LMOP Workshop: LFGE Status Update & Technology Trends

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LANDFILL METHANE OUTREACH PROGRAM

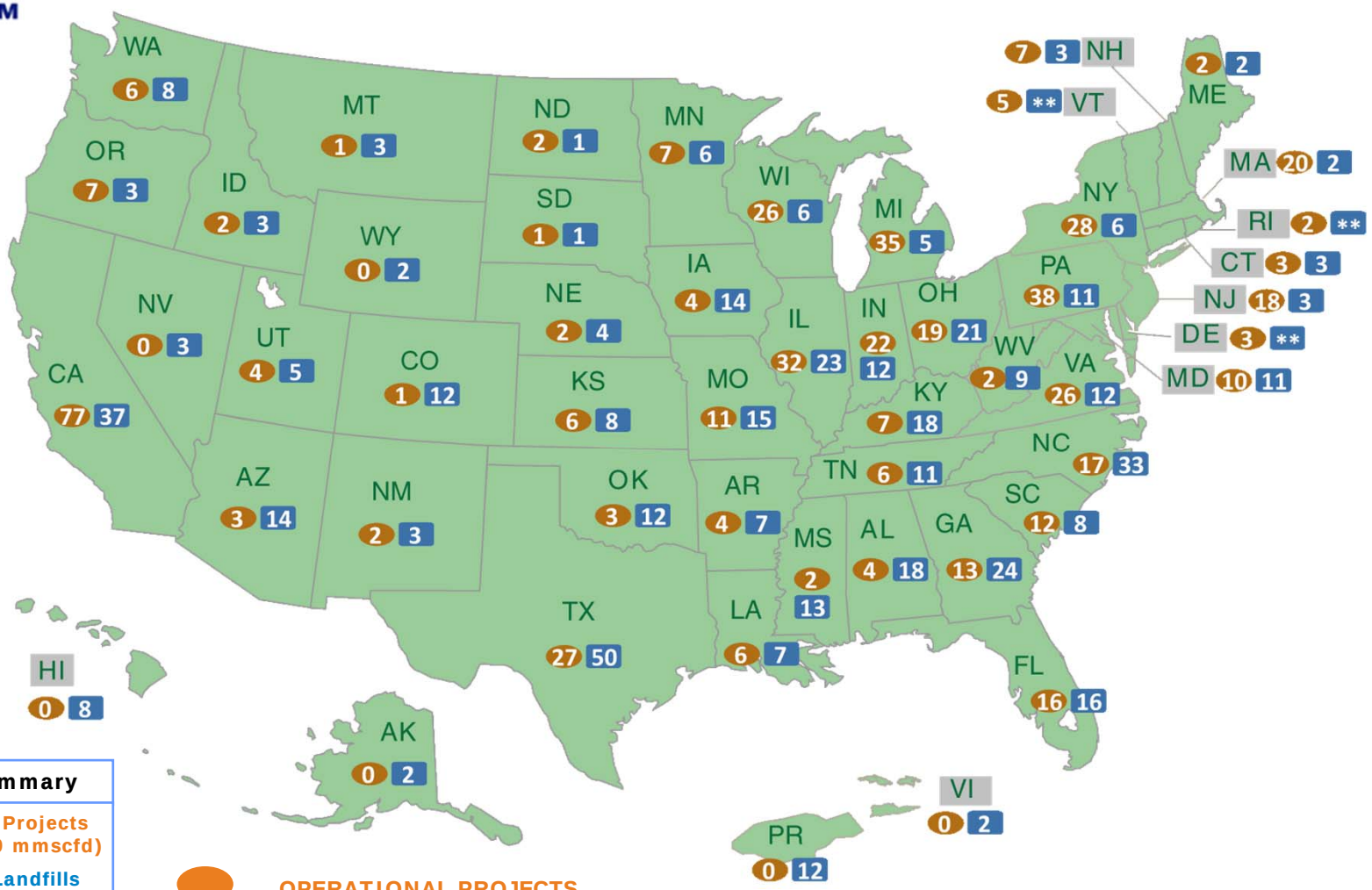
Presentation Overview

- State of LFG industry
- Electricity project trends & case studies
- Direct use project trends & case studies

