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ENERGY FROM MUNICIPAL SOLID WASTE

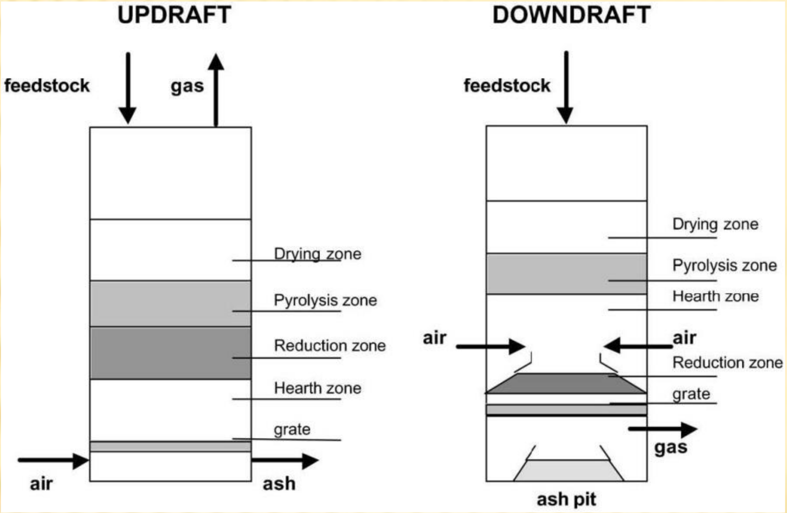
Energy from Municipal Solid Waste

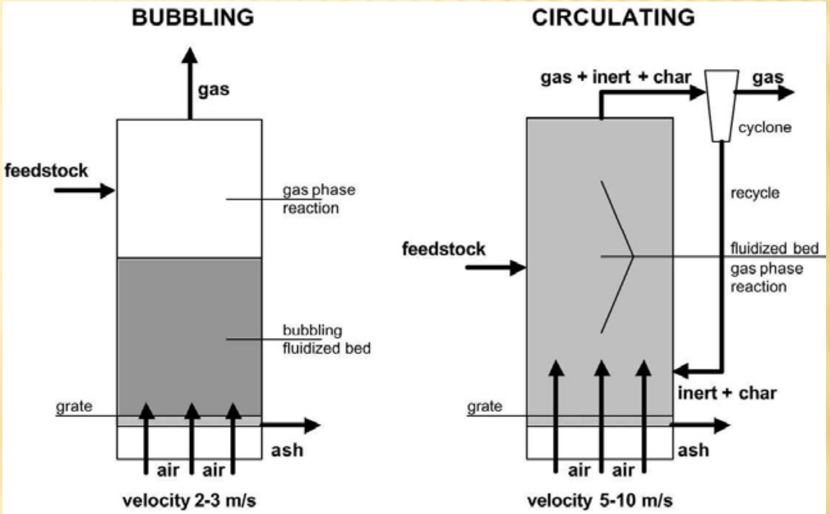
GASIFICATION THEORY & PRACTICE

GASIFICATION
KEY ENGINEERING FACTORS

- Technologies differ in many aspects but rely on four key engineering factors:
  - Reactor design;
  - Gasification reactor atmosphere (level of oxygen or air content);
  - Internal and external heating; and
  - Operating temperature

REACTOR DESIGN
CONVENTIONAL GASIFIER REACTORS

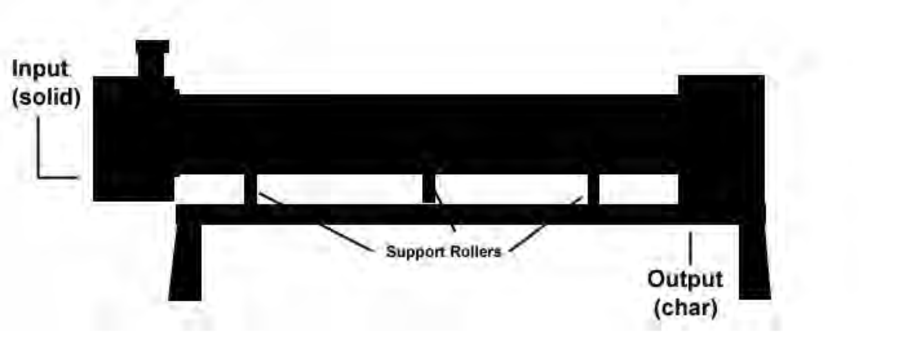




Fluidized bed **Fixed Bed**

- Generally oriented as vertical columns
- Lack agitation in the reaction zone - Leads to numerous technical issues
  - significant need for control of feedstock size and moisture content
  - potential dead zones

REACTOR DESIGN
ROTARY KILN GASIFIER REACTOR



- Horizontally oriented reaction vessel placed on a slight slope
- Natural rotation provides agitation of feedstock at high temperatures
  - Allows for a complete conversion of the material to gas
- Lack of a definable contacting bed
  - Able to accept a wide variety of feedstock shapes and sizes

GASIFICATION REACTOR ATMOSPHERE

- Feedstock is subjected to high heat, pressure, and either an oxygen-rich or oxygen-starved environment within the gasifier.
  - Can be air or oxygen in combination with steam.
  - To a point, the water present takes part in a positive manner toward the formation of desired syngas end products

REACTOR HEATING

- In general, gasification reactions are endothermic.
  - Need for some source of energy
- May be heated
  - External to the vessel
    - Reminiscent of predominately pyrolytic processes where the intent is shifted from the production of syngas to production of an energy rich char.
  - Internally
    - combustion of some of the product gases
    - through the application of auxiliary heat.

OPERATING TEMPERATURES

- Can be varied depending upon the desired composition of the syngas.
  - Lower temperatures favor
    - Tar and ash production are favored
    - larger particulate sizes
  - Higher temperatures
    - Tar production tends to decrease
      - probably due to extended thermal cracking and steam reforming reactions

THE GASIFICATION PROCESS

- Pyrolysis (devolatilization):
  - As carbonaceous fuels are heated volatiles are released and char is produced.
  - Often produces hydrocarbon liquids (pyrolytic oils)
- Combustion:
  - Volatiles and char react with oxygen to form carbon dioxide and carbon monoxide.
  - The heat produced promotes subsequent gasification reactions.
- Gasification:
  - Char reacts with carbon dioxide and steam to produce syngas

GASIFICATION REACTIONS

- Reactions
  - Carbonaceous solid and water.

    $$C + H_2O \longrightarrow CO + H_2$$

  - Carbonaceous solid and carbon dioxide.

    $$C + CO_2 \longrightarrow 2\ CO$$

  - Carbonaceous solid and hydrogen.

    $$C + 2\ H_2 \longrightarrow CH_4$$

- Other
  - Water Shift Reaction (High temperature, exothermic, catalytic).

    $$CO + H_2O \leftrightarrow CO_2 + H_2$$

- Product Temperature dependence
  - Higher temperatures (approximately 1000 deg C),
    - CO and H_2 (more than 85% by volume)
  - Lower temperatures:
    - CH_4 and CO_2

EMISSION BYPRODUCTS

- Ash:
  - mineral matter and particulates
- Nitrogenous Products:
  - ammonia and NOx;
- Volatile Organic Emissions (VOCs):
  - tars and oils
  - from a system that is not working optimally

Energy from Municipal Solid Waste

THE PROJECT

ROTARY GASIFICATION PROJECT OVERVIEW

- Managed by US Army Corps of Engineers.
- Funded by Strategic Environmental Research and Development Program (SERDP).
- Additional funding approved for later 2015

ROTARY GASIFICATION PROJECT PARTNERS

- National Renewable Energy Laboratory (NREL)– Golding, CO.
- Federal Environmental Protection Agency (EPA).
- Army Corps of Engineers - Construction Engineering Research Laboratory (CERL).
- United States Military Academy – West Point.
- Watervliet and Picatinny Arsenals.

