Landfill Gas to Liquid Fuels

A comparison of landfill gas treatment options

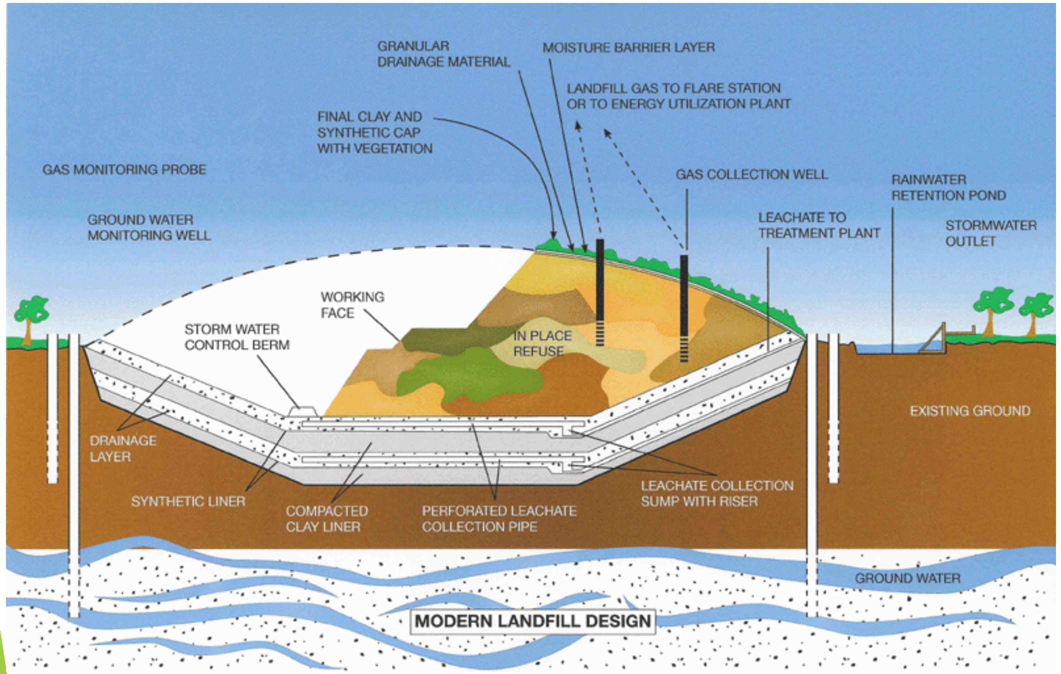
Ryan A. Kent

University of South Florida

Chemical & Biomedical Engineering Department

What happens to your Trash?

- 251 MM tons/year of municipal solid waste (MSW) is produced in United States.
- Average landfill equivalent energy of 350 barrels oil/day in CH4
- LFG cannot be released into atmosphere and must be treated or used.



MSW is transported via Trucks to Facility

MSW is buried in layers and compacted

Landfill is covered and gas is piped to flares

What is Landfill Gas?

LFG is composed of 100’s of different gases
Main components (by volume)

Compon
CH4
CO2

Component	% Composition
CH_4	55
CO_2	42
N_2	1.7
O_2	~0.4
H_2S	0.07 (700 ppm)
Siloxanes	0.00009 (0.9 ppm)