State of the National LFG Industry

- Over 550 operational projects in 46 states annually supplying:
  - **13 billion kilowatt-hours** of electricity and **100 billion cubic feet** of LFG to direct-use applications
- Currently ~510 candidate landfills
  - Total gas generation potential of these sites:
    - 215 billion cubic feet per year (~12,500 MMBtu/hr) OR
    - total electric potential of 1,160 MW (~9.5 million MWh/yr)

LFG Energy Projects and Candidate Landfills



Nationwide Summary
551 OPERATIONAL Projects (1,697 MW and 309 mmscfd)
~510 CANDIDATE Landfills (1,165 MW or 580 mmscfd, 13 MMTCE Potential)

OPERATIONAL PROJECTS

CANDIDATE LANDFILLS*

* Landfill is accepting waste or has been closed for 5 years or less and has at least 1 mmtons of waste and does not have an operational/under construction LFGE project or is designated based on actual interest/planning.

** LMOP does not have any information on candidate landfills in this state.

These data are from LMOP's database as of April 12, 2011.

Many Untapped LFG Resources (cont.)

- ~510 landfills have a gas collection system but no energy project
  - Potential of 300,000 MMBtu/day or 1,070 MW
- ~110 landfills have an energy project and excess LFG available
  - Potential of 78,000 MMBtu/day or 280 MW
- ~950 landfills do not have a gas collection system
  - Potential of 220,000 MMBtu/day or 800 MW

Electricity Generation

- **Most prevalent type of project in the US – accounting for about 2/3 of operational projects**
  - In US, 1100 MW of capacity from over 300 operational projects
- **Electricity sold to utility, cooperative or nearby customer**
- **Average project size: 4 MW (500 kW - 50 MW)**

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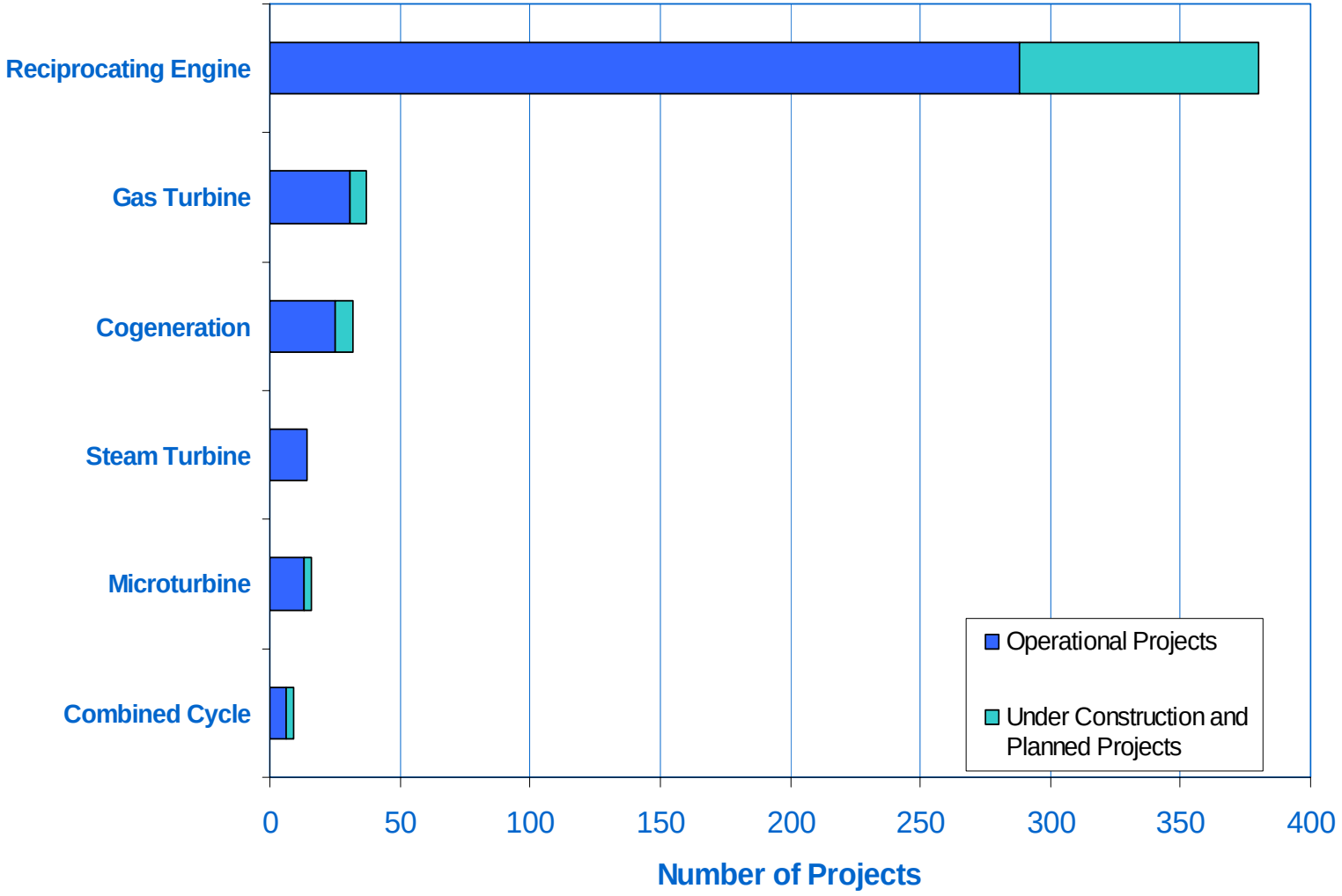
Technology Trends
Electricity Projects



