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Syngas from Non-Recycled Plastics (NRP): The Enerkem Process

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Outline

- Objective
- Background (NRP waste, Gasification, Enerkem WTFC)
- Plastic Trials
- Results (Syngas comparison, Methanol projections)
- Conclusions and future work

Objective

- To determine, through pilot testing, the impact of non-recycled plastics (NRP) on gasification. Specifically, with regards to:
  - Carbon and thermal efficiencies
  - Final product yields
  - Environmental and economic impacts

•Pilot testing conducted at Enerkem's Waste-to-Fuels and Chemicals (WTFC) facility in Edmonton, Canada

Thermal Treatment of Non-Recycled Plastics (NRP)

- **Gasification:** partial oxidation of a hydrocarbon fuel using an oxidant at a substoichiometric ratio

- Potential energy recovery from NRP via thermal treatment:

FUEL TYPE	LOWER HEATING VALUE (LHV) (BTU/LB)
Natural gas	20,300
Crude Oil	18,400
Non-recycled plastics (NRP)	**14,000**
Petroleum coke	12,700
US coal	9,800-11,200
Wood	6,000

Source: Themelis et. al. (2011)

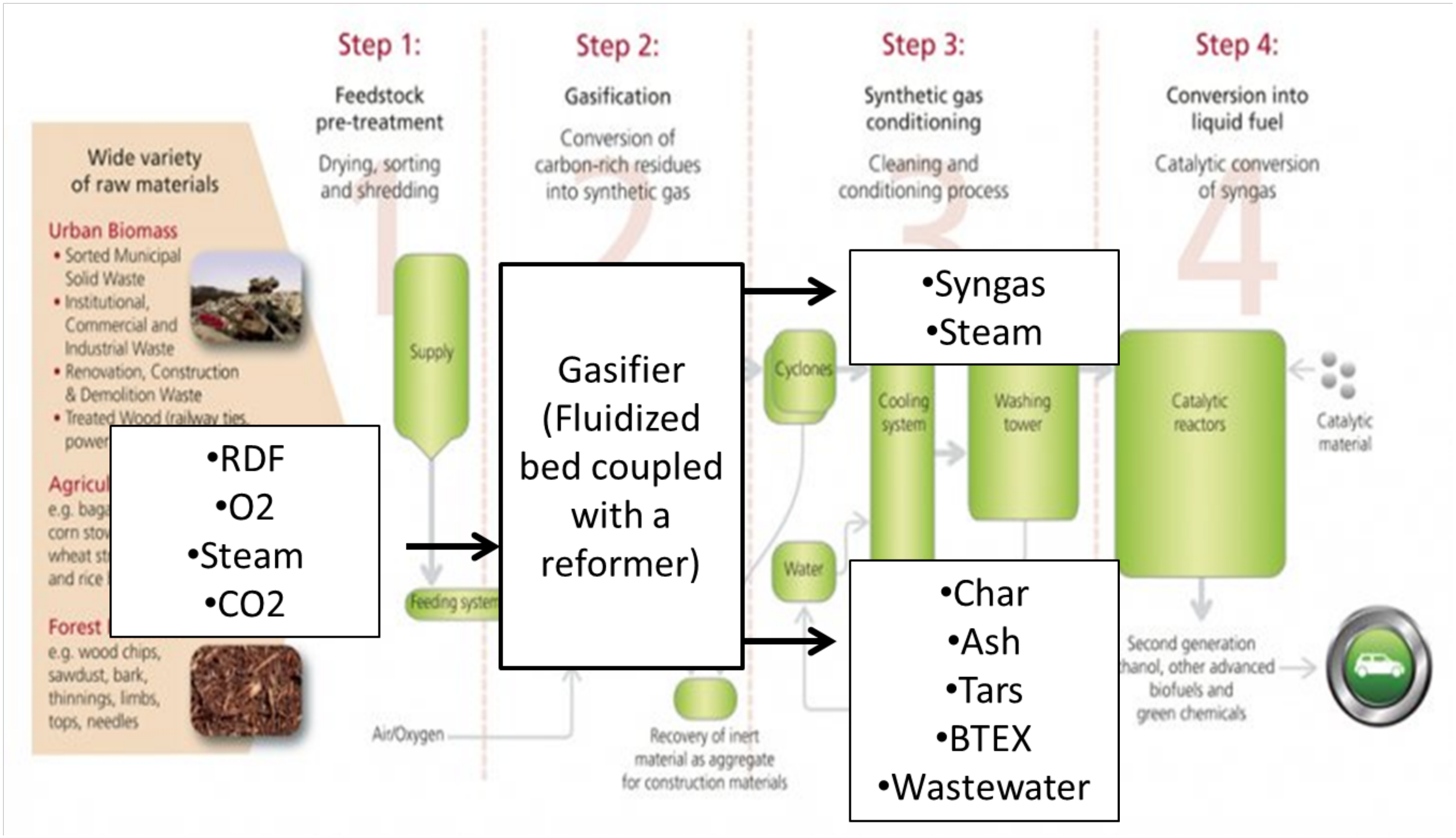
Enerkem's Waste to Fuels and Chemicals Process (WTFC)

General Overview:

Refuse Derived Fuel → GASIFICATION W/ O2 &STEAM → **Syngas** (H_2, CO, CO_2, CH_4) → SYNTHESIS REACTIONS → **Methanol and/or Ethanol**