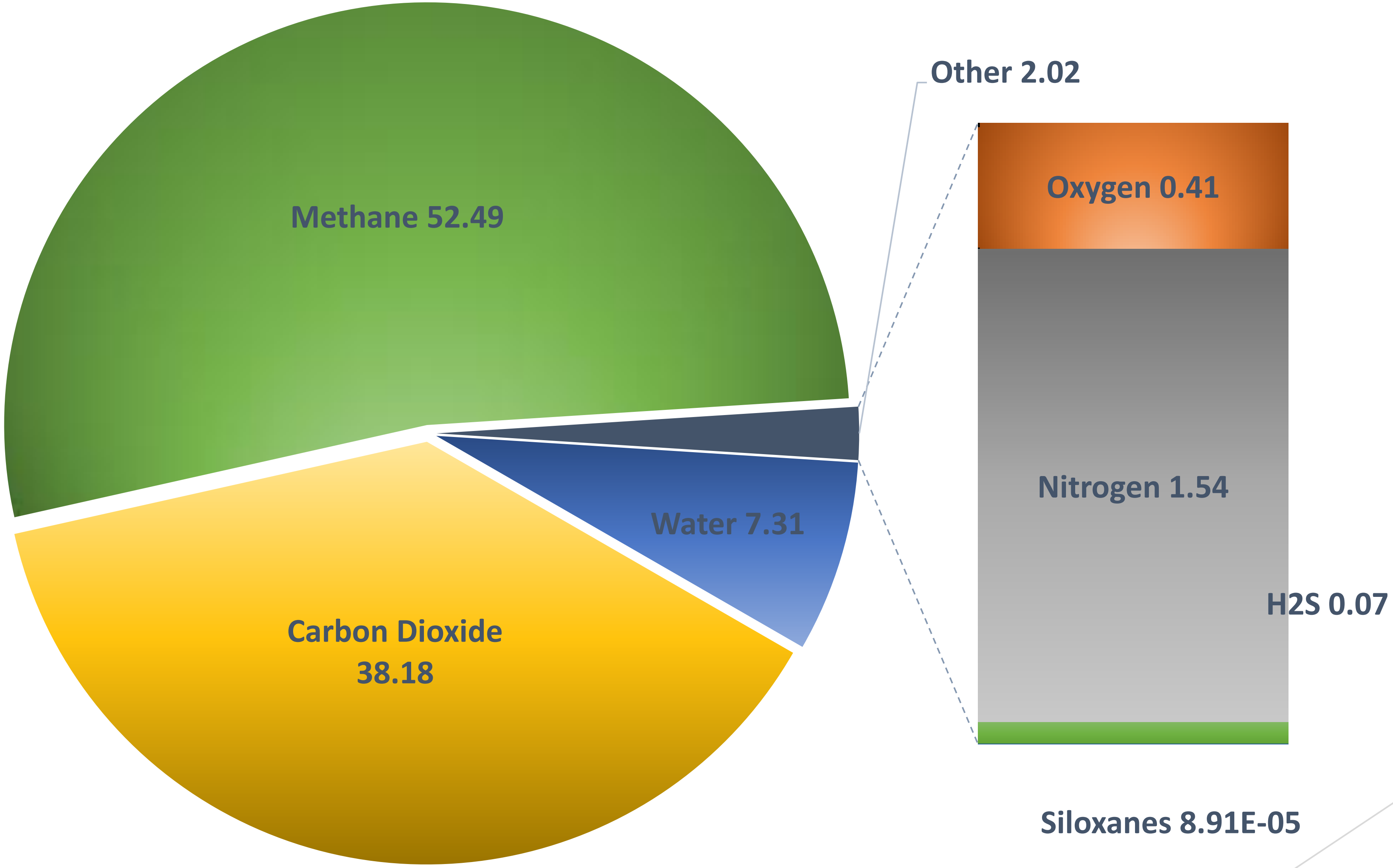
Compon
CH4
CO2
N2
O2
NMOC
H2S

Other gases include small amounts of

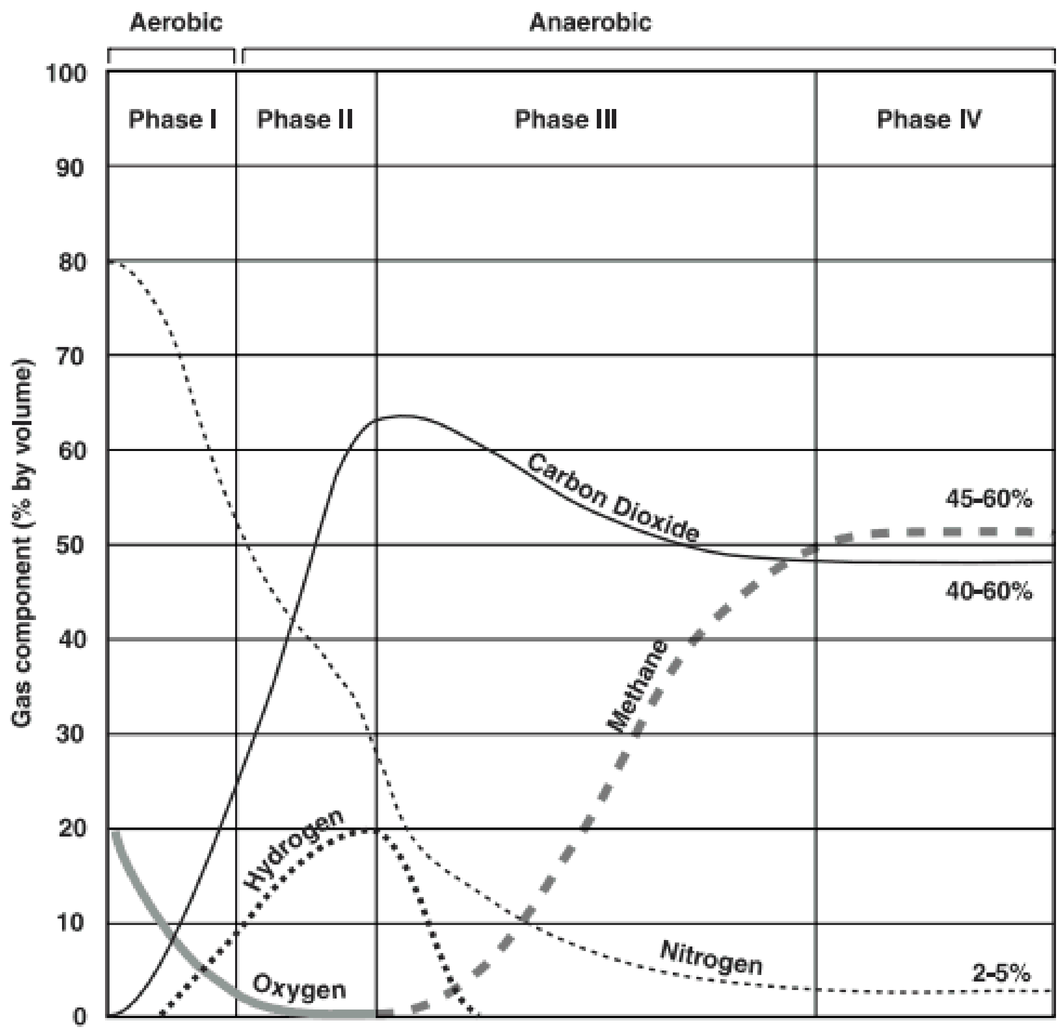
- Nitrogen
- Oxygen
- Ammonia
- Sulfides
- Hydrogen
- Carbon monoxide
- non-methane organic compounds (NMOCs)

NMOCs
acrylonitrile, benzene, 1,1-dichloroethane, 1,2-cis dichloroethylene, dichloromethane, carbonyl sulfide, ethyl benzene, hexane, methyl ethyl ketone, tetrachloroethylene, toluene, trichloroethylene, vinyl chloride, and xylenes.

% Composition of Sat. LFG



What is Landfill Gas?



Note: Phase duration time varies with landfill conditions

Source: EPA 1997

LFG is produced through three main processes

- Bacterial Decomposition (Most significant contribution)
- Volatilization
- Chemical Reactions

Current Options for Landfill Waste Mitigation

Flaring

- Burns all combustible gases and contaminants
- Produces waste gases

Waste to Electricity

- Range of technologies
  - Mass Burn
  - Gas Turbine
  - Advanced Gasification

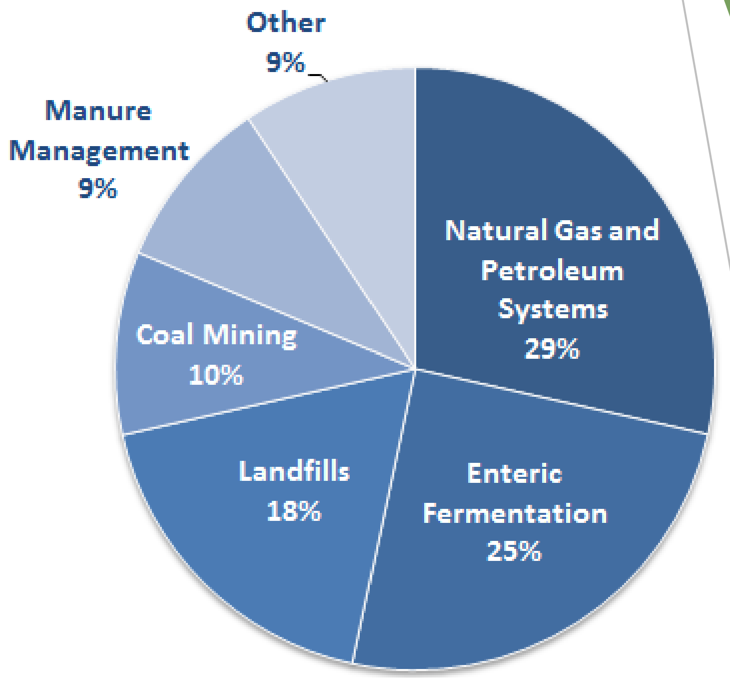
LFG to LNG/CNG

- Compression or Liquefaction of Methane in LFG to form Natural Gas.

Positives	Negatives
• Cheap • Easy	• Wastes Valuable resource
• Widespread usage • Decreases waste landfilled	• Competes with cheaper power options • Low product Value
• Easily Scalable • Produces pipeline quality gas	• High equipment cost • Product competes with cheaper alternatives
• High value product • Widespread usage • Domestic Fuel Source	• New process • More complicated process

Why Landfill Gas to Liquid Fuel?

- Fuel
  - Domestic fuel production
  - Storable
  - High density fuel source
- Carbon offset
  - Greenhouse gas mitigation
- Use of waste for fuel production



U.S. Methane Emissions by Source

Motivation

Hypothesis: Conversion of waste Landfill Gases into liquid hydrocarbons is a more feasible system than other proposed technologies.

