered Fuel Cell Systems

The 1.5 MW fuel cells, provided by Bloom Energy, run on biogas from AD facilities and all power generated goes directly to meeting the store's electrical load. IKEA now has these installed at no less than 6 stores in the US.

CalBio and Bloom Energy to Generate Renewable Electricity from Dairy Waste

On-Site Power Solution Will Dramatically Reduce Methane Emissions from Dairies by Using Captured Biogas to Generate Electricity without Combustion



Benefits

- Higher efficiency (~60%) than turbine (~40%) or reciprocating engine (~30%) combustion
- Lower carbon emissions per unit of electricity produced

Challenges

- Removal of H2S and other contaminants from the biogas prior to FC
- Type/design of FC to handle biogas and variability

Research & Development

— The Future of Waste-to-Energy?

Research and Development

→ Inventive methods under development for producing hydrogen from waste

- A new biofuel system that decomposes lignin found in biomass with a molybdenum catalyst to produce high value-added compounds plus extra electrons. The electrons extracted in the process are used to generation hydrogen through electrolysis.
- Biogas reforming technology development – dry reforming, dual reforming, tri-reforming
- Purdue University using yeast to break down food waste into clean hydrogen, with minimal pre-processing steps and higher efficiency than more common waste to hydrogen technologies
- Waste CO2 → Algae → Fuels

*Thank You

→ The Power of Commitment