MAKEL ENGINEERING

Low NOx HCCI Technology for CHP Applications

California Energy Commission
IEPR Lead Commissioner Workshop on
Combined Heat and Power in California

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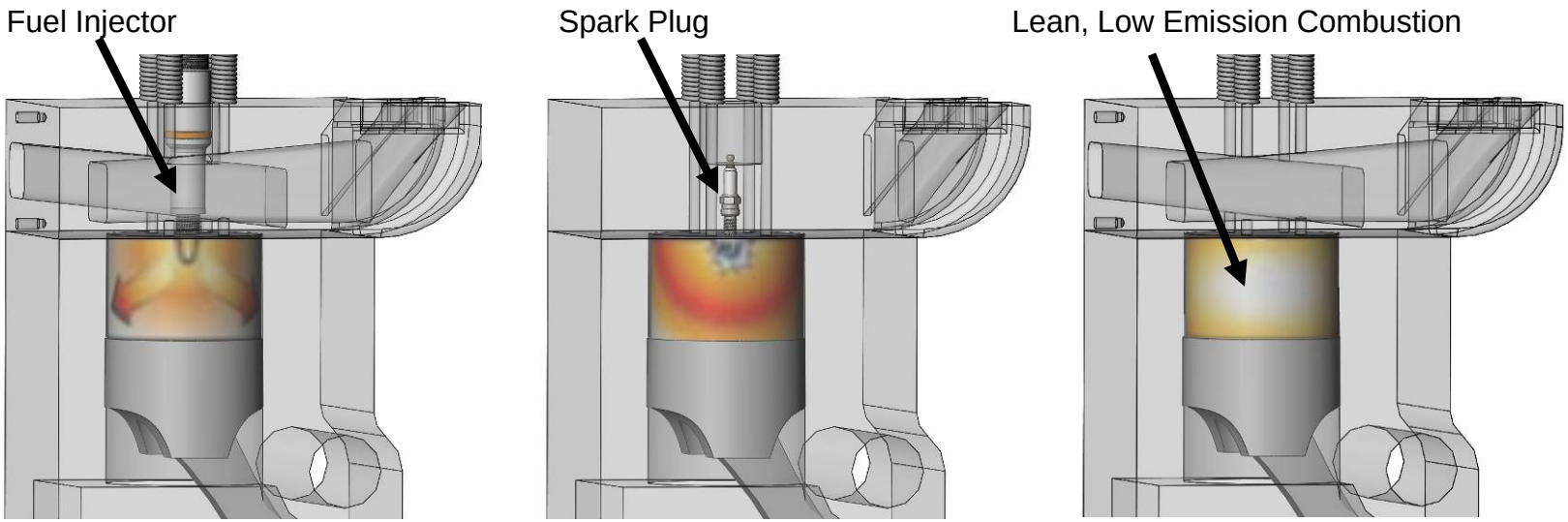
"Research Powers the Future"

What is HCCI?

HCCI is a combination of the well-known spark ignition and compression ignition engine concepts, enabling the use of fuels with very low energy content, such as biogas, to achieve

high thermal efficiency and **low emissions.**



COMPRESSION IGNITION

SPARK IGNITION

HOMOGENEOUS CHARGE COMPRESSION IGNITION

Why HCCI for CHP Applications?

Benefits:

