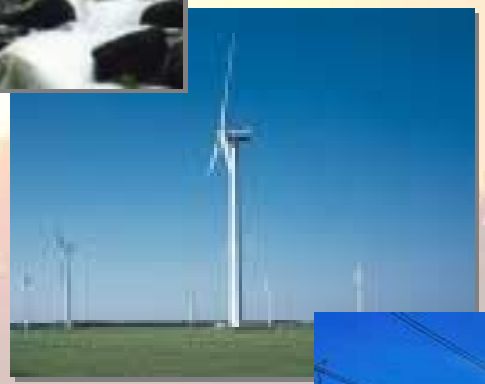


Usage of Landfill Biogas

Jerry Leone

General Manager – Renewable Energy

Options for Using LFG

- **Electricity production**
  - reciprocating engines
  - combustion turbines
  - external combustion engine (future)
- **Direct use as a boiler, furnace, or kiln fuel**
- **Upgrade to pipeline quality gas**
- **Microturbines and fuel cells**
- **Niche alternatives**

Technology Trends

- **Electricity Generation**
  - Currently 2/3 of US operational projects generate electricity
  - These projects represent over 1,000 MW of capacity
  - 80+ electricity projects in construction or planning
- **Direct Use**
  - Trend toward more direct-use projects
  - 21 operational in 1990
  - 106 operational in 2001
  - Expect dramatic increase in future

Direct Gas Utilization

- Use of LFG as fuel in brick/cement kilns and furnaces
- Gas conveyed to nearby customer for use in boiler
- Space heating (limited)
- Over 75 projects
- Pipelines 1 to 15 miles

LFG Direct Use

- **Advantages**
  - Simplest technology
  - Generally, minimal processing requirements
  - Able to use gas as it becomes available
  - Most cost effective
  - Two party agreement
  - Higher priced commodity

- **Disadvantages**
  - Requires locating an end user
  - Could require utility status classification
  - Easements may need to run through urban areas

Electricity Generation

- Most prevalent application
- Electricity sold to utility or nearby customer (rare)
- Size: 500 kW to 50 MW
- Caterpillar, Jenbacher, Deutz, Waukesha
- Requires min. gas cleaning