- Problems Faced:
  - Down Scaling of Fischer Tropsch Synthesis Reactor (FTSR)
  - Removing contaminants from LFG
    - Siloxanes
    - Sulfides
    - Halides
  - Modeling a competitive Large scale process
    - Lab scale: 0.1 ft3/min
      - Kinetic Data and Reactor Modeling
    - Full Scale: 2500 ft3/min
      - Using literature and industry data

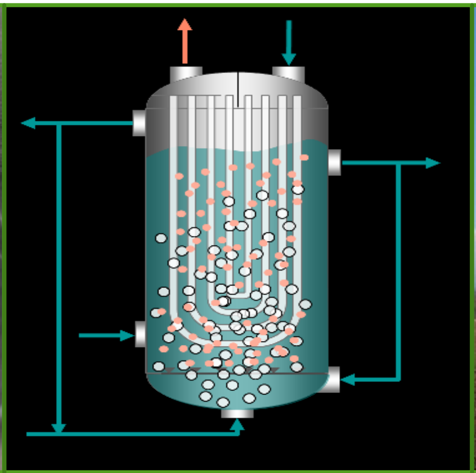
The Process

Pretreatment

- Iron Solid Scavenger
- Activated Carbon/Silica Bed

Tri-Reforming

- Convert LFG to Syngas
  - CO2 Reforming
  - Steam Reforming
  - POx of Methane

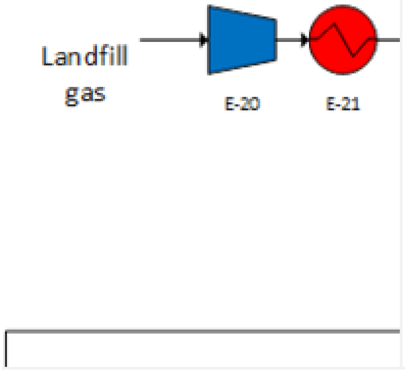


Fischer Tropsch

- Convert Syngas to Long chain hydrocarbons

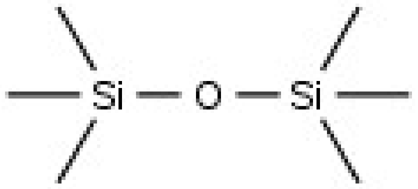
Separations

- High Quality Diesel
- Low quality gasoline sold for upgrading
- Unused portions to combustion


Landfill gas
E-20
E-21

Pretreatment

- Required contaminant removal
  - 250 lb/day of hydrogen sulfide
  - 3 lb/day of siloxanes
- Hydrogen Sulfide Removal
  - Liquid Scavenger
  - Solid Scavenger
  - Liquid Redox
- Siloxanes Removal
  - Adsorption
  - Gas-Liquid extraction



Siloxane

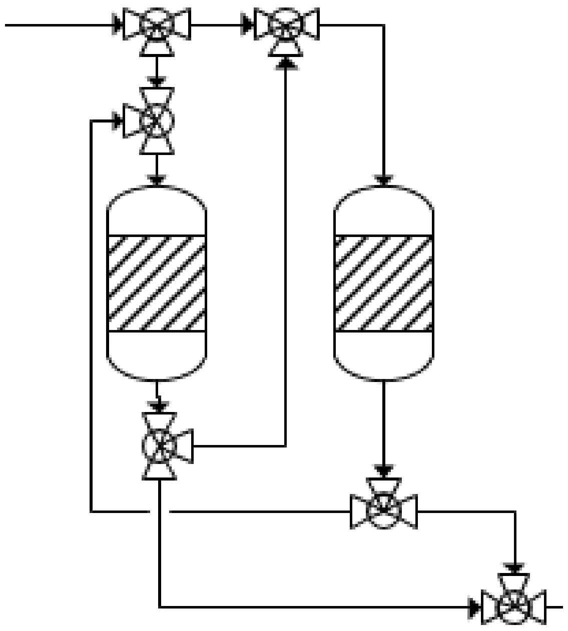
Hydrogen Sulfide

Pretreatment-Hydrogen Sulfide Removal

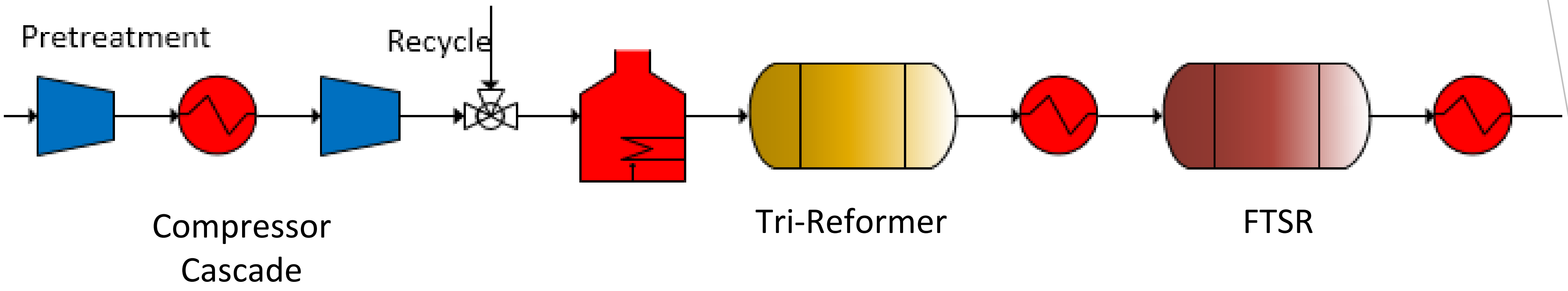
	Liquid Scavenger	Solid Scavenger	Liquid Redox
Gases treated			
Acid Gas	Yes	Yes	Yes
Natural Gas	Yes	Yes	Yes
Product Streams	Biodegradable liquid	Non-hazardous solid	Sulfur Cake for fertilizer
Cost			
Operating	$10/lb of S	$3.50/lb of S	$0.15/lb of S
Equipment	Low	Moderately Low	Moderately High
General application guidelines	100 lb of Sulfur per day	Less than 300lb of Sulfur per day	less than 20 tons of Sulfur per day

Pretreatment

- Hydrogen Sulfide Removal
  - Two packed beds of iron oxide solid scavenger
    - Lag/Lead Series operation
  - Sulfatreat © and Sulfa-rite © are commonly available scavengers
    - 0.01-0.02 lb of sulfur removed per lb of solid
- Siloxanes Removal
  - Two beds of either acid washed activated carbon or silica gel will be used.
  - 0.005 - 0.01 lb of siloxanes removed per lb of packing.
  - Water removal required before entering bed