WHY SUNY COBLESKILL?

- SUNY Cobleskill's available diversified biomass "test-feed“
  - Paper
  - Green
  - Animal Waste
  - Cafeteria Wastes
  - Organic Municipal Solid Wastes

PARTNER/FUNDING OBJECTIVES

- **Create a design for a deployable waste-to-energy (WTE) system that meets the requirement of the SON:**
  - Based on gasification
  - Processes 1 to 3 tons/day of mixed, non-hazardous solid waste, with minimal sorting or pretreatment required
  - Self-powered, with net positive, exportable electric energy
  - Sized to fit two, 20 foot shipping containers

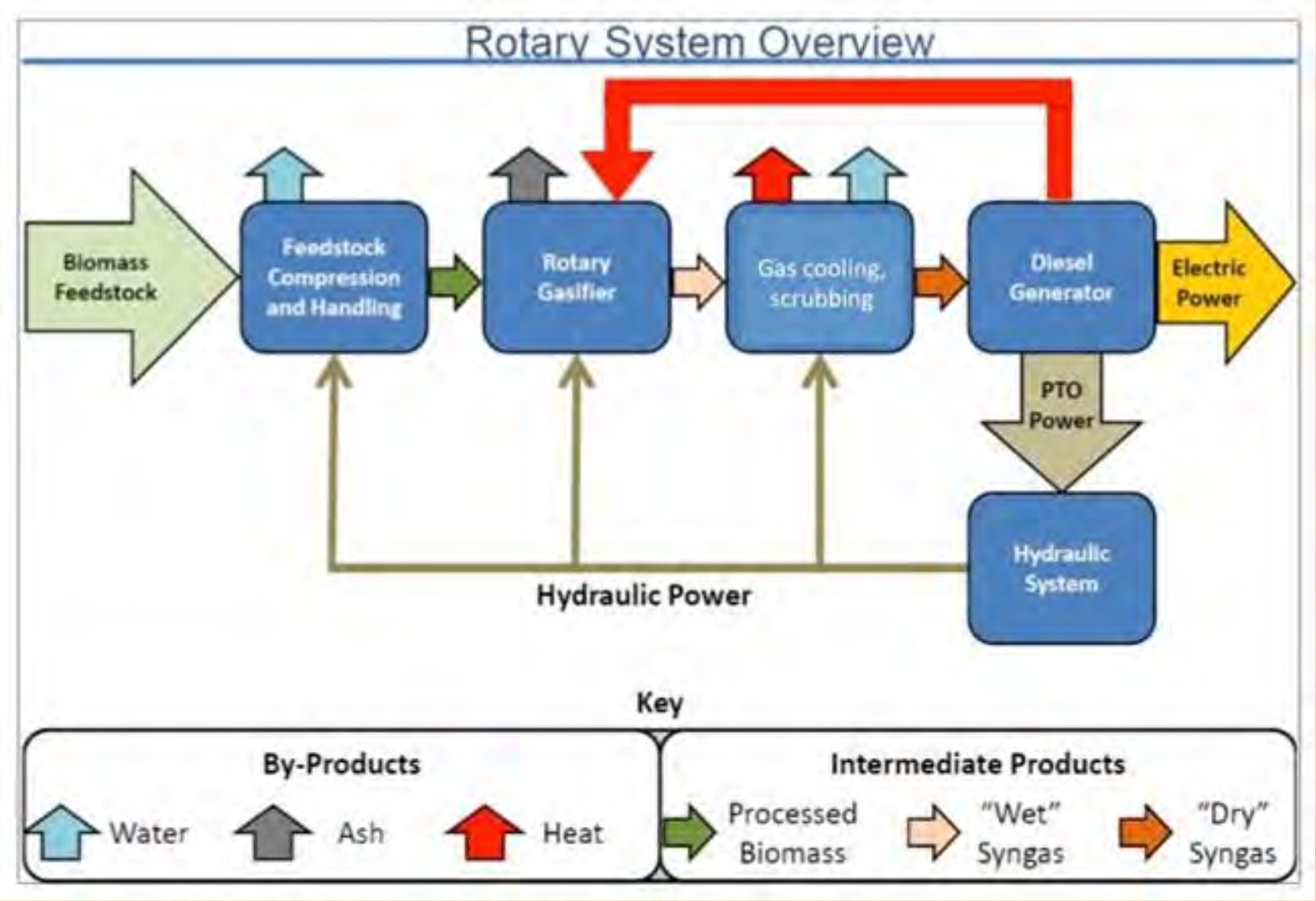
Energy from Municipal Solid Waste

INCLINED INDIRECT FLAME PYROLITIC ROTARY GASIFIER(IIFPRG)

COBLESKILL PROCESS

- Unique Rotary Gasification.
- Produces gaseous and (potentially) liquid fuels.
- Accelerates what naturally occurs in the earth over thousands of years to less than 20 minutes (startup time).
- End product is the generation of electricity and potential liquid fuels from waste and biomass.
- Military use on forward operating bases as liquid fuel substitute while eliminating base waste

IIFPRG GENERAL FLOW DIAGRAM



THERMOCHEMICAL MODEL

- Based on *proximate analysis* of feedstock: HHV, volatiles, fixed carbon, ash, moisture
- For 60kW generator, syngas flow to engine limits to 2 ton/day max.

Dry Feedrate - lb/hr	125
Feedstock Moisture %	40%
Volatile Matter % DB	80%
Fixed Carbon % DB	10%
Ash % DB	10%
Feedstock HHV - BTU/lb	6000
Oxygen Content in Syngas %	1.50%
Pin Factor	1.25
Shell Convection - BTU/hr/ft^2	2400
Watershift Reaction %	0%
Program Outputs	
Wet Feedrate - lb/hr	175
Gasifier Syngas Net Flow - scfm	64
Syngas HHV - BTU/scf	149
Equivalance Ratio	0.18

INITIAL ENERGY CALCULATIONS (CERL) USED IN ENERGY BALANCE

Operating Power Summary	
Maximum Driver Power of M-1	.5 BHP
Total Hydraulic Motor Power M-2	8.3 BHP
Total Hydraulic Motor Power M-3	2.8 BHP
Design power of Hydraulic Motor M-4	2.2 BHP
Power of Feedstock Handling System	9.3 BHP
Total Hydraulic Motor Power	23.1 BHP
Hydraulic Motor Efficiency	95%
Net Hydraulic Power	24.3 BHP
Engine Hydraulic Pump Eff.	95%
Shaft Power Consumed at Engine Hyd. Pump	25.6 BHP
Gross Engine Shaft Power	99 BHP
Net Engine Shaft Power	73.4 BHP
Efficiency of Generator Head	90%
Estimated Usable Power Generated	49.6 kW (66.51 BHP)

Available Thermal Energy for Water Heating	
Usable Water Temperature	180 deg. F
Recoverable Heat from Scrubbing Fluid	35,000 BTU/hr
Recoverable Heat from Engine Cooling System	153,660 BTU/hr
Maximum Recoverable Exhaust Gas Energy	77,780 BTU/hr
Total Recoverable Heat for Water Heating	266,440 BTU/hr
Water Flow Rate at 160 F in and 180 F out	26.6 GPM

All required motors and pumps are driven by the power takeoff on the diesel generator, keeping the system completely self sufficient. The system also presents the opportunity for cogeneration through the use of wasted heat.