Diversity of Project Types
Electricity Generation

Internal Combustion Engine (range from 100 kW to 3 MW)

Gas Turbine (range from 800 kW to 10.5 MW)

Microturbine (range from 30 kW to 250 kW)

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Internal Combustion Engine

- Most common technology
- Ideal for projects 800 kW to 3 MW
- Characteristics:
  - Relatively low cost
  - High efficiency
  - Fit gas output of most landfills

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Gas Turbines

- Technology suitable for larger gas flows – capable of 3-5 MW
- Significant economies of scale
- Disadvantage:
  - Turbines require high gas compression, causing high parasitic load loss
- Turbines are more corrosion resistant, fairly compact and have lower O&M costs
- May require siloxane removal which will increase project costs

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Microturbines

- **Sizing:** 30-250 kW
- **Why select technology?**
  - Small LFG quantities required
  - % CH_4 composition of gas can be as low as 35%
  - Add and remove fairly easily
  - Easier interconnection to grid
  - Low NO_2 emissions

Electricity Case Study

Coffin Butte Landfill Corvallis, Oregon

- The Coffin Butte Landfill LFGE facility
  - 2007 expansion project from 2.4 MWs to 5.66 MWs
  - Electricity is sold to Pacific Northwest Generating Cooperative
  - Expansion project removes emissions equivalent of:
    - 3,200 vehicles,
    - 38,000 barrels of oil, or
    - Planting 4,500 acres of forest

Reciprocating Engine Case Study

Ox Mountain Landfill, Half Moon Bay, CA

- At 11.4 MW, one of the largest LFG electricity projects in the country
- Using new temperature swing adsorber (TSA) activated carbon technology to clean LFG

LMOP 2009 Project of the Year

- Overcame air quality permitting & threatened species hurdles
- Alameda Municipal Power & City of Palo Alto Utilities aggressively surpassing renewable energy requirements

Direct Gas Utilization

- Gas piped to a nearby customer for use in boiler, furnace, kiln or other combustion device
- About 100 projects in the US
- Pipeline length range from .3 to 10 miles
  - less than 3 miles is most feasible
- Gas used at off-site end user