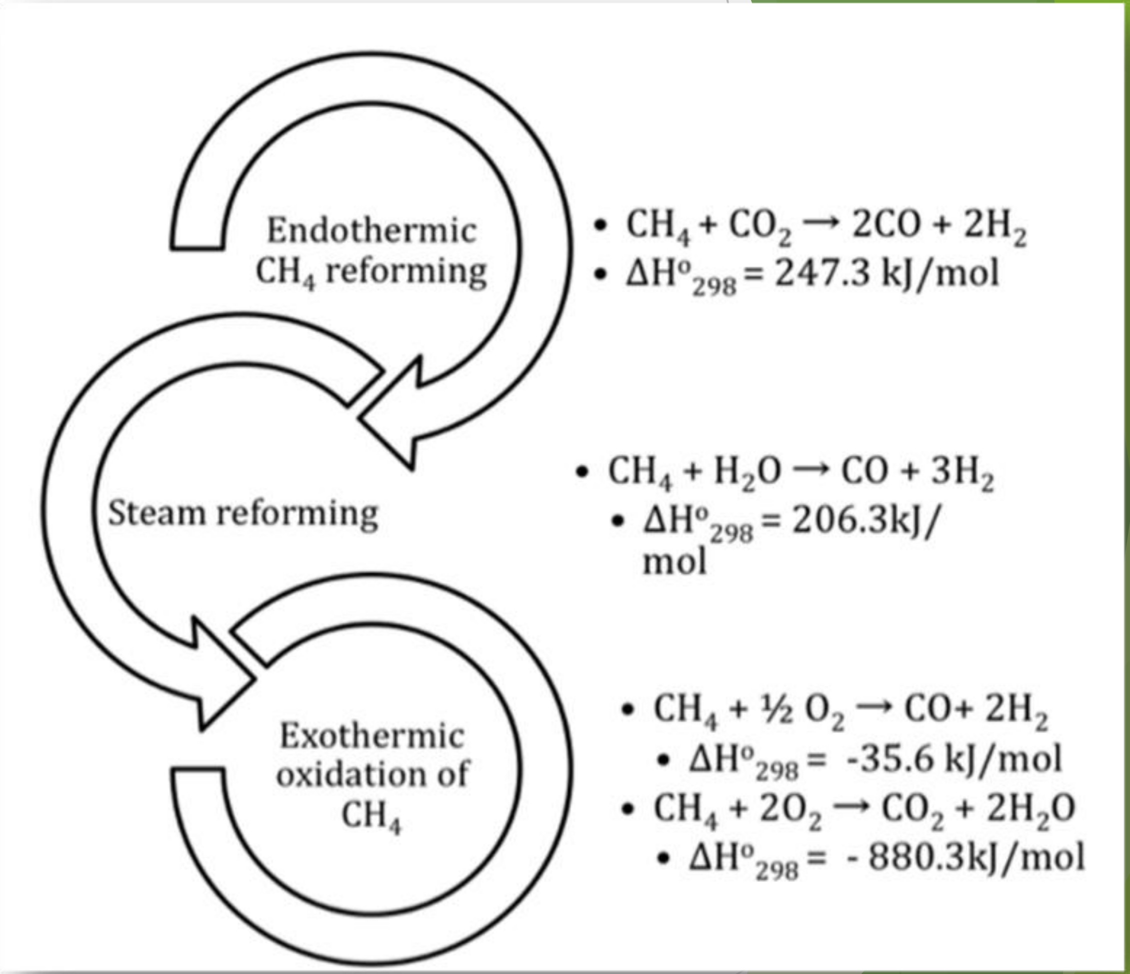


Reactor Section

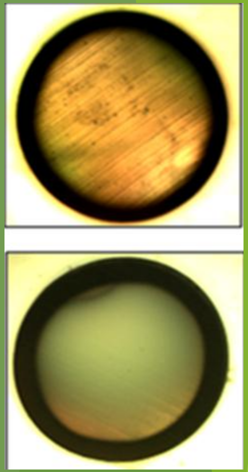


Tri-Reforming

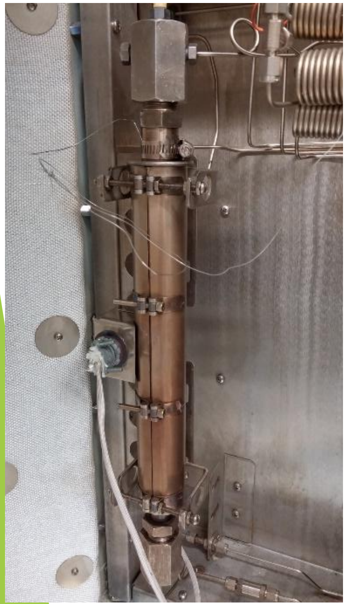
- Catalyst
  - $Ce_{0.6}Zr_{0.4}O_4$ support 8% Ni 8% Mg loaded
- Operated at 800 C and 20 barg
- ~99% conversion of CH4
- 100% conversion higher hydrocarbons



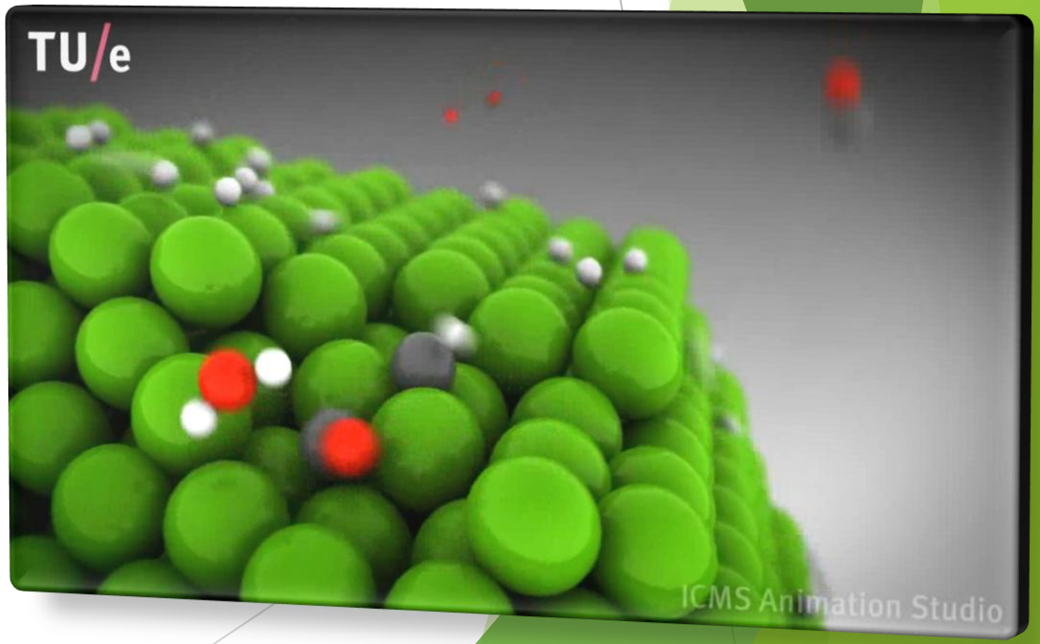
Fisher Tropsch Synthesis



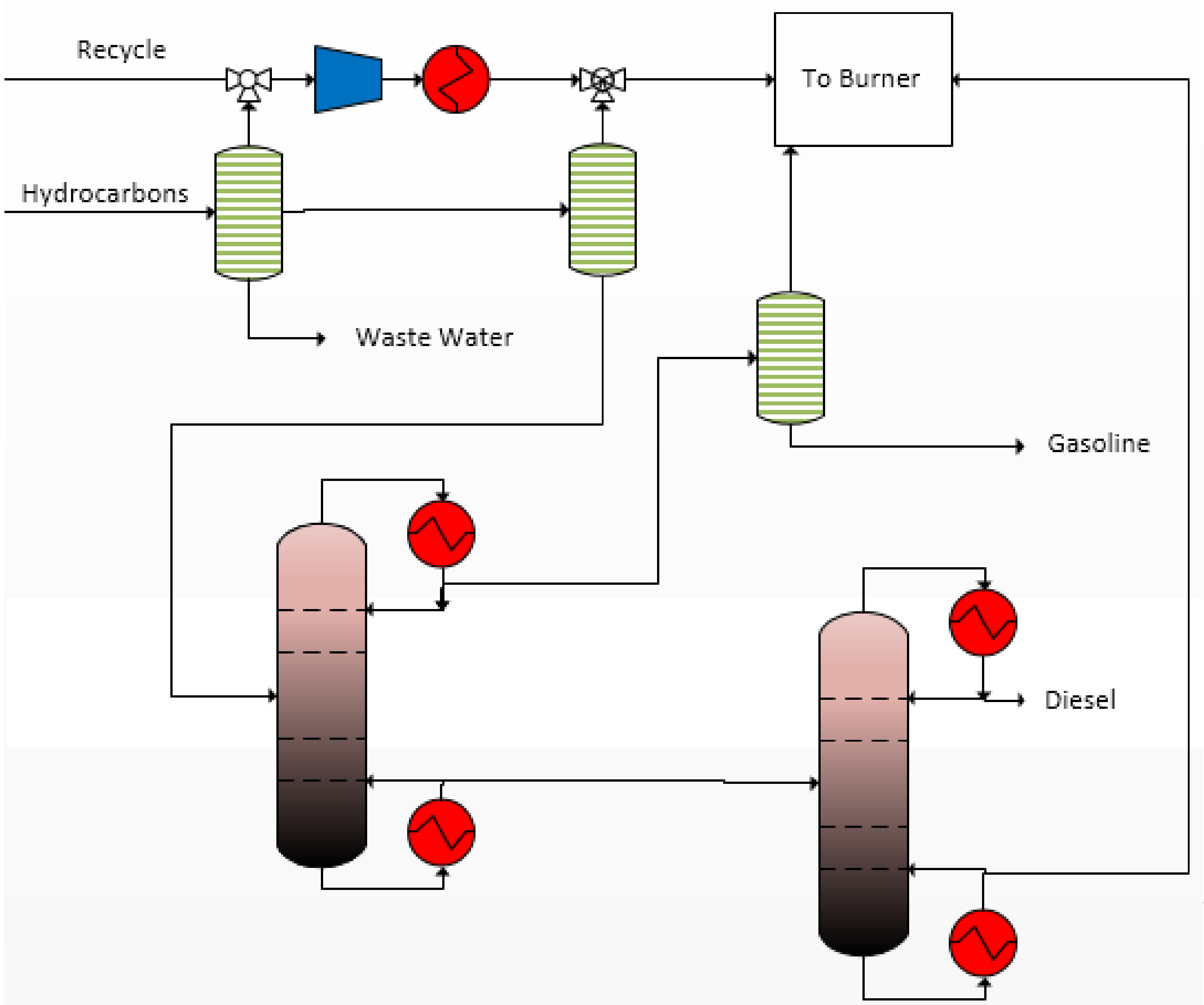
- Catalyst
  - Silica Eggshell Catalyst
  - Silica Core with cobalt surface covered in silica shell
  - Increases selectivity via pore sizing
- Operated at 230 C and 20 barg