Electricity Generation

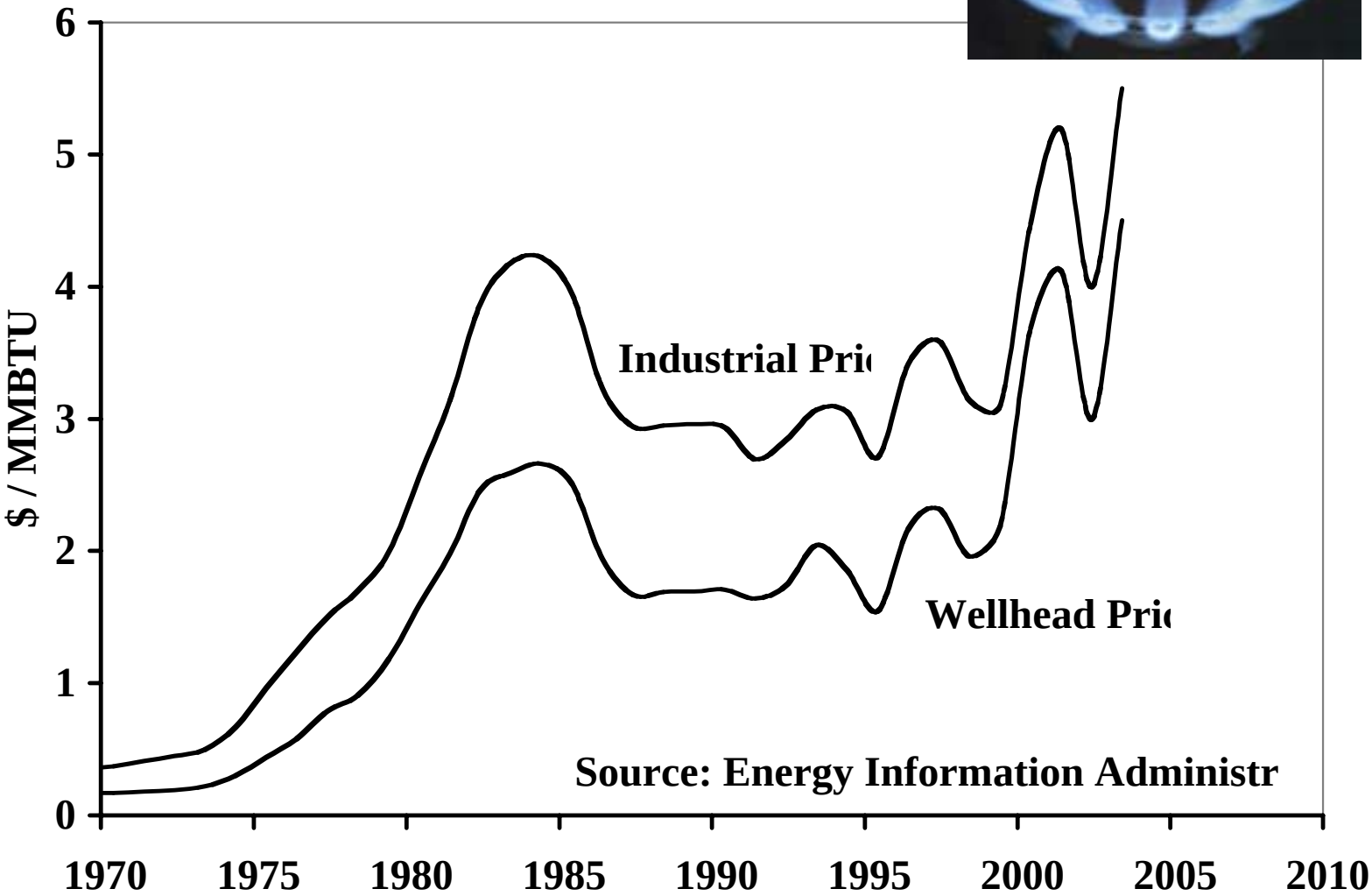
- **Advantages**
  - No local end user needed
  - Power could be used on-site
  - Allows waste heat recovery

- **Disadvantages**
  - Higher capital and costs
  - Utilities can be difficult to deal with
  - Long term agreement necessary
  - Some markets not competitive enough

Pipeline Quality Gas Upgrade

- **Advantages**
  - Cost effective only for landfills with high gas volumes
  - Beneficial in areas where natural gas prices are high
  - Potential to produce "Dry Ice" (Liquid CO_2) for sale
  - High maintenance requirements
- **Disadvantages**
  - High capital costs due to substantial processing requirements
  - Extensive treatment (remove nitrogen, CO_2, and other constituents)
  - Conform to strict quality specifications
  - Economics only work for large landfills

Gas Price History



Pipeline Quality Gas Upgrade

- **Technology Advances**
  - New, lower cost technologies entering the market
  - Physical and/or chemical removal of impurities

Pipeline Quality Gas Upgrade

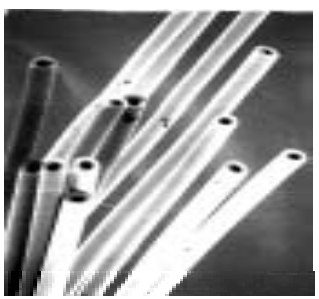
Ukrainian technology installed in Alabama (US)