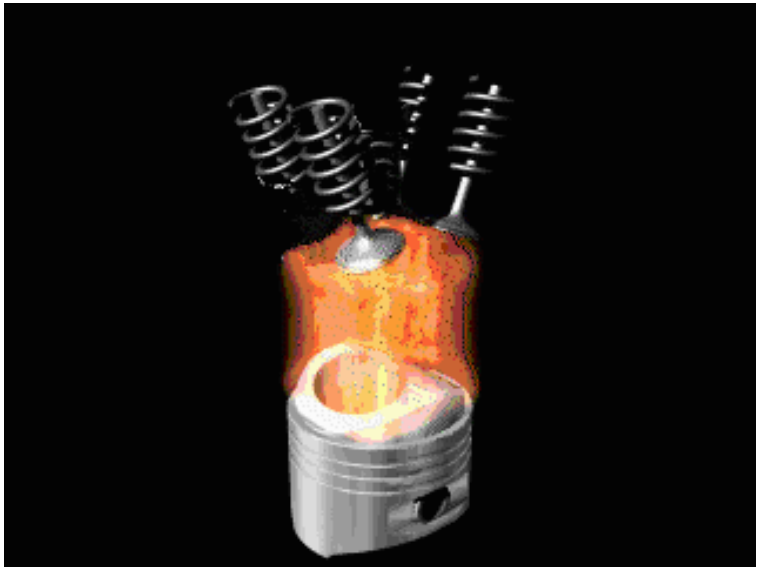
- Highly efficiently: Electrical (>35%) / Thermal (>45%)
  - Reduced fuel consumption
  - Lower electricity costs for CHP owners
  - Displaces need for equivalent amount of fossil fuel
- Low emissions: No NOx after treatment required (< 3 ppm)
  - Reduced air pollutants
- Fuel Flexibility
  - Wide range of renewable gaseous biofuels (i.e. Syngas, digester gas, landfill gas)
- Low cost CHP system: ~ $1200 $/kW
  - Comparable to SI engine without ongoing exhaust after treatment costs

Technical Challenges:

- Biogas operation: Variable BTU content and composition
  - Expertise and state of the art control systems are required to sustain HCCI
- CHP heat transfer components: Conventional CHP components are limited for HCCI
  - HCCI exhaust gas is typically cooler than reciprocating engines
- Continuous operation: Variable thermal and electrical loading
  - Active specialized control systems are required to ensure operation over extended periods

Application to Biogas

To control HCCI combustion timing (when it fires)
"active thermal conditioning" of the inlet charge is required



**Courtesy of UC Berkeley Combustion Analysis Laboratory (CAL)

- The intake charge temperature for methane based biogas needs to be elevated to auto-ignite in HCCI mode
- This is a function of:
  - Compression ratio
  - Boost pressure
  - Cylinder geometry
  - Block temperature
- Active control system

MARKET FOCUS 1: Biogas from Dairies

"California dairies have a methane production potential of about 40 million ft3/day*, translating to nearly 160,000 kW capacity potential in energy generation, nearly doubling California's biomass based CHP capacity"

Biomass Based CHP by Application**	Capacity (kW)	Share
Wastewater Treatment	68,235	37.65%
Justice/ Public Order	37,000	20.42%
Agriculture	25,940	14.31%
Food Processing	25,000	13.80%
Solid Waste Facilities	18,760	10.35%
Utilities	4,600	2.54%
District Energy	1,300	0.72%
Colleges/Universities	380	0.21%
Total Biomass CHP Installed Capacity	**181,215**	**100.00%**
Projected Dairy Biogas Capacity	**160,000**	

"Dairies have significant market share in terms of biogas capacity"

*Ken Krich et al, Biomethane from Dairy Waste - A Sourcebook for the Production and Use of Renewable Natural Gas in California, p23-24, http://www.calstart.org

**Energy and Environmental Analysis, Inc., Combined Heat and Power Units located in California, http://www.eea-inc.com/chpdata/States/CA.html

MARKET FOCUS 2: Light Industrial

Market penetration for *Light Industrial* applications are encouraging:

- **Food Processing Plants**
- **Hotels**
- **Hospitals**
- **Waste Water Treatment Plants**

Optimal Site infrastructure is key:

- **Thermal load profile**
- **Electrical load profile**

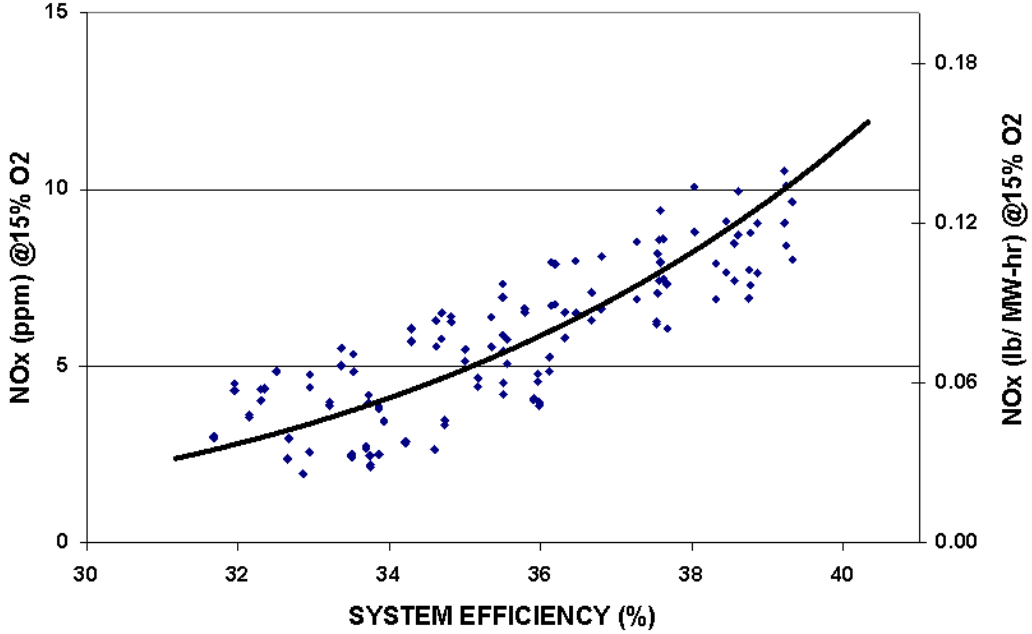
HCCI Based Systems

- System 1: Landfill Gas HCCI
  - Demonstrated a 30kW class HCCI system at an active landfill capable of achieving ultra low NOx and high efficiency
    - Final demo completed 2007
- System 2: HCCI Biogas for DG
  - Characteristics of system:
    - >35% efficiency
    - California ARB DG certifiable for biogas combustion
    - Industrial standard grid connection (Induction generator)
- System 3: CHP HCCI
  - Characteristics of system:
    - >80% CHP efficiency
    - California ARB DG certifiable for biogas combustion
    - HCCI specific heat recovery components

Landfill Gas HCCI (30 kW)

(CEC PIER Grant #: PIR-02-003)

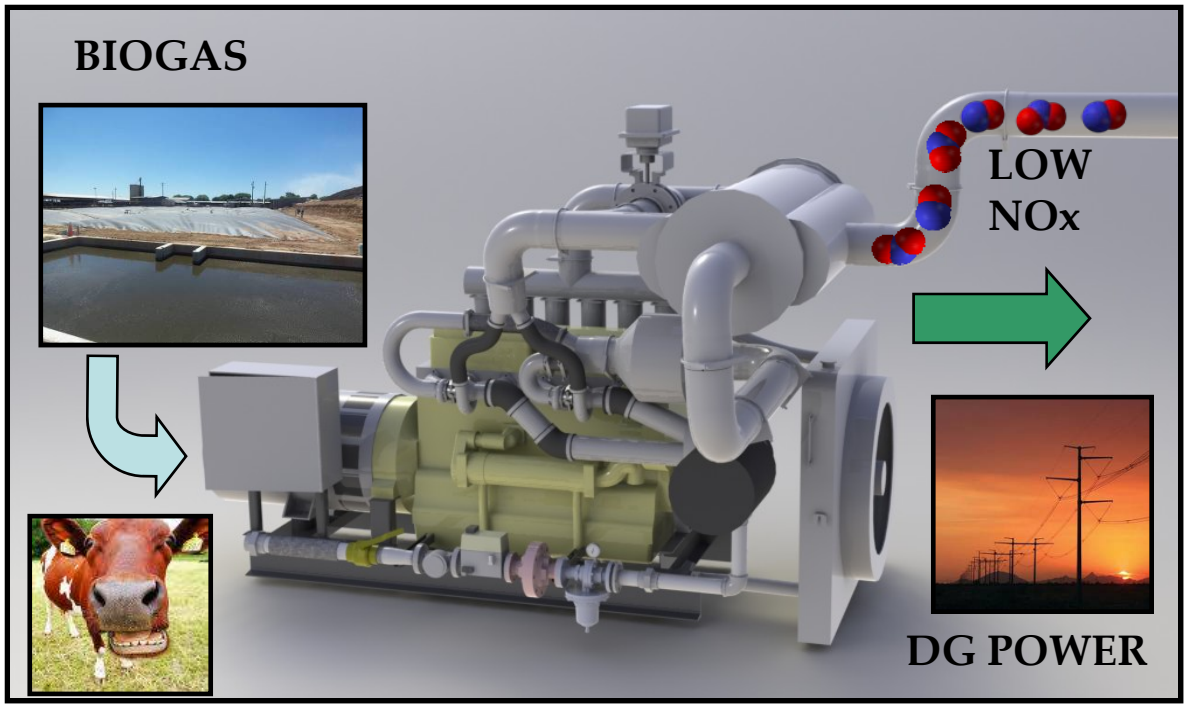
- Prototype HCCI engine demonstrated at an active California landfill site
- 500 hrs of operating time with LFG
  - Operating efficiency >35% over a range of operating conditions
  - NOx emissions on the order of 5 PPM