$$\boxed{(2n + 1)\ H_2 + n\ CO \rightarrow C_nH_{(2n+2)} + n\ H_2O}$$

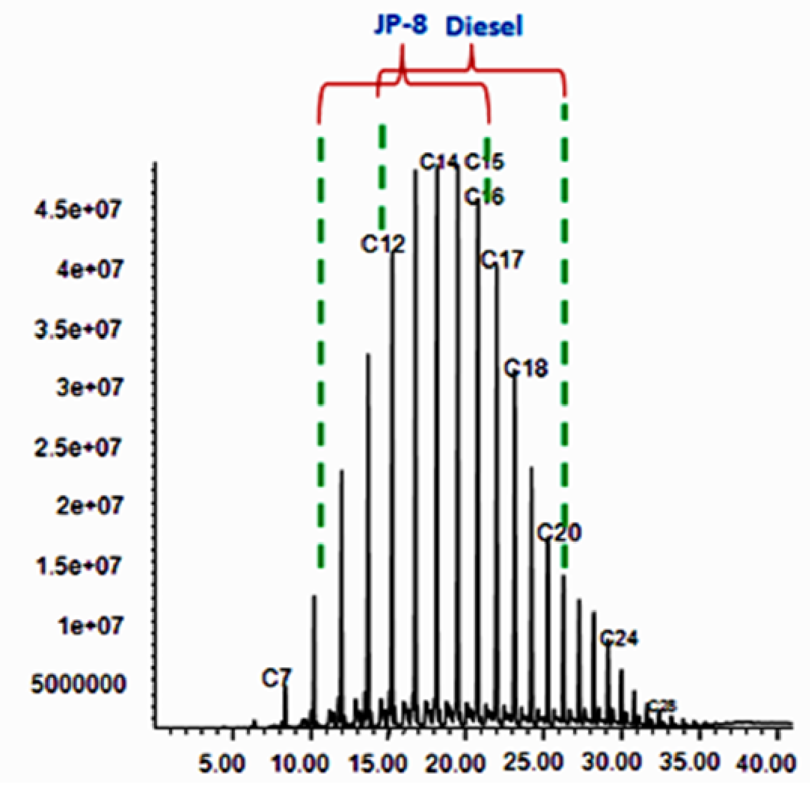


Separations



The Product

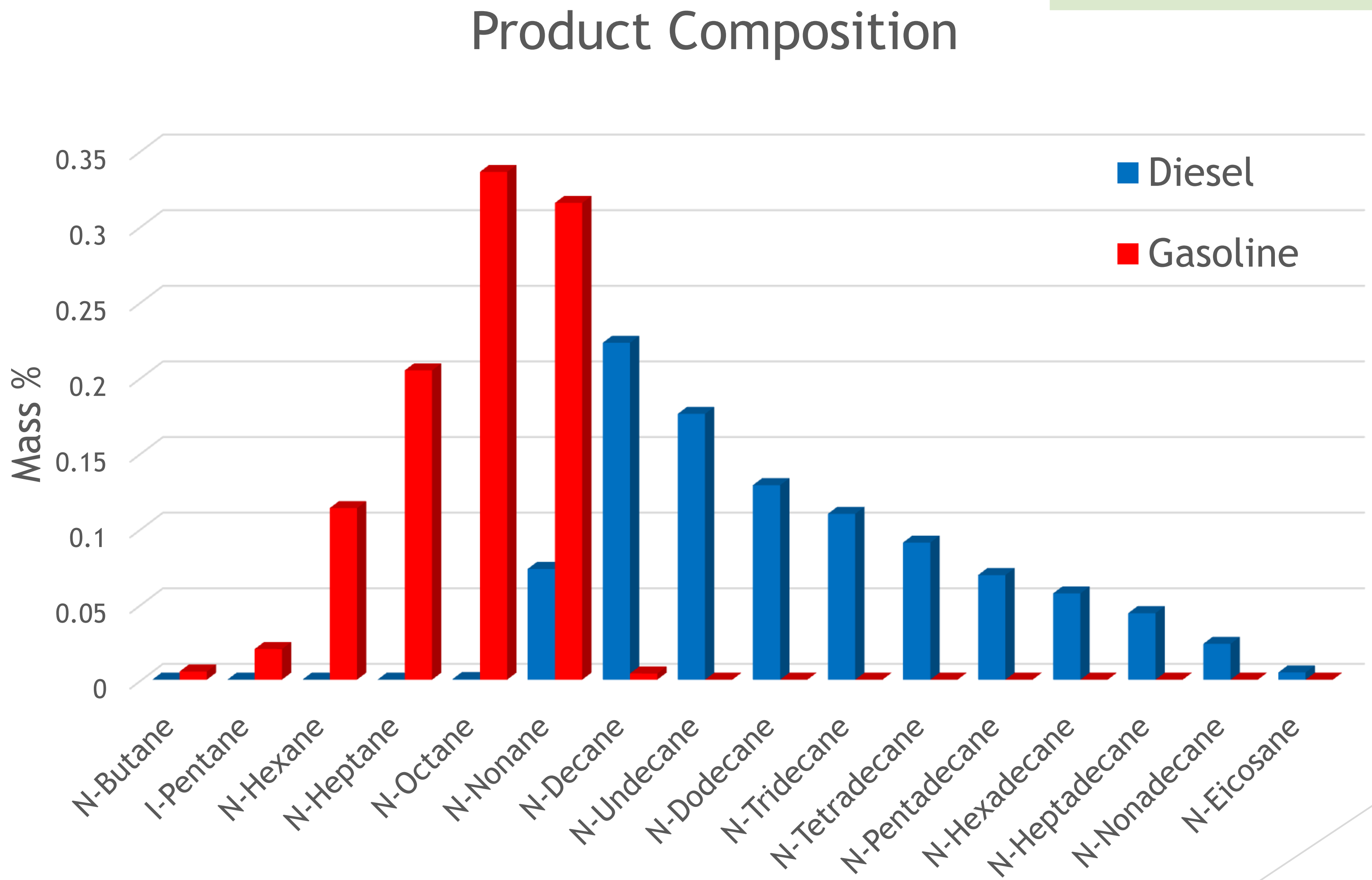
- Hydrocarbons available for Diesel
  - ~80% by mole usable
  - ~C_9-C_{19}
  - diesel fuel of higher quality than petro chemically derived
- Can produce varying amounts of
  - gasoline components
  - Kerosene available for JP-8 upgrading
  - Light gas for running the plant