WASTE MIX SELECTION

- Design of waste mixes to emulate average data from CENTCOM reports
- Variations to account for mission, hourly, or personnel

	SERDP Long Term	50% Tires	100% Construction	50% Food	50% POL	50% Plastics
Component % Wet Basis	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Actual Moisture Content	26.5%	13.1%	11.7%	45.9%	21.6%	18.1%
Wet Feed Rate lbs/hr	190.5	161.0	158.6	258.8	178.6	170.8
Dry Feed Rate lbs/hr	140.0	140.0	140.0	140.0	140.0	140.0
Tot Wet Wt for 6 Hr Test - lbs	1143.2	966.1	951.3	1552.7	1071.4	1025.0
Wt per Bag - lbs (100 bags)	11.4	9.7	9.5	15.5	10.7	10.3
Component % Dry Basis	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Pro-Rated % VM	78.8%	67.5%	65.1%	79.5%	84.7%	84.8%
Pro - Rated % Ash	10.4%	16.9%	20.9%	9.3%	5.1%	5.2%
Pro-Rated % FC	10.7%	15.7%	13.2%	12.5%	10.3%	10.6%

STANDARD MIX GASIFIER FEED PROPORTIONS WITH MOISTURE CONTENTS

No.	Feedstock Type	Description	Component % Wet Basis	Pro Rated Moisture	Wet Feed Rate, lbs/hr
1	Cardboard	OCC, corrugated	15%	1.2%	14.6
2	Mixed Paper	Office, news, any mixed clean paper	15%	1.2%	14.6
3	HDPE	Plastic	6%	0.0%	5.8
4	PET	Plastic	6%	0.0%	5.8
5	PP	Plastic	6%	0.0%	5.8
6	Food	Campus Cafeteria Food Waste	20%	15.8%	19.4
7	Wood	Plywood, construction waste wood	24%	9.4%	23.3
8	Inerts	Metals, glass	4%	0.0%	3.9
9	Textiles	Polyester blends and cotton	4%	0.3%	3.9
	Totals =		100%	28.0%	97.2

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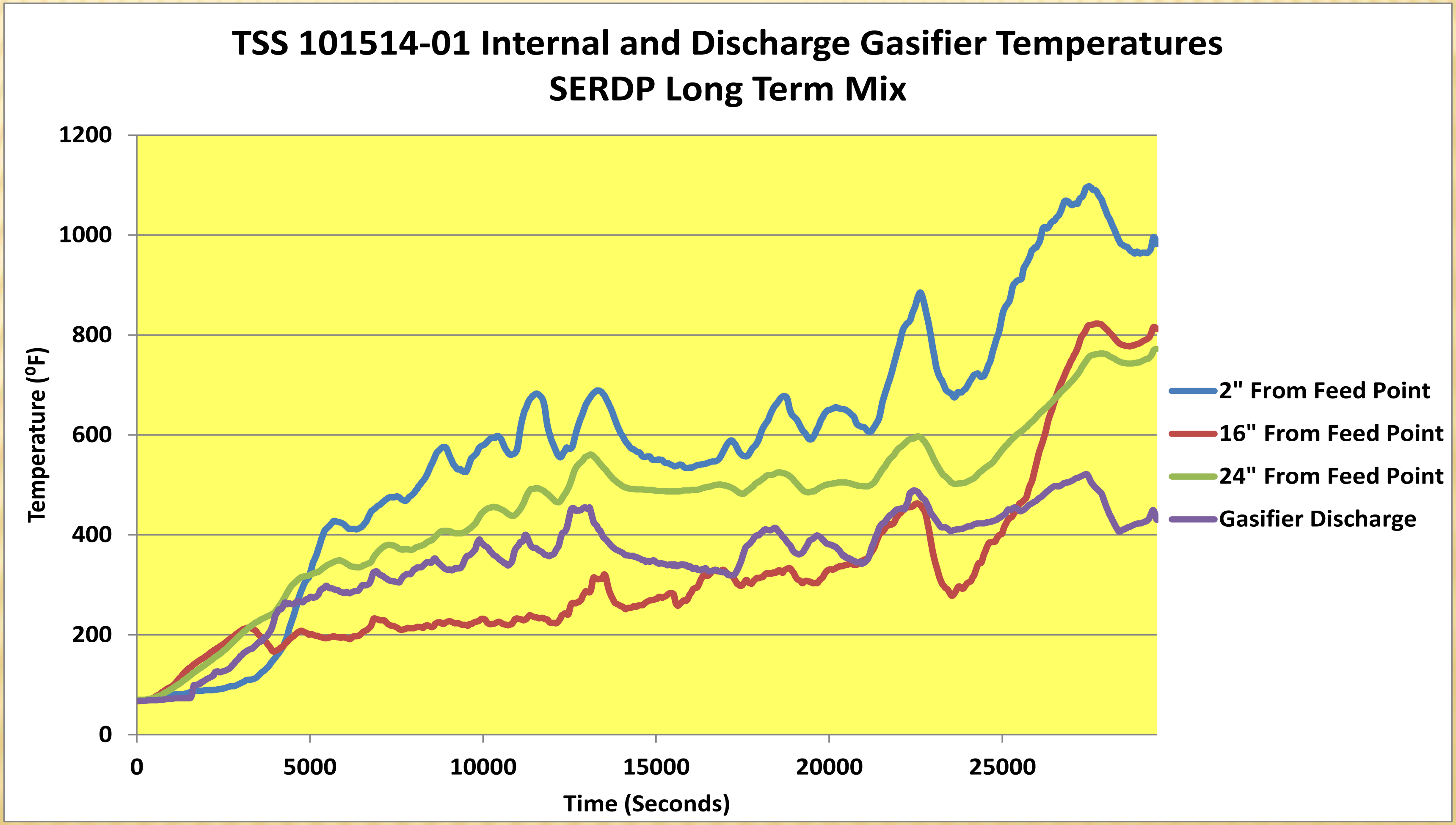
IIFPRG DATA ANALYSIS