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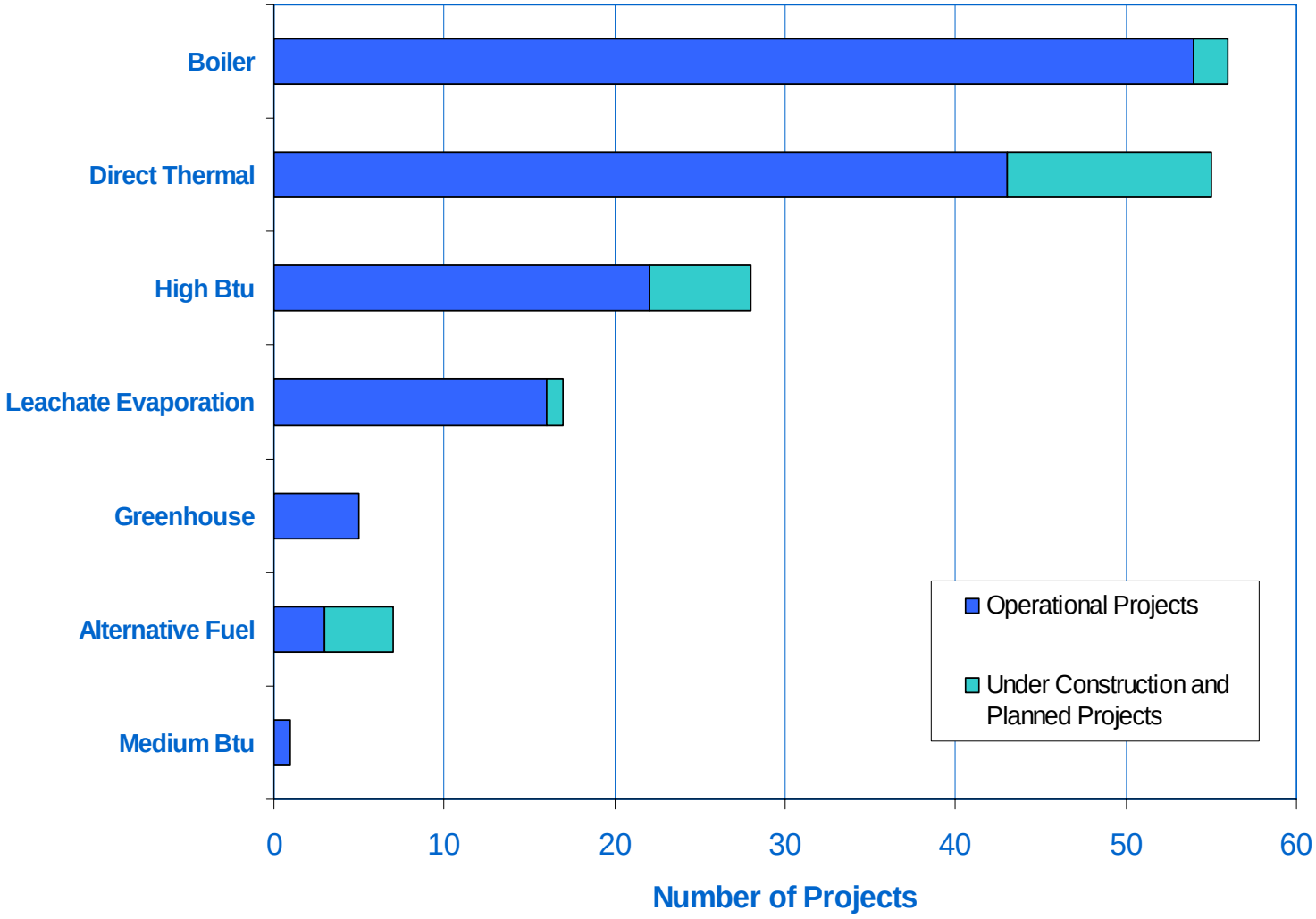
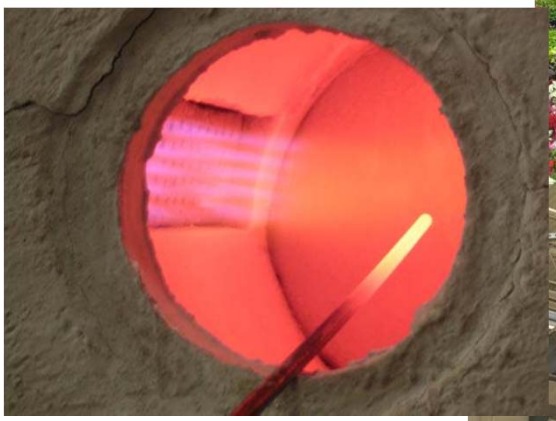
Technology Trends
Direct-Use Projects



Diversity of Project Types
Direct Use of LFG

- Direct-use projects are growing!
  - Boiler applications – replace natural gas, coal, fuel oil
  - Direct thermal (dryers, kilns)
  - Natural gas pipeline injection (medium- & high-Btu)
  - Ethanol production
  - Greenhouses
  - Infrared heaters
  - Leachate evaporation
  - Vehicle fuel (LNG, CNG)
  - Glassblowing & pottery
  - Blacksmithing
  - Hydroponics
  - Aquaculture (fish farming)