Hydrocarbon Waxes

Water
+
Dissolved
Hydrocarbons

Diesel Properties	
Flash Point (C)	56.4
Freezing Point (C)	-36.2
Cetane Index	71.35



Total Capital Investment

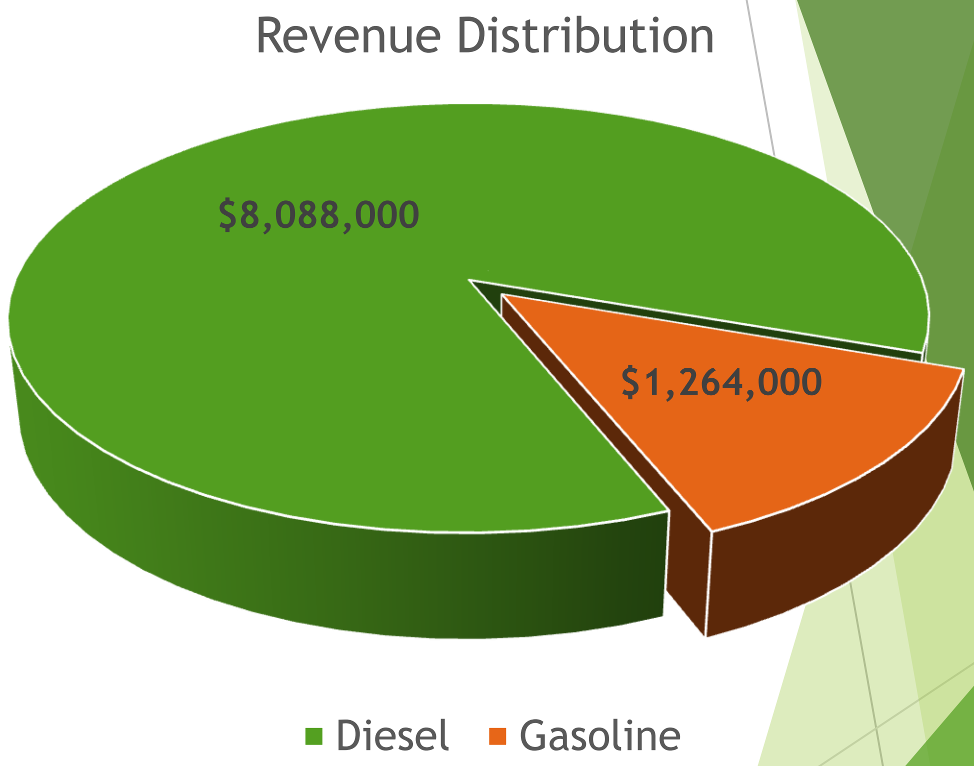
- Fixed Capital Investment
  - $11.4M
- Working Capital
  - $1.7M
  - 15% of FCI
- Land Cost
  - Assuming Zero or Low Lease

Setup Parameters	
Fixed Capital Investment	$ 11.4 Million
Manufacturing Cost	$ 5.2 Million
Yearly Revenue	$ 9.4 Million
Plant Life	15 years
Operating Days/Year	350
Depreciation Method	MACRS (9 years)

Total Capital Investment ~ $13.1M

Revenue

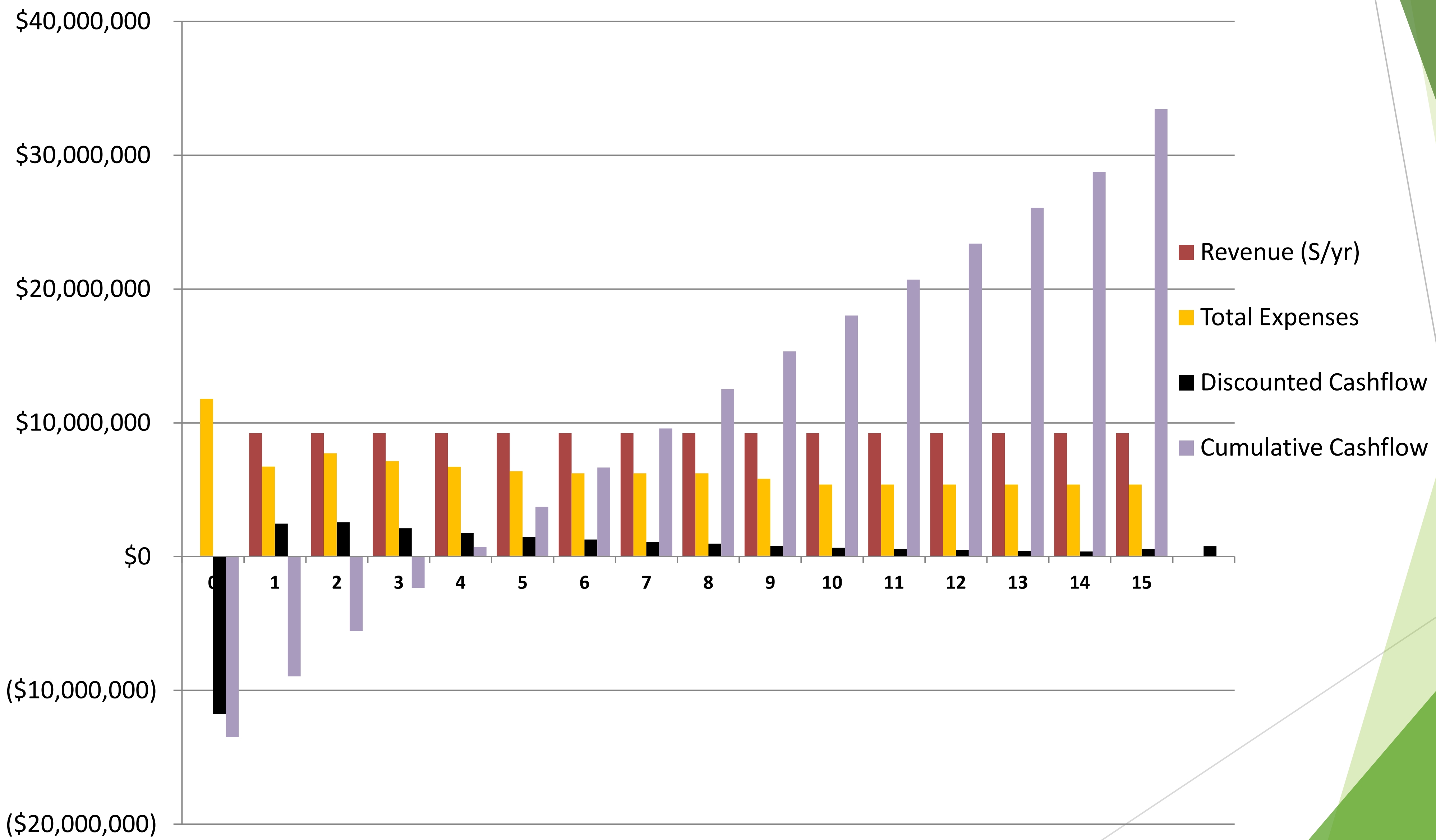
- Diesel
  - 2,022,000 US gallons per year
  - $4.00 per gallon
  - $8,088,000 per yr
- Low Quality Gasoline Precursor
  - 842,400 US gallons per year
  - $1.50 per gallon
  - $1,264,000 per yr