IIPRG GASIFIER TEMPERATURES USING THE STANDARD MIX

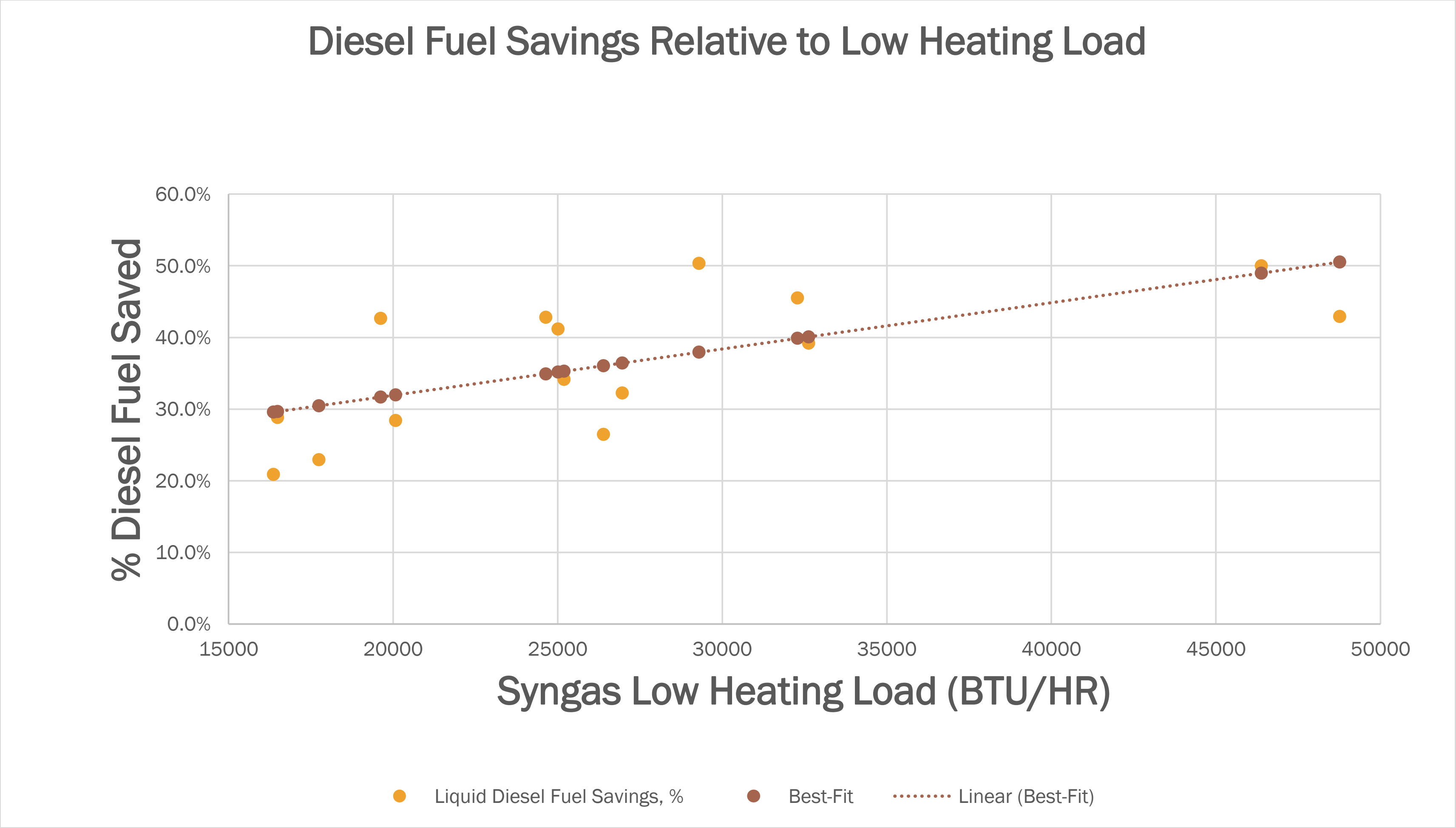


PERCENT DIESEL FUEL SAVINGS WITH SYNGAS SUBSTITUTION

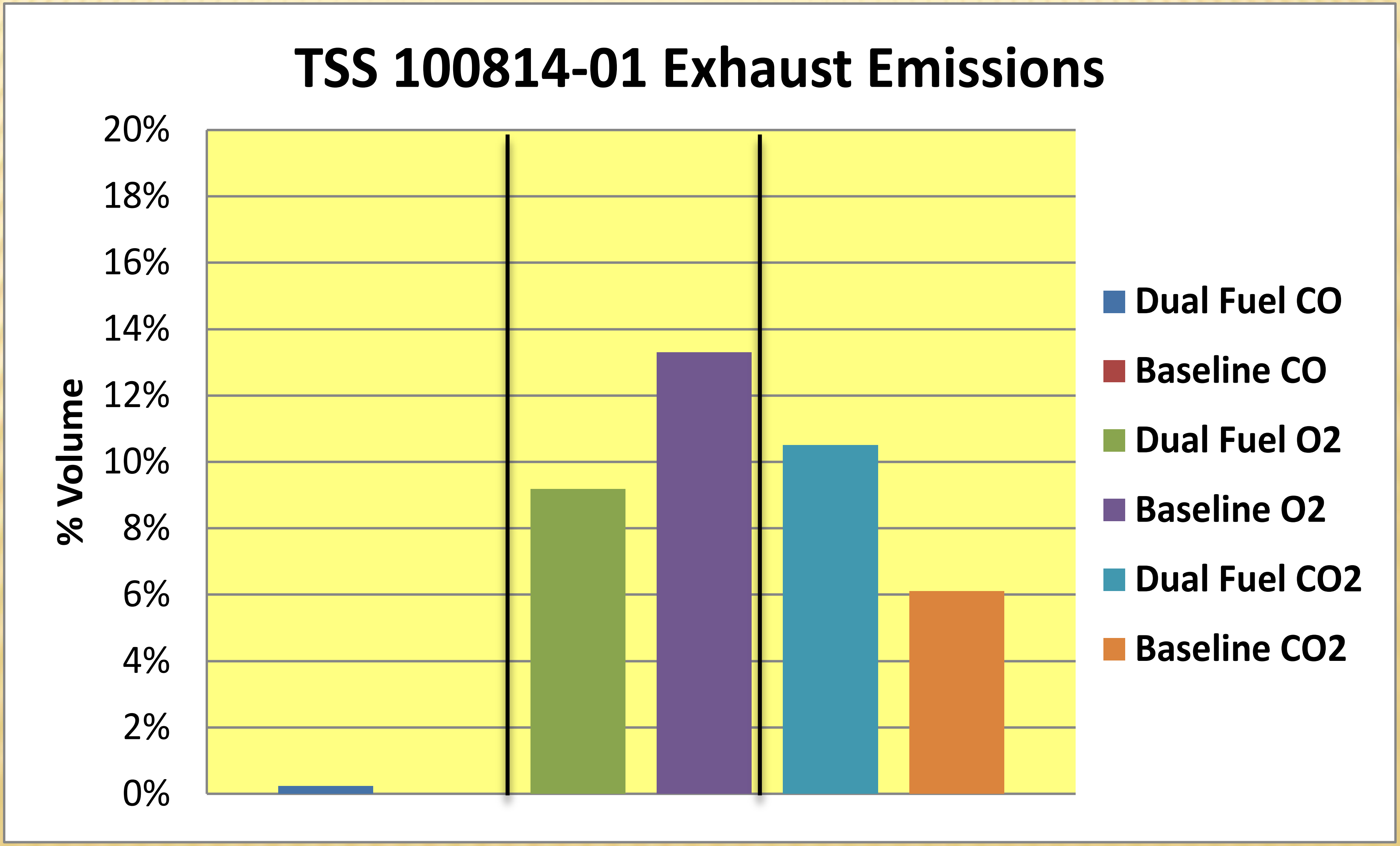
Statistic	% Diesel Fuel Saving
Average	44.7%
Min	19.0%
Max	78.1%
Standard Deviation	16.2%