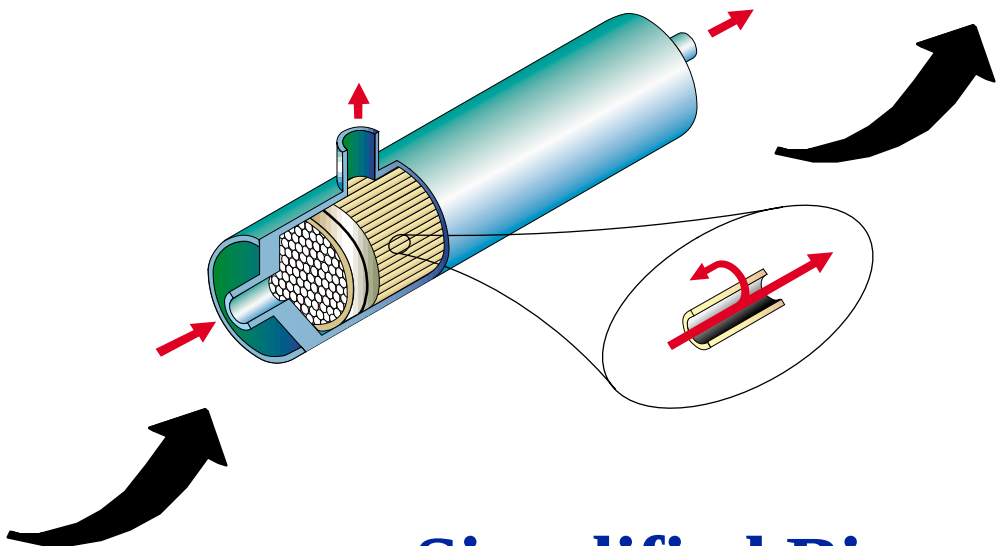
AIR LIQUIDE™

MEDAL

MEMBRANE SEPARATION SYSTEMS

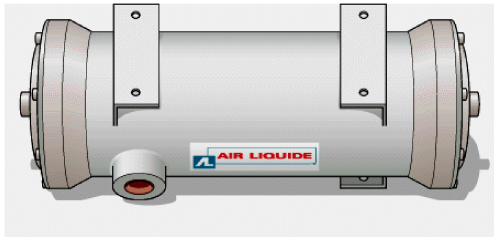
DUPONT AIR LIQUIDE

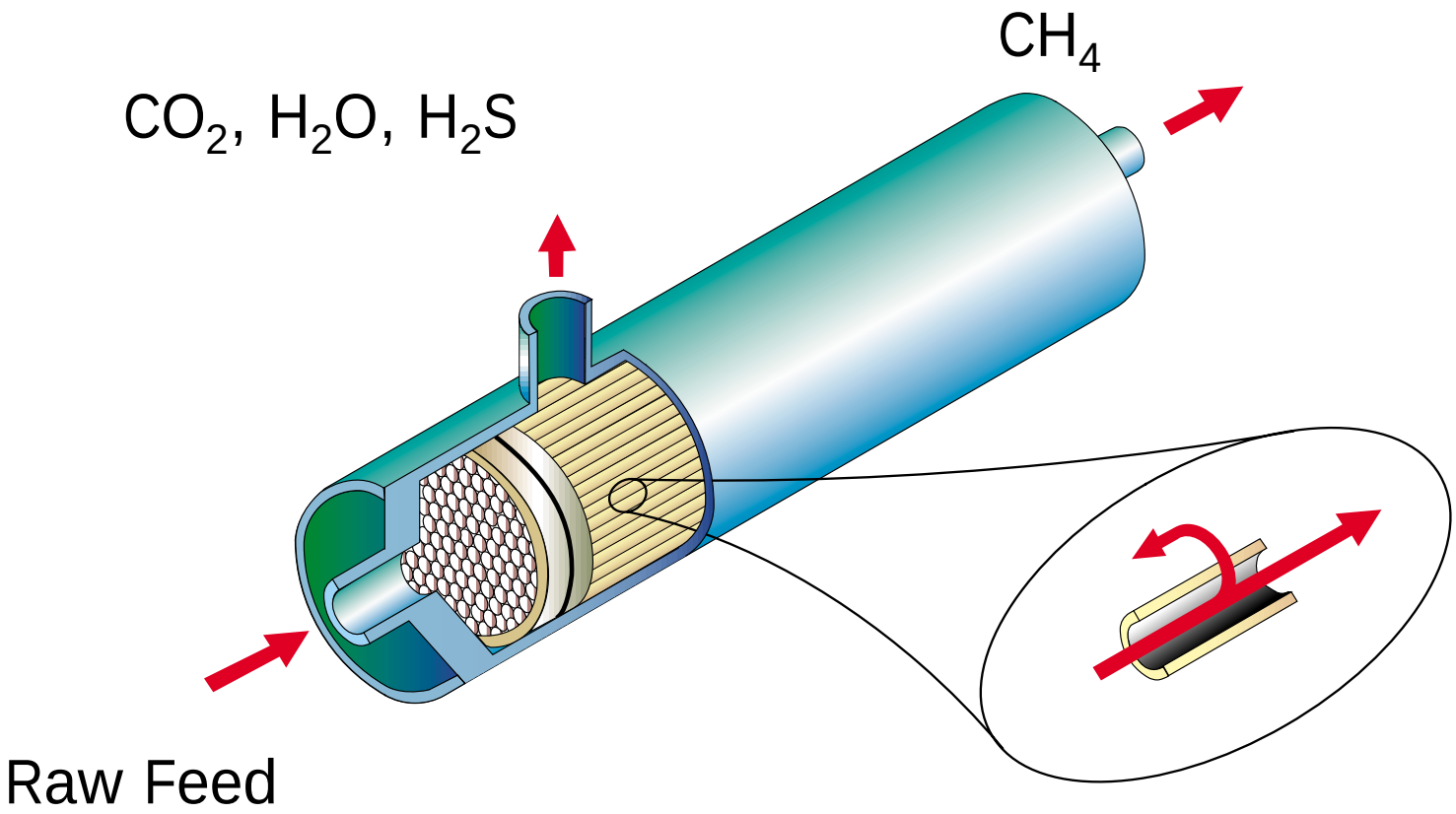




Simplified Biogaz System

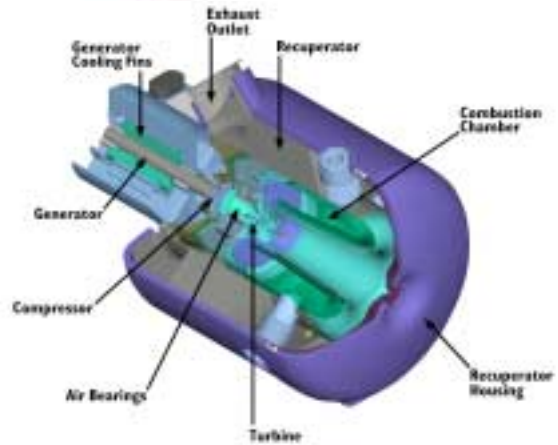
Membrane Module





Microturbine Overview

- A high speed turbo-charged generator that produces stationary power
- Proven within aviation industry
- Available in sizes ranging between 25 kW to 75 kW



Microturbines

- **Advantages**
  - Low emissions
  - Multiple fuel capacity
  - Light weight/small size
  - Requires a lower degree of pretreatment than high BTU or fuel cell systems
  - Lower maintenance costs
  - Modules can be linked to increase in gas flow

- **Disadvantages**
  - Low efficiencies
  - Has been tested mostly for natural gas applications
  - Limited track record of performance
  - Requires gas cleaning

Fuel Cells

- Chemically convert gas to electricity
- Extensively used in NASA space applications
- Demonstration phase for LFG
- May be possible to extract hydrogen

Fuel Cells

- **Advantages**
  - High efficiency
  - Minimal emissions
  - Modular
  - Mature technology when used with natural gas
- **Disadvantages**
  - Limited track record of performance on LFG
  - Extensive pretreatment required for LFG
  - High Cost

Niche Alternatives

- **Greenhouses**
  - **- use of CO_2**
- **Vehicle Fuel**
  - **– CNG**
  - **– LNG**
- **Leachate Evaporation**
- **Pottery and glass blowing**

Energy Xchange
A Renewable Energy Center

Summary of Technology Trends

- Growth in direct use projects
- Greater diversity in project types
- Many proven/cost effective ways to use LFG
- Selection of technology is site specific
- Technologies exist for low and high volumes of gas
- Alternatives are emerging