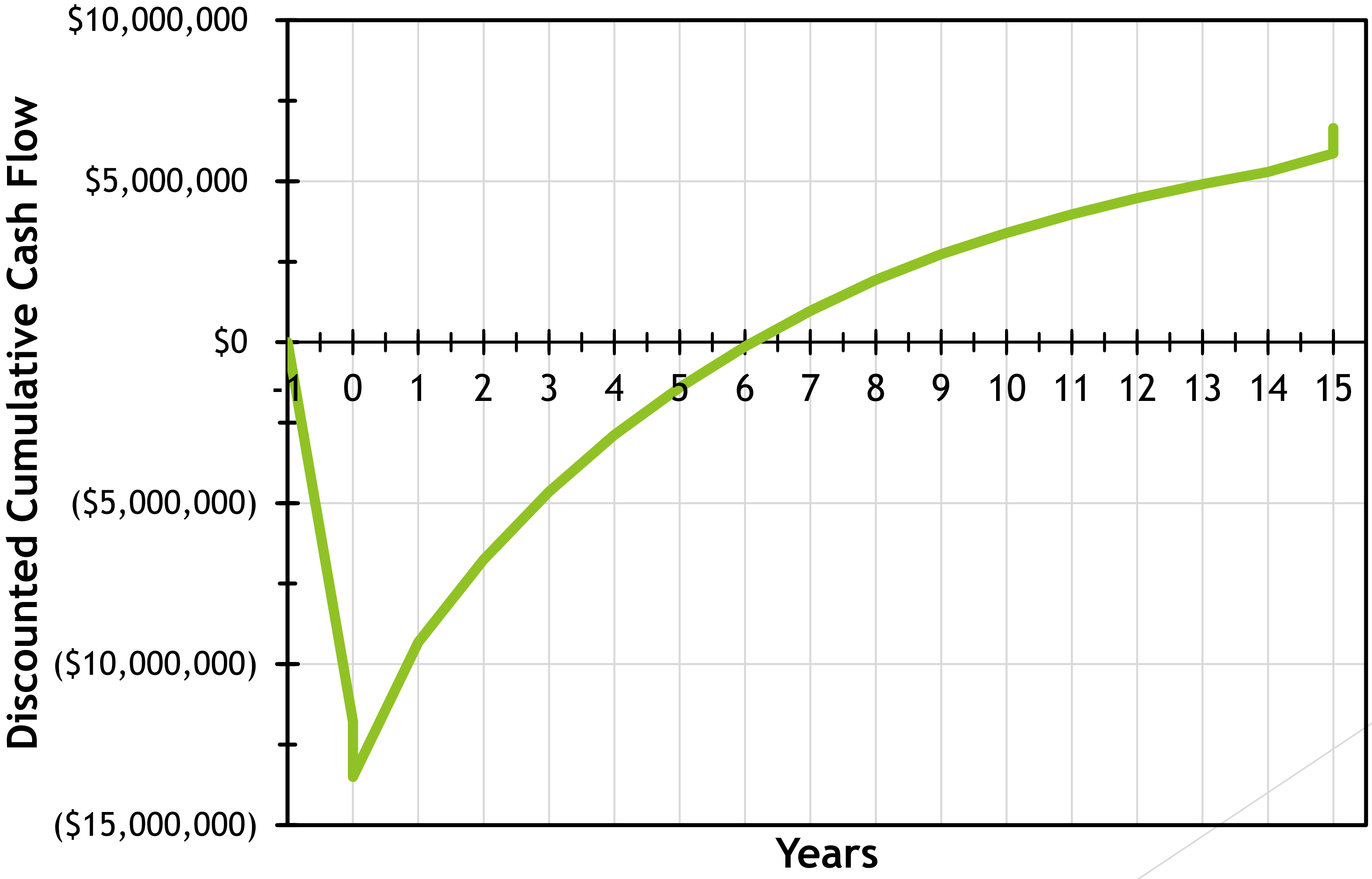
Feasibility Analysis

Parameter	
Plant Life	15 years
Operating Days/Year	350
Depreciation Method	MACRS (9 years)
Net Present Worth (NPW) i=15%	$ 7.1 Million
Return on Investment (ROI)	38%
Discounted Payback Time	~6.5 years