Diesel fuel savings are calculated for 32 CLIP Tests collected from 10 continuous runs of 1 to 4.5 hours in duration

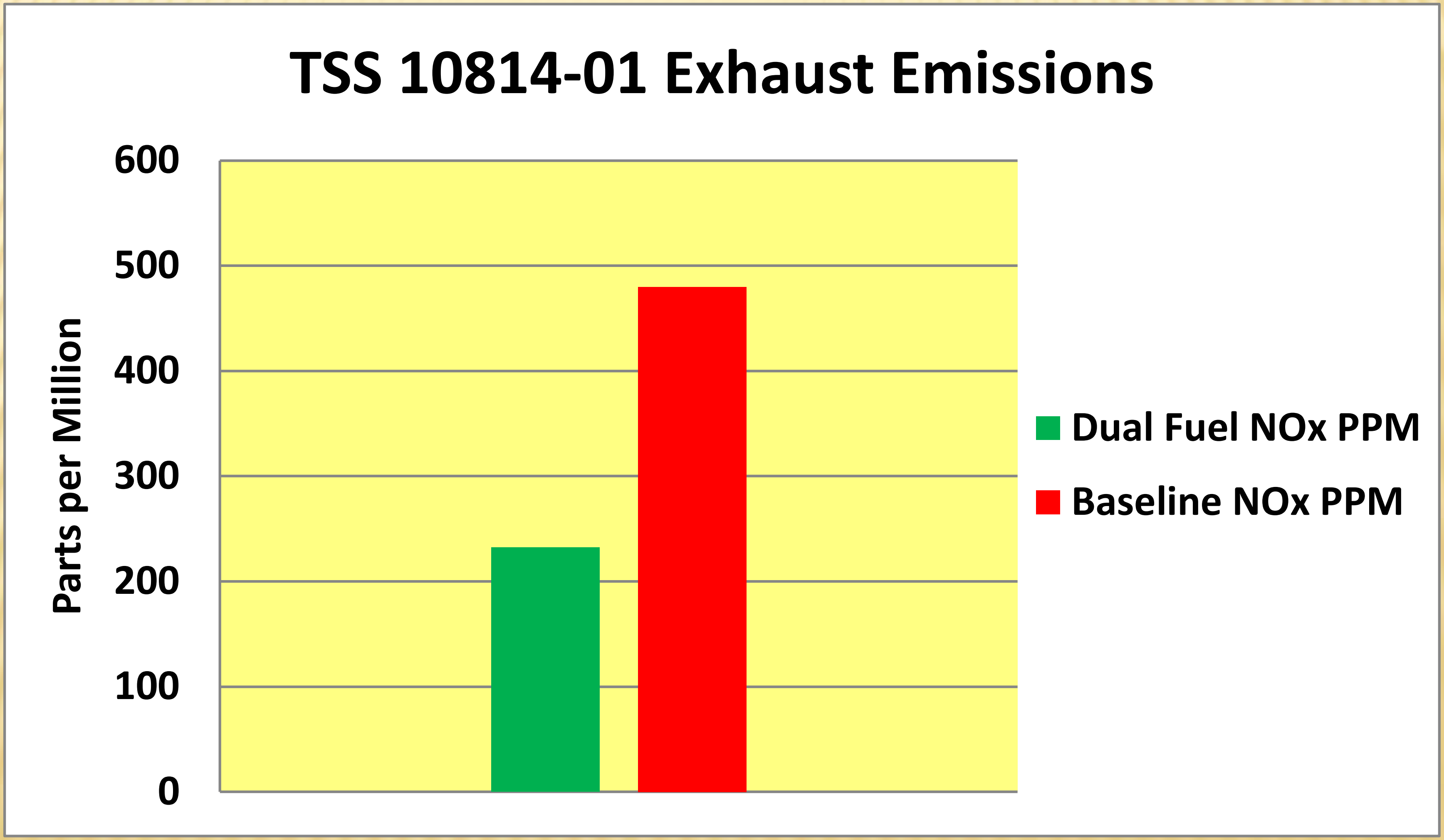
DIESEL FUEL SAVINGS RELATIVE TO LOW HEATING VALUE