Greenhouse
Jackson County, NC



Glassblowing
Jackson County, NC

Infrared heater - Lorton, VA

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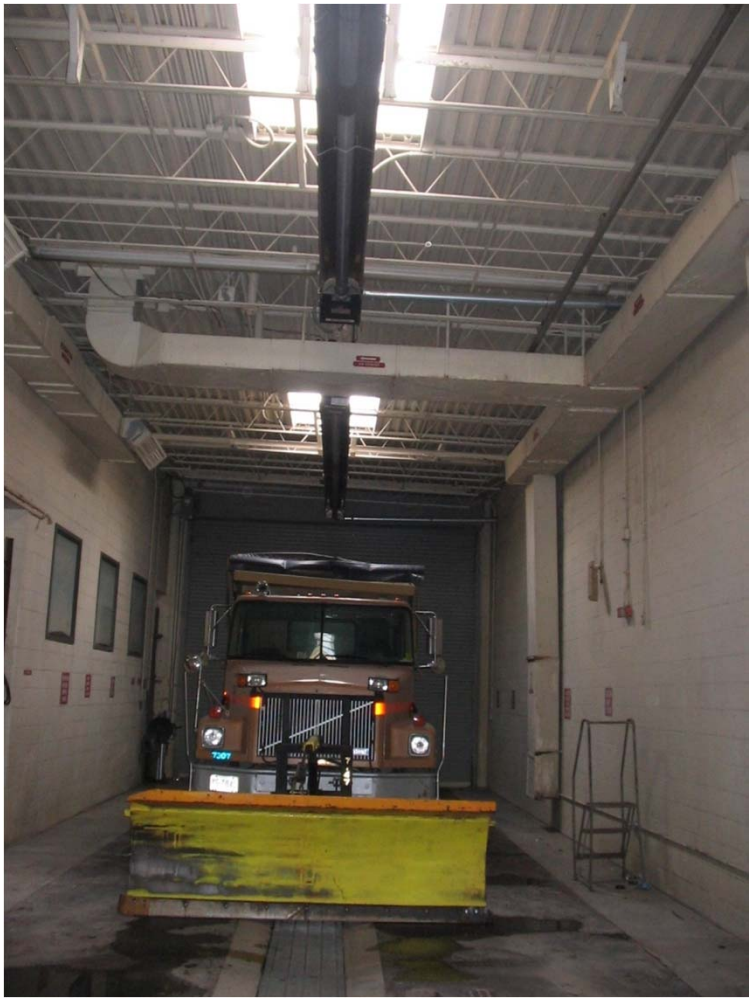
Direct Use Applications

Greenhouses

- Use both electricity and heat
- Carbon dioxide can be used to grow greenhouse plants
- 6 operational greenhouse projects in the U.S.

Infrared Heaters

- Used to heat storage and maintenance facilities
- Excellent application for small amount of gas and minimal energy requirements
- No gas pre-treatment required (unless siloxanes are found)



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Leachate Evaporation

- Utilize LFG to treat leachate
- Commercially available technology
- Projects can typically treat 10-20 thousand gallons of leachate per day
- Popular technology where leachate disposal is unavailable or expensive
- Units operate in the U.S. and internationally
  - 14 operational in the U.S.

Direct Use/CHP Case Study

H_2Gro Greenhouses
Lewiston, NY

- 11 engine-generator sets produce a total of 12 MW of electricity
- Provides all electrical & heating requirements for H_2Gro's Greenhouse
- Excess electricity sold to grid
- Test so successful, expanded to 7½ acres and produces 3.5 million lb tomatoes/yr