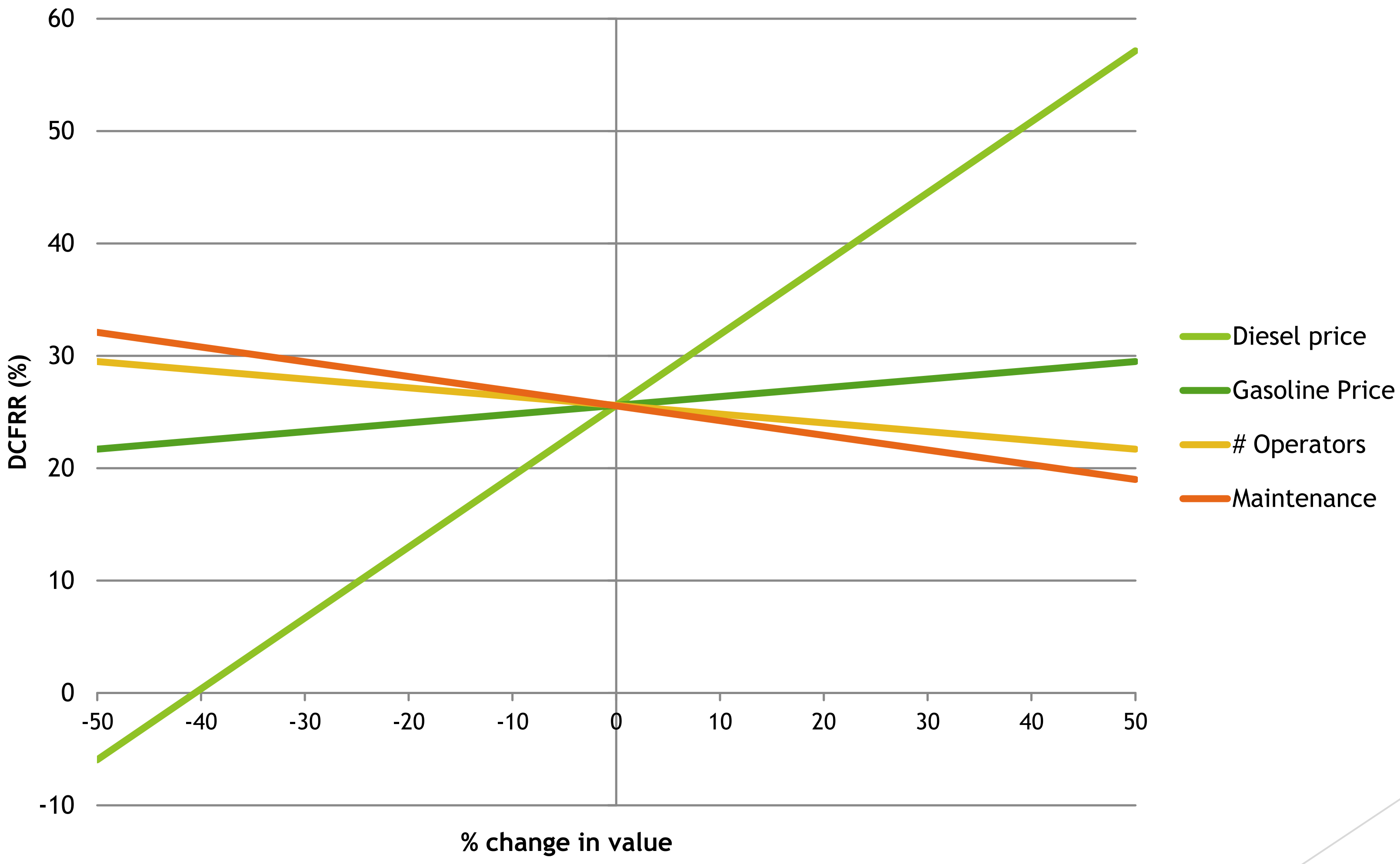
Cumulative Cash Flow



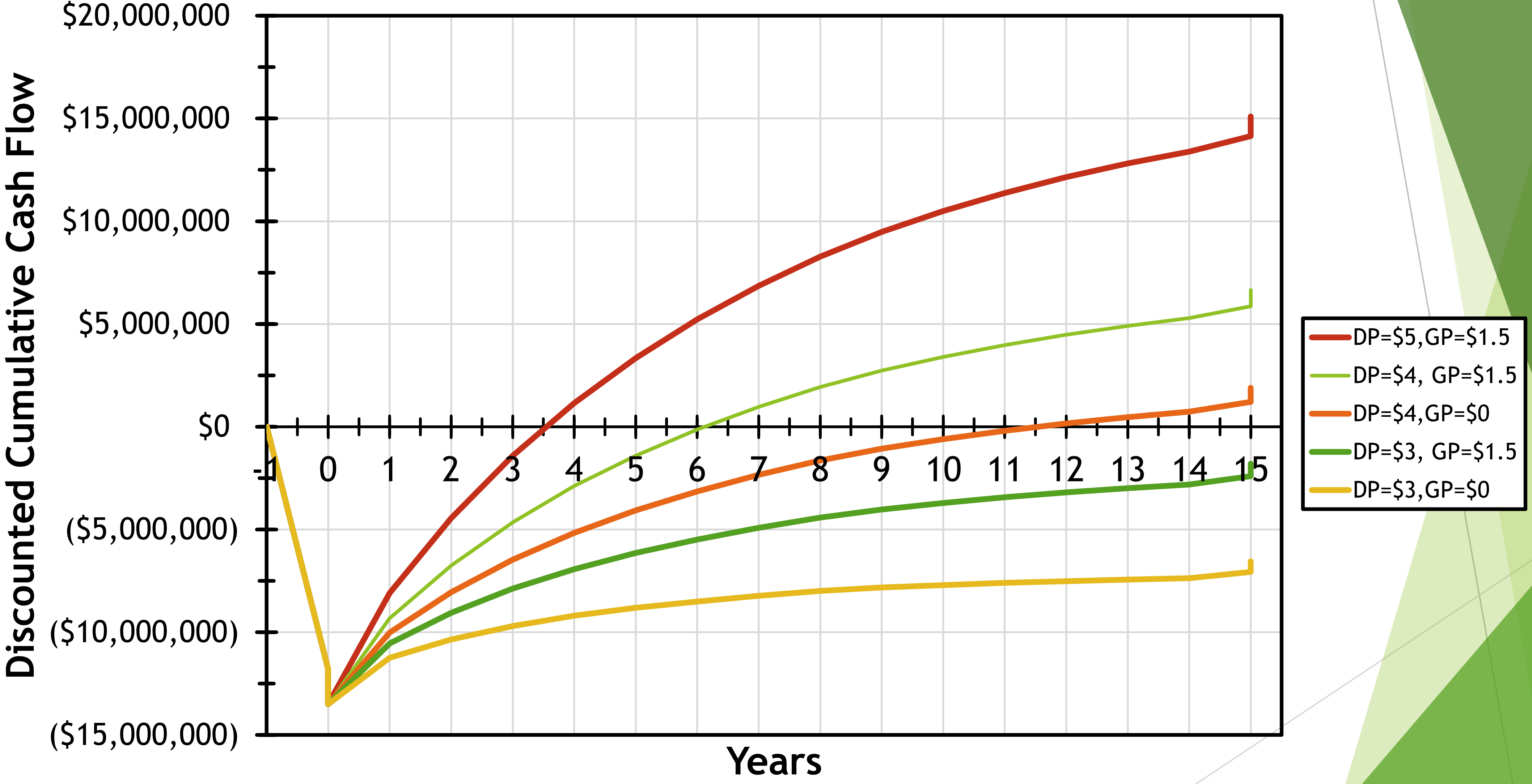
Discounted Cumulative Cash Flow Diagram



Sensitivity Analysis



Sensitivity of Product Price



Techno-Economic Analysis

- Boundary Conditions
  - All facilities compared on 2500 ft^3/min
  - Piping costs are considered uniform for all facilities
  - Estimation based on best technologies in field.

- Selling Prices
  - Electricity: 6 cents/kWh
  - Compressed Natural Gas: $2.56 GGE
    - Pipeline gas: 9 $/1000 SCF
  - Price of Diesel: 4 $/gallon Market Price

Choosing a Technology

	Flaring	Electricity	CNG	Liquid Fuel
FCI (MM $)	1.0	9.4	9.6	11.4
Operating Cost (MM $/yr)	0.06	1	4	5.2
Revenue (MM$/yr)	-	3.5	6.2	9.4
NPW (MM $)	-1.1	-0.5	1.2	5.9
DCFRR	-	**0.13**	**0.14**	**.25**

Conclusions

- Flaring
  - No use for larger installations which could use LFG as a resource
- Electricity
  - Remains a formidable option due to widespread utilization
- LFG to CNG
  - Shows promise for modular installment but incurs a high operating cost for the product delivered.
- LFG to Liquids has the highest rate of return
  - However the technology also incurs a higher risk
  - Return will increase as diesel prices rise and natural gas price falls

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  - Research and Innovation Center
- National Collegiate Inventors and Innovators Alliance

Hinkley Center
for Solid and Hazardous
Waste Management

NCIIA
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References

- Gardezi, S. A., et al. (in review). "Effect of Catalyst Preparation Conditions on the Performance of Eggshell Cobalt/SiO2 Catalysts for Fischer-Tropsch Synthesis." Catalysis Letters.
- Walker, D. (2012). Catalytic Tri-Reforming of Biomass-Derived Syngas to Produce Desired H2:CO Ratios for Fuel Applications. Chemcial & Biomedical Engineering, University of South Florida. **Masters**.
- Walker, D. M., et al. (2012). "Synthesis gas production to desired hydrogen to carbon monoxide ratios by tri-reforming of methane using Ni–MgO–(Ce,Zr)O2 catalysts." Applied Catalysis A: General **445-446**: 61-68.
- Gardezi, S. A., et al. (2013). "Thermochemical biomass to liquid (BTL) process: Bench-scale experimental results and projected process economics of a commercial scale process." Biomass and Bioenergy **59**: 168-186.
- Läntelä, J., et al. (2012). "Landfill gas upgrading with pilot-scale water scrubber: Performance assessment with absorption water recycling." Applied Energy **92**: 307-314.
- Themelis, N. J. and P. A. Ulloa (2007). "Methane generation in landfills." Renewable Energy **32**(7): 1243-1257.
- Environmental Protection Agency
  - http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html
- http://www.merichem.com/company/overview/technical-lit/tech-papers/small-capacit