HCCI Biogas for DG

(CEC PIER Grant #: PIR-08-042, PIER-RESCO PROGRAM)

- Larger engine block under development capable 100kW
- Low emission and high efficiency profile
- HCCI components:
  - Stock diesel engine block
  - Thermal conditioning system
  - HCCI control system

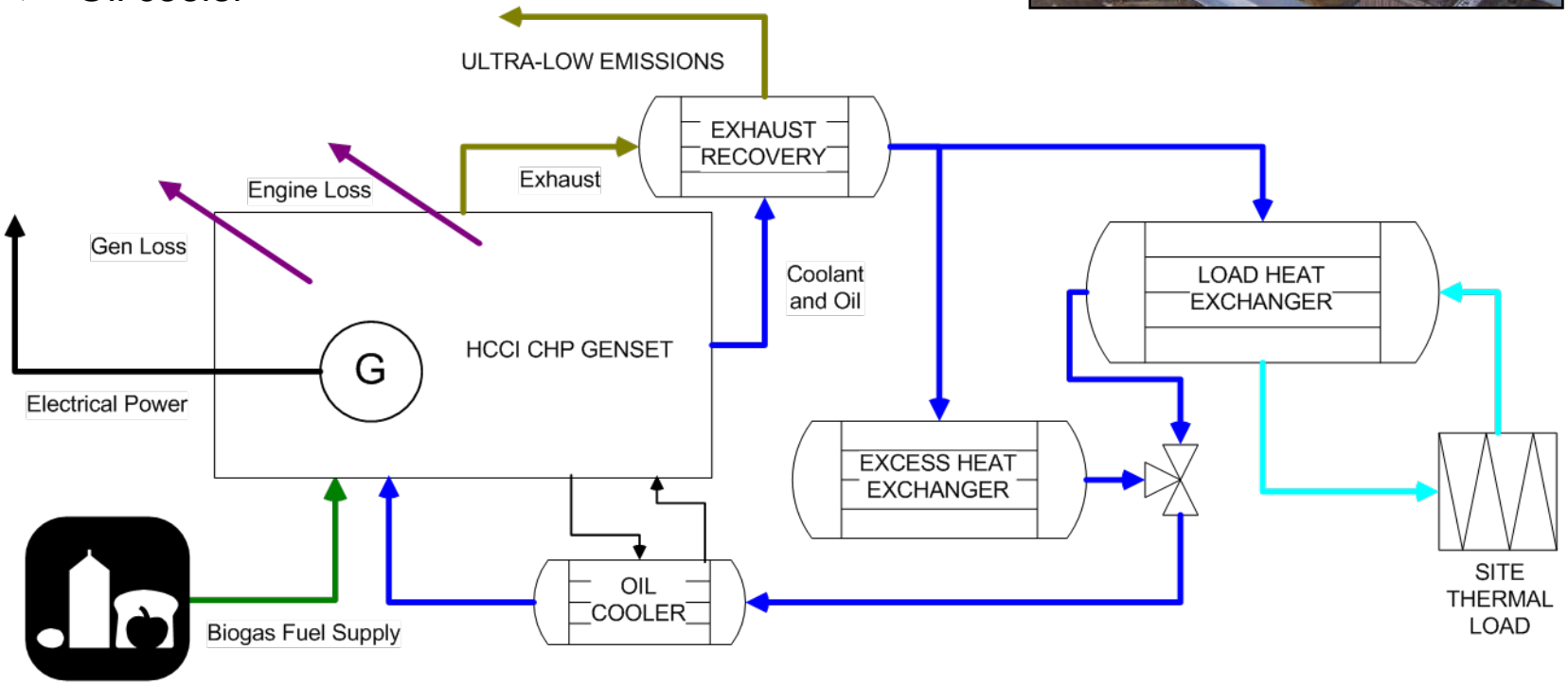


Concept for scaled up HCCI systems

HCCI CHP System

(CEC PIER Grant #: PIR-09-014, PIER-EPAG PROGRAM)

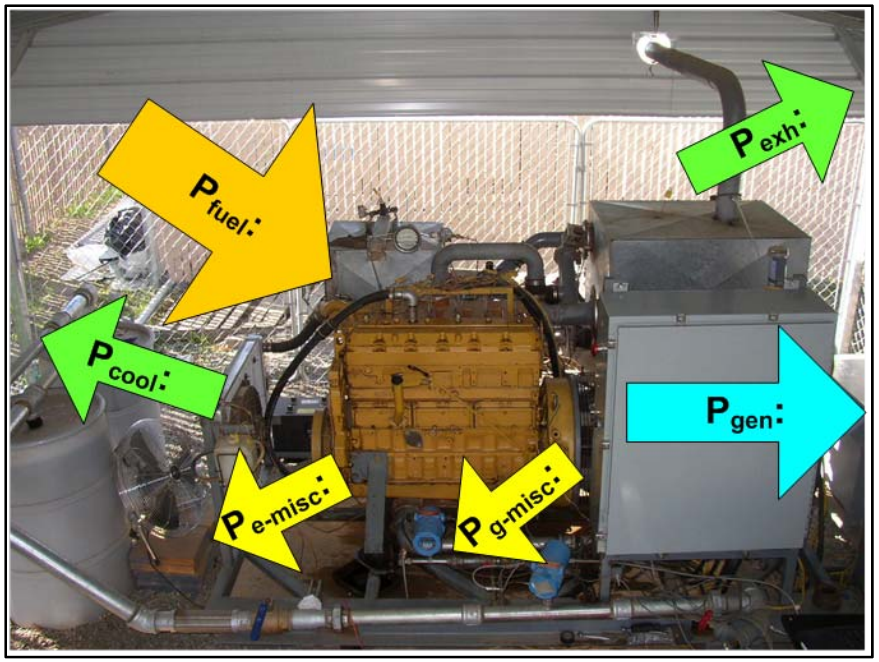
- Using closed loop recovery system, CHP efficiencies in the 80%-90% range are expected
- Heat recovery components:
  - Standard engine water jacket
  - Exterior engine block jacketing
  - Exhaust heat exchanger
  - Oil cooler



Operation with Simulated Biogas

Consistent with modeling, testing with simulated biogas (~60% methane, ~40% carbon dioxide) indicates that CHP efficiencies > 80% can be achieved

Sym.	Definition	Fraction of $P_{fuel:}$ (%)
P_{fuel}	Power from combustion of fuel	100%
P_{cool}	Power rejected by engine coolant and oil	30%
P_{exh}	Power loss from escaping exhaust gases (after heating intake charge)	20%
$P_{e\text{-}misc\text{-}loss}$	Engine power losses	11%
$P_{g\text{-}misc\text{-}loss}$	Generator power losses	4%
P_{gen}	Electrical power output	35%



Field Demonstration Sites

Working in conjunction with SMUD:

Tollenaar Holsteins Dairy in Elk Grove, CA

- Site specifics:
  - 2000 head
  - Currently installed digester
  - Producing ~150kW of electricity
- CHP Application:
  - Thermal Management of Digester
  - Hot water for wash down
- Deployment: mid-2012

Cal-Denier Dairy in Galt, CA

- Site specifics:
  - 800 head
  - Currently installed digester
  - Producing ~65kW of electricity
- CHP Application:
  - Hot water for on-site laundry facility
- Deployment: early-2013

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