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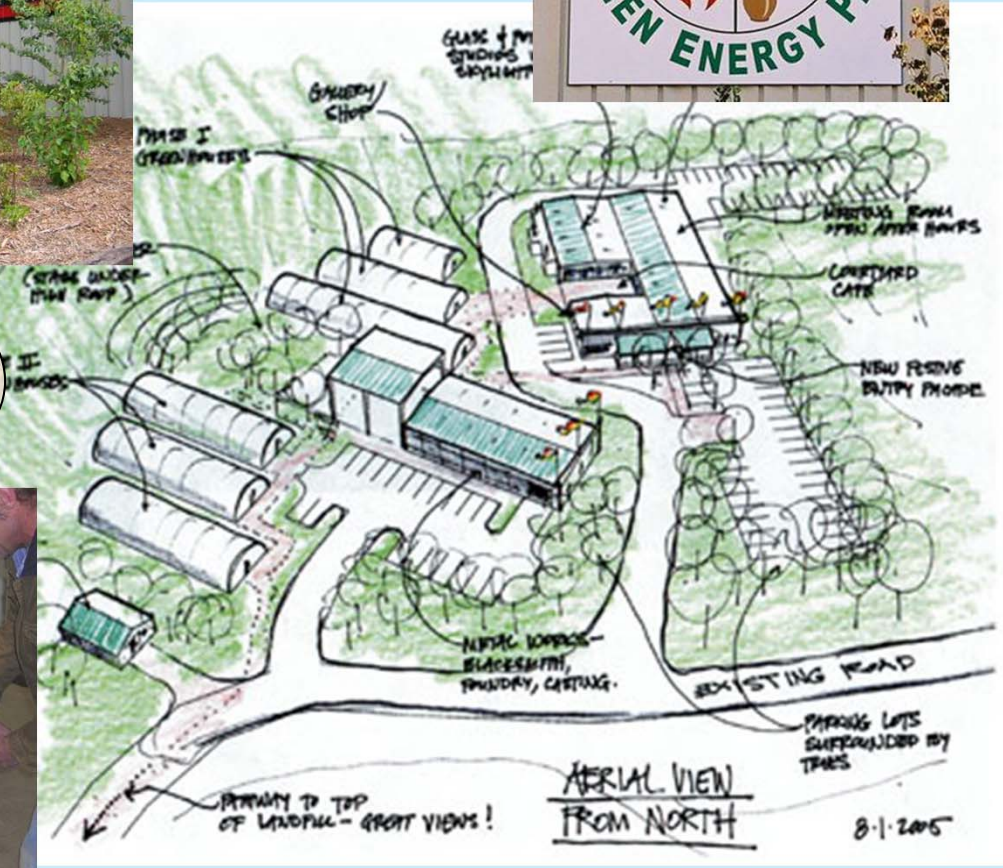
Direct-Use Case Study

Jackson County Green Energy Park

Sylva, NC

LMOP 2006 Project of the Year



Direct-Use Case Study

Seward County Landfill (KS)

- Project is a public/private partnership with National Beef
- 70 scfm of LFG is piped 1,500 feet to wastewater lagoon

- LFG and gas from covered lagoon is captured and used to fuel boilers at National Beef

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Direct-Use Case Study

City of Sioux Falls Regional Landfill & POET Landfill Gas Energy Project (SD)

- 1,250 scfm of gas is transported via an 11-mile pipeline to POET's 105-million gallons/year ethanol plant
- LFG reduces the plant's natural gas usage by 2/3
- Landfill is currently expanding LFG wellfield to further offset the plant's natural gas use
- City takes advantage of the sale of carbon credits from the project, in addition to the sale of the LFG

Combined Heat and Power

- **Advantages**
  - Greater overall energy recovery efficiency from waste heat recovery - up to 80%
  - Specialized CHP systems available
  - Flexible - hot water or steam generation from recovered heat
- Systems are usually more costly to implement

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CHP and Direct-Use Case Study

BMW Manufacturing Greer, SC

LMOP 2003 *Project of the Year*

- 9.5-mile pipeline from Palmetto Landfill to BMW
- 2003 – 4 gas turbines retrofitted to burn LFG
- 2006 – Converted paint shop to utilize LFG in oven burners & for indirect heating
- LFG accounts for nearly 70% of BMW's energy needs
- To date, LFG has saved BMW an annual average of $5 million in energy costs

LMOP 2006 ***Energy End User Partner of the Year***

Conversion to High-Btu Gas

- Gas is purified from 50% to 97- 99% methane
- Removal of carbon dioxide is primary step
- Three main technologies to do this
- Uses include:
  - Inject treated product into natural gas pipeline
  - CNG and LNG can be used to fuel landfill equipment, refuse trucks and general commercial vehicles