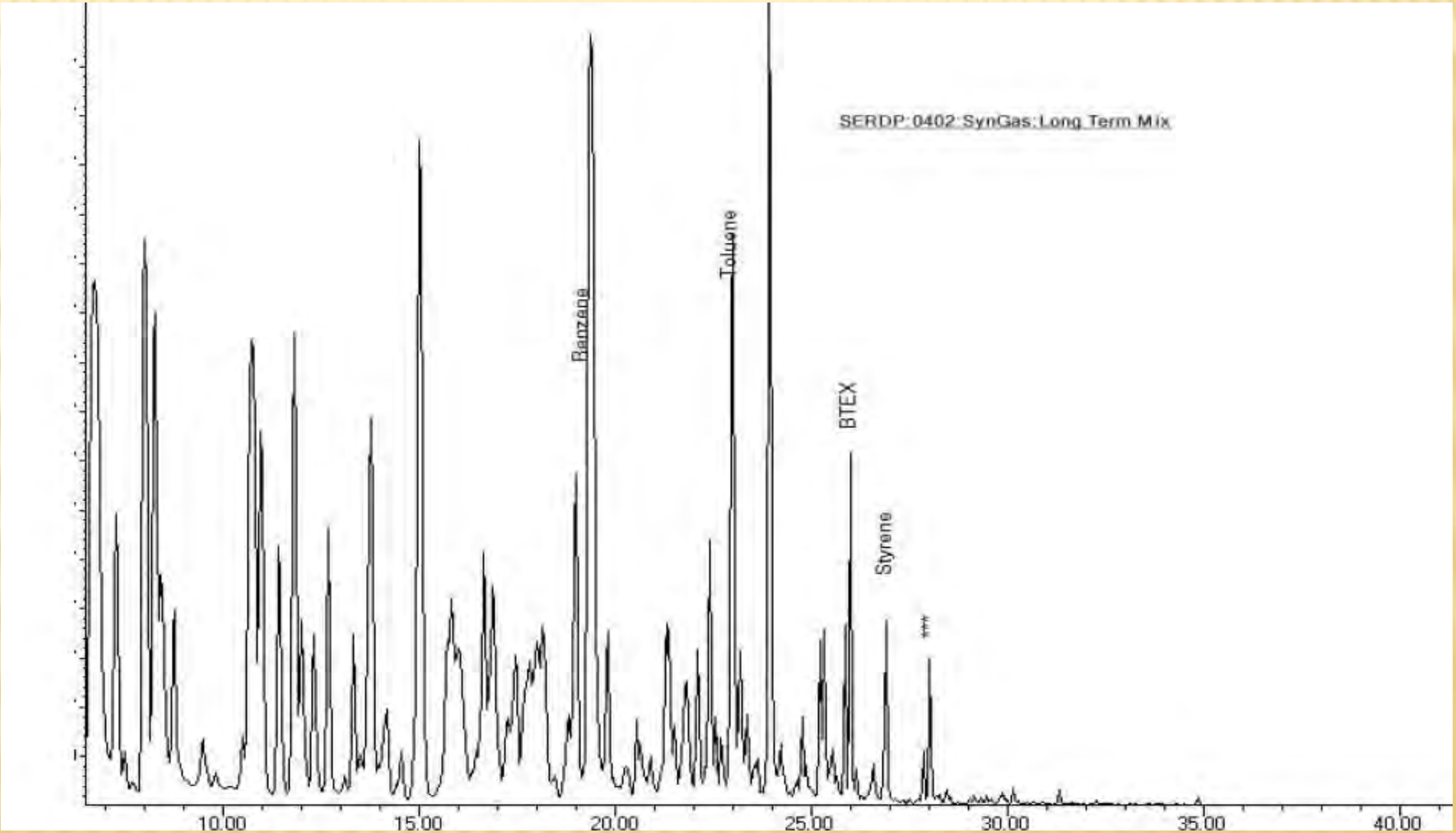
EMISSIONS ON STANDARD MIX



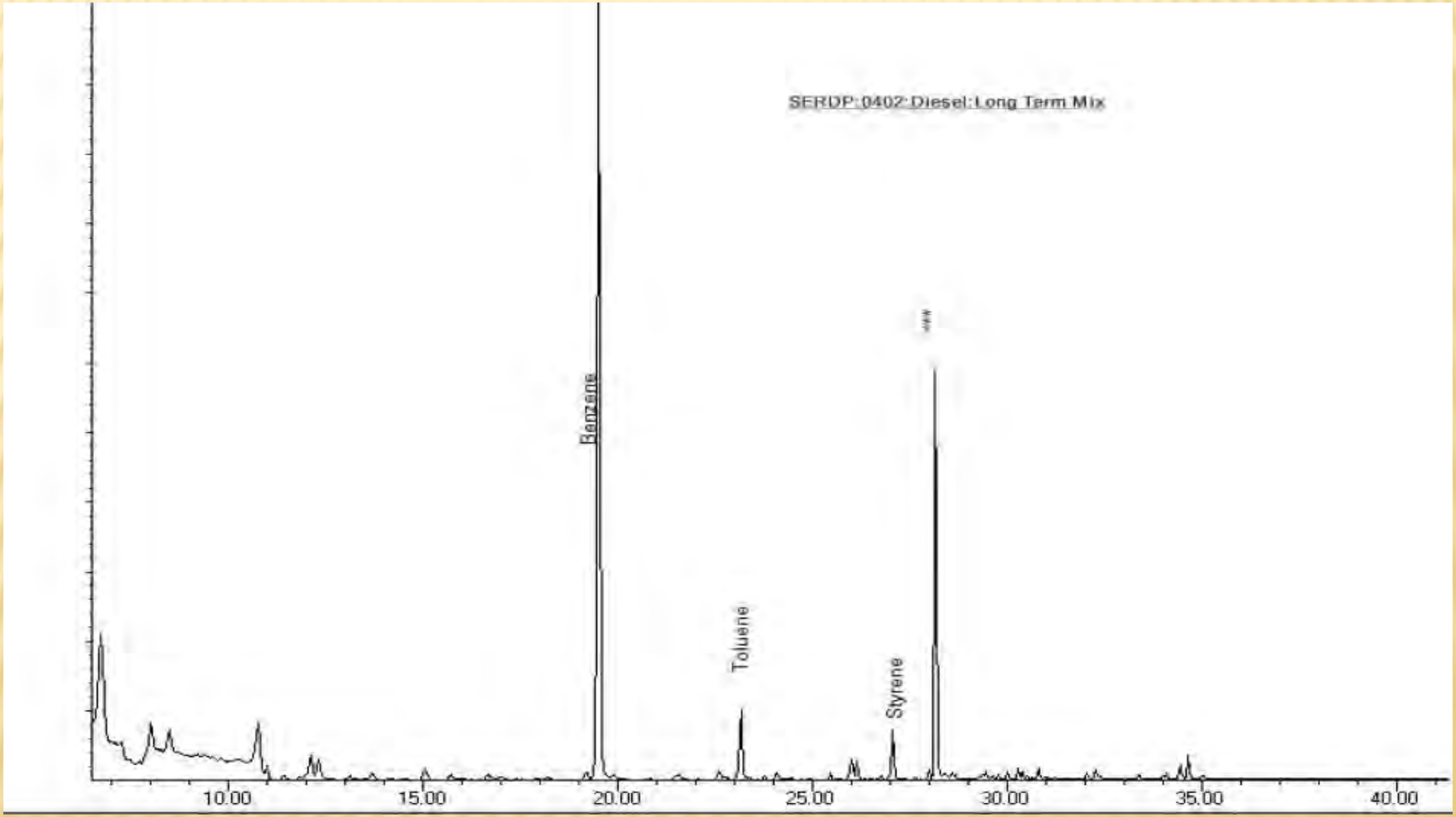
NO_X EMISSIONS



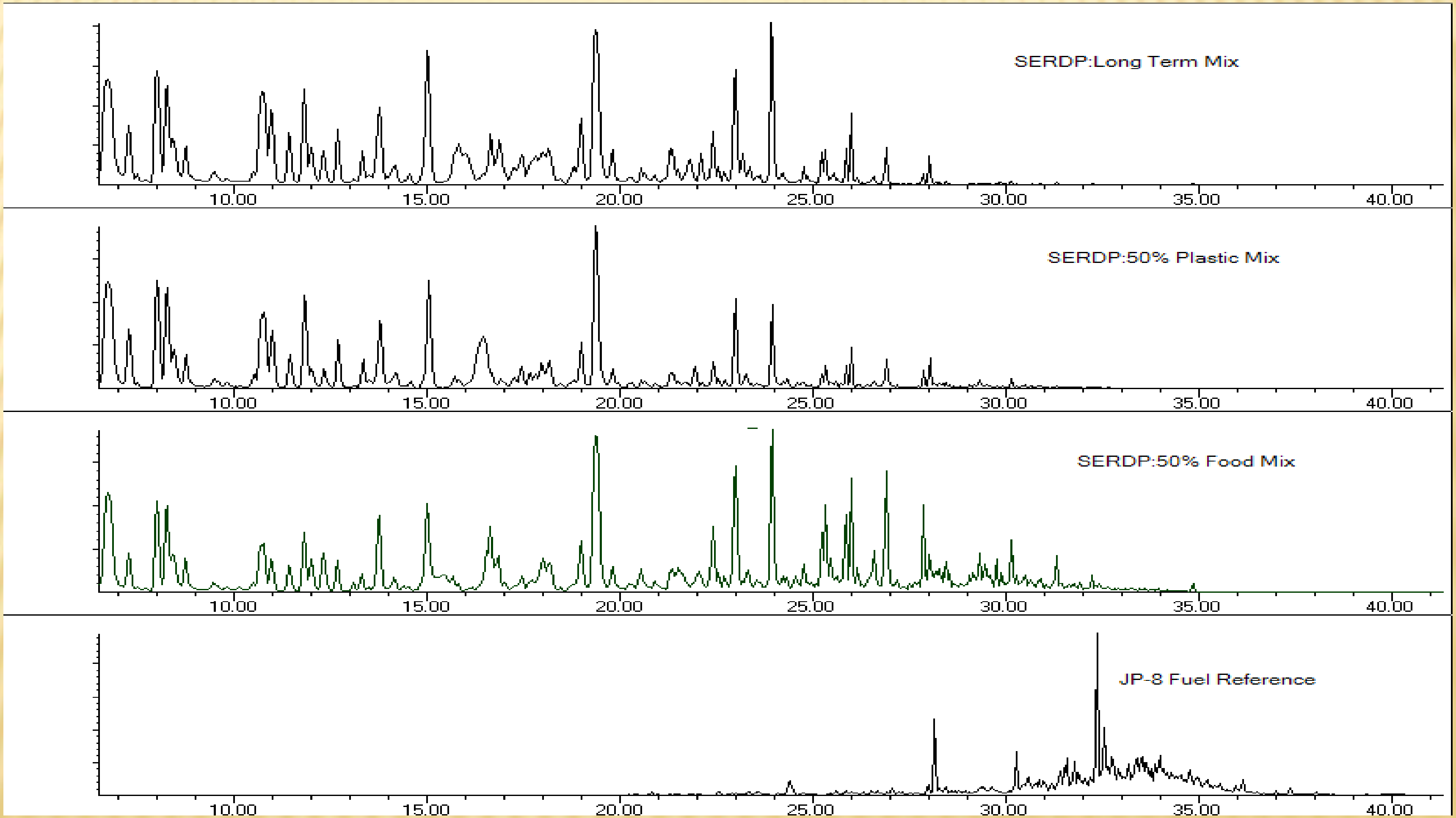
STANDARD MIX - SYNGAS ANALYSIS
GC – MASS SPEC



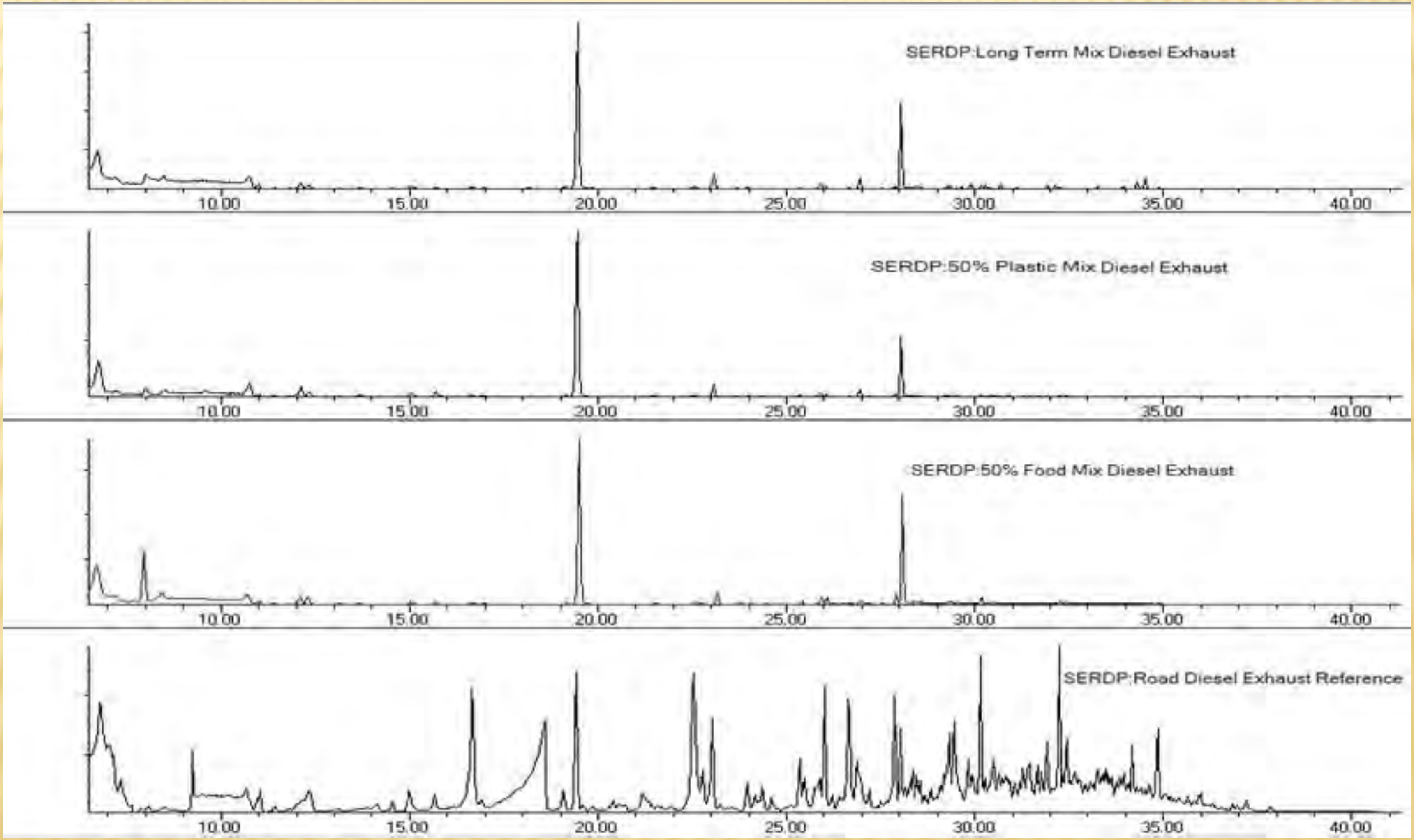
STANDARD MIX – DIESEL EXHAUST ANALYSIS GC – MASS SPEC



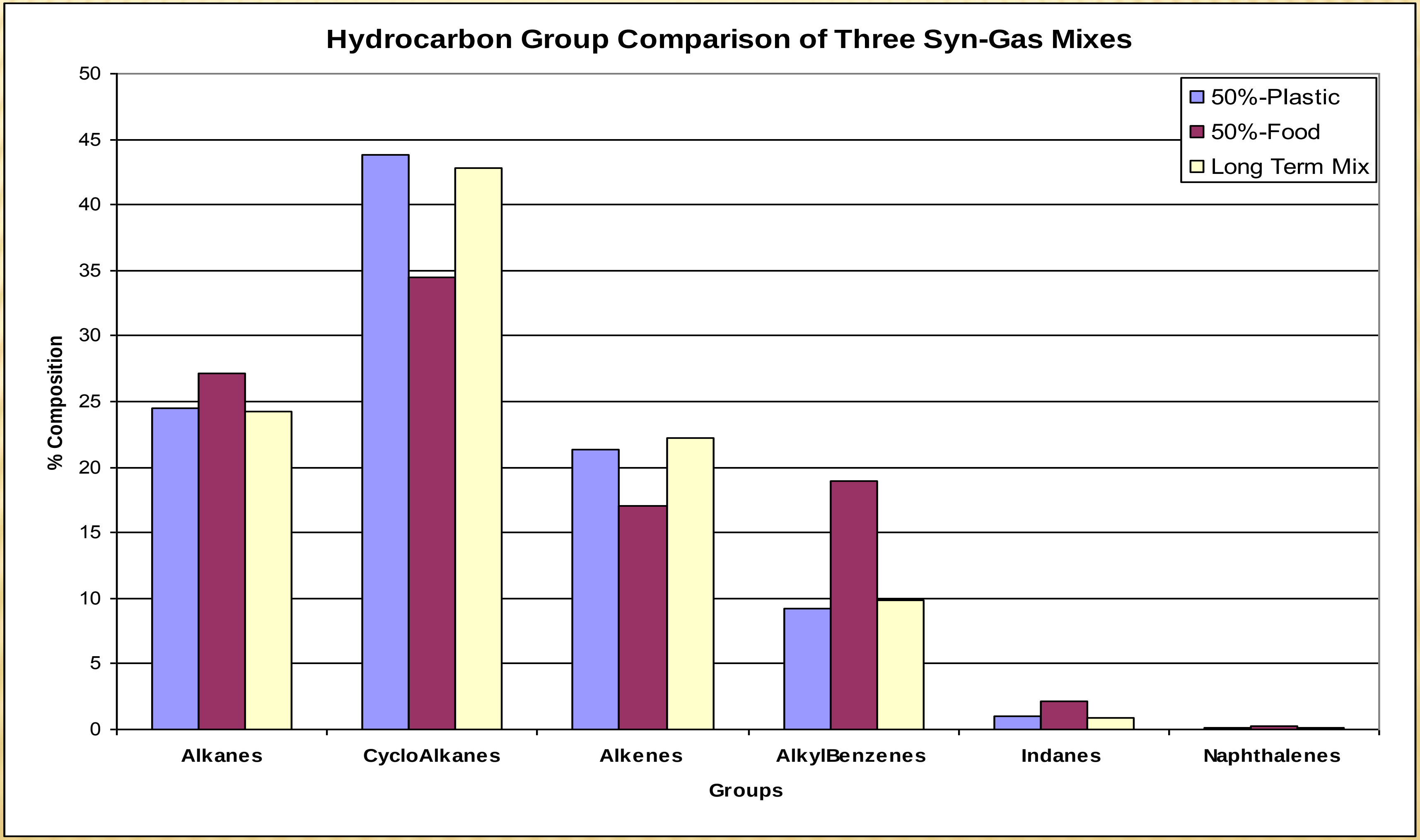
SYNGAS FEED COMPARISONS WITH JP-8 GC – MASS SPEC



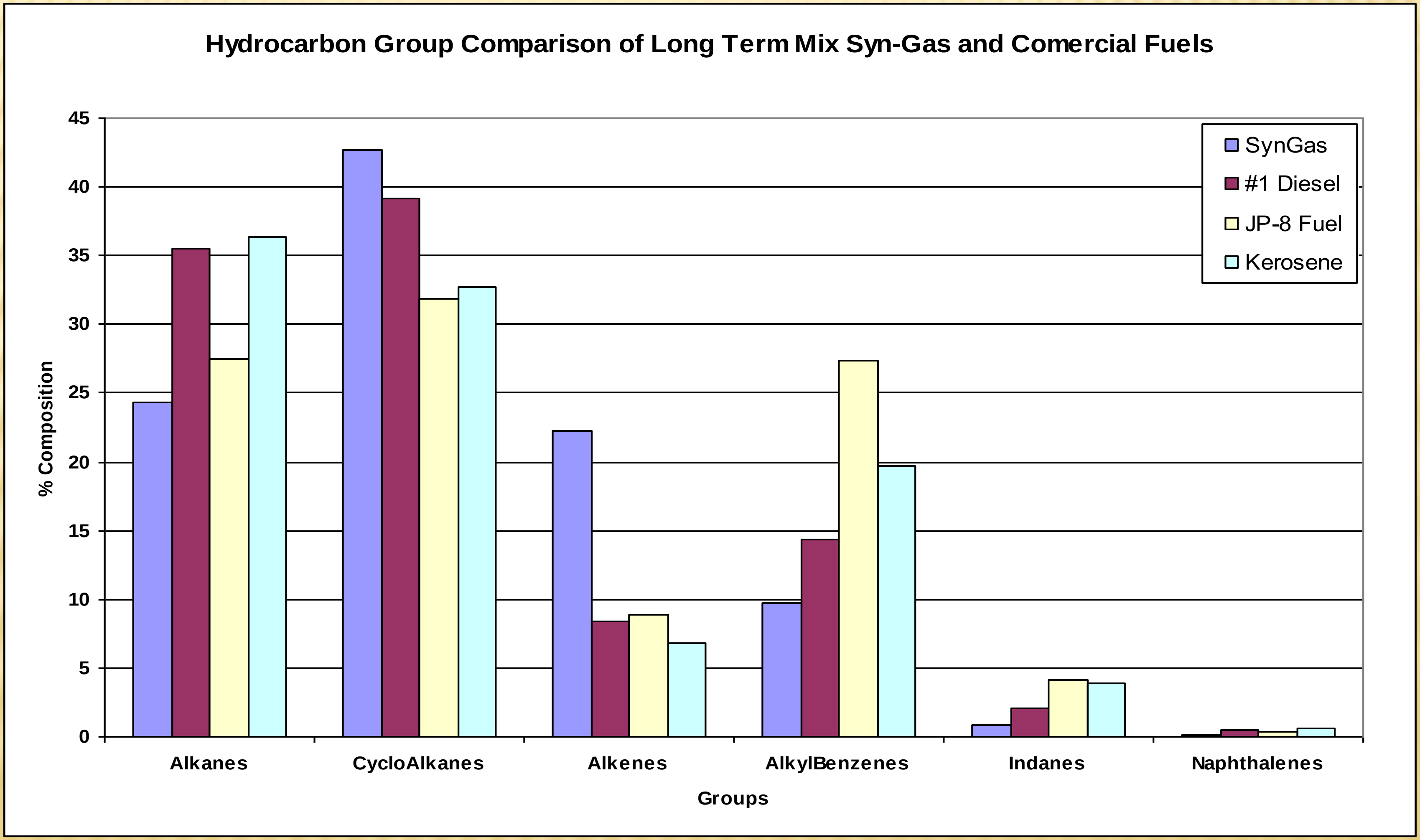
EXHAUST COMPARISONS TO ROAD DIESEL GC – MASS SPEC



SYNGAS HYDROCARBON GROUP COMPARISON



SYNGAS HYDROCARBON GROUP COMPARISON TO COMMERCIAL FUELS



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CONCLUSIONS & FUTURE

COMPARISON WITH STATE OF THE ART

IIFPRG

- Feed Sizing
  - Little to no feed preparation
- Moisture content
  - Have experienced good gas quality and acceptable tar with up to 50% moisture in feed
- Gas Quality
  - Good gas quality
  - Able to substitute an average of 45% for diesel fuel with values up to 78%
- Rapid Startup and Shutdown
- Acceptable exhaust emissions – Reduced NOx

STATE OF THE ART

- Feed sizing
  - Required for vertical units
  - Not required for rotary kilns
- Moisture content
  - Poor gas and unacceptable tar with moisture much over 10%
- Gas Quality
  - Generally lower gas quality
- Often Long Startup and Shutdown
- Acceptable exhaust emissions

GOOD NEWS

- Project continues to be a technical success.
- Meets the military objectives.
- Fuel gas has higher energy than expected.
- Able to reach performance targets at 50% of the design flow.
- Significant findings with liquid fuels.

POSSIBLE NEXT STEPS

- Back feed electrical power onto campus grid using induction generation.
- Enhance hydrogen production by splitting water.
- Cogeneration using non-digestible ag wastes and silage plastics.
- Liquid fuels from wastes.
- Develop waste/biomass battery concept.
- Increase generation capacity.
- Fully automate.
- Develop miniature size.

FUTURE DIRECTIONS

- Commercialization.
  - Cruise Ships.
  - Disaster relief (FEMA).
  - Long Island Energy Infrastructure Development.
- Patent Pursuit (April 2015).
- SBIR (Small Business Innovation Research).