Conversion to High-Btu Gas

- Disadvantages
  - Must meet strict standards of pipeline
  - Costly technology
  - Economical for large scale only

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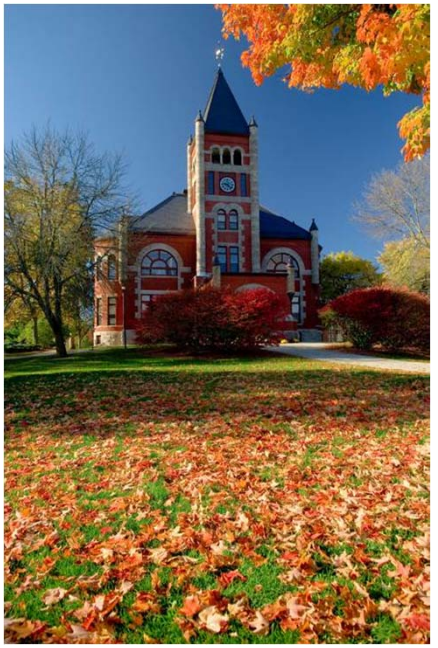
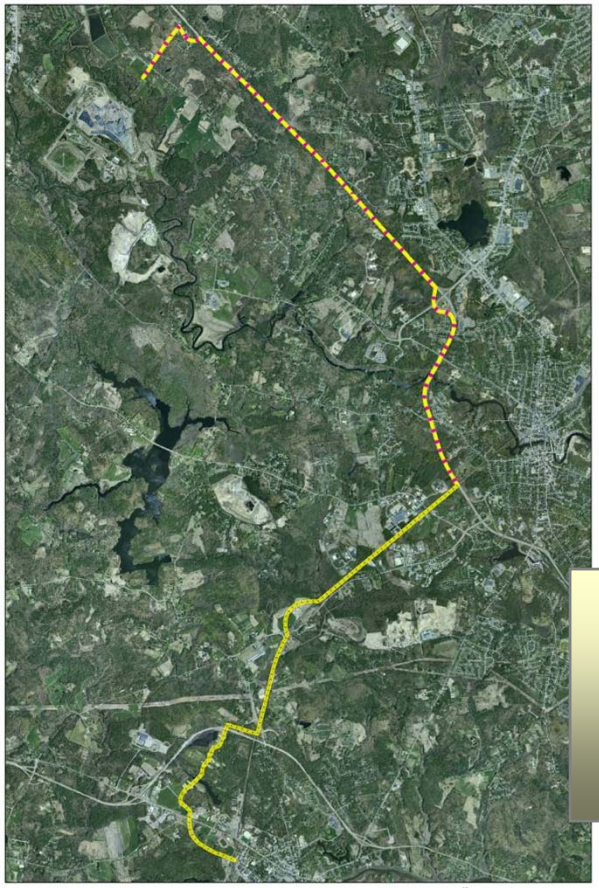
High-Btu Case Study

Univ. of New Hampshire EcoLine™ - Rochester, NH





- LFG provides up to 85% of campus electric & heat needs
- 12.7-mile pipeline from Turnkey Recycling & Environmental Enterprises LF
- Cleaned LFG fuels existing CHP gas turbine & new turbine

LMOP 2009 Project *of the Year*

EcoLine™ CH4 UNH Power Partnership

High Btu Case Study

Veolia ES Greentree LF
Kersey, PA

- Largest designed high Btu LFGE project in U.S.
- Significant cleaning of the gas required
- 7-mile pipeline from landfill to processing

- Volume of LFG flared reduced by >90%
- Expect ~2 billion cf/yr product quality gas

LMOP 2007 Project of the Year

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LFG for Vehicle Fuel

- Biodiesel production facility
- CNG to fuel landfill equipment and fleet vehicles or transit buses
- Offsets need for diesel fuel
- Methanol to biodiesel
- Ethanol production

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Alternative Fuel Case Study

Altamont Landfill, Livermore, CA

LMOP 2009 Project of the Year

- Project co-developed by Waste Management and Linde, LLC
- Converts about 2,000 -2,500 scfm of LFG into ~13,000 gallons of LNG
- Provides fuel for nearly 300 garbage trucks
- Received state grants from 4 entities: $2.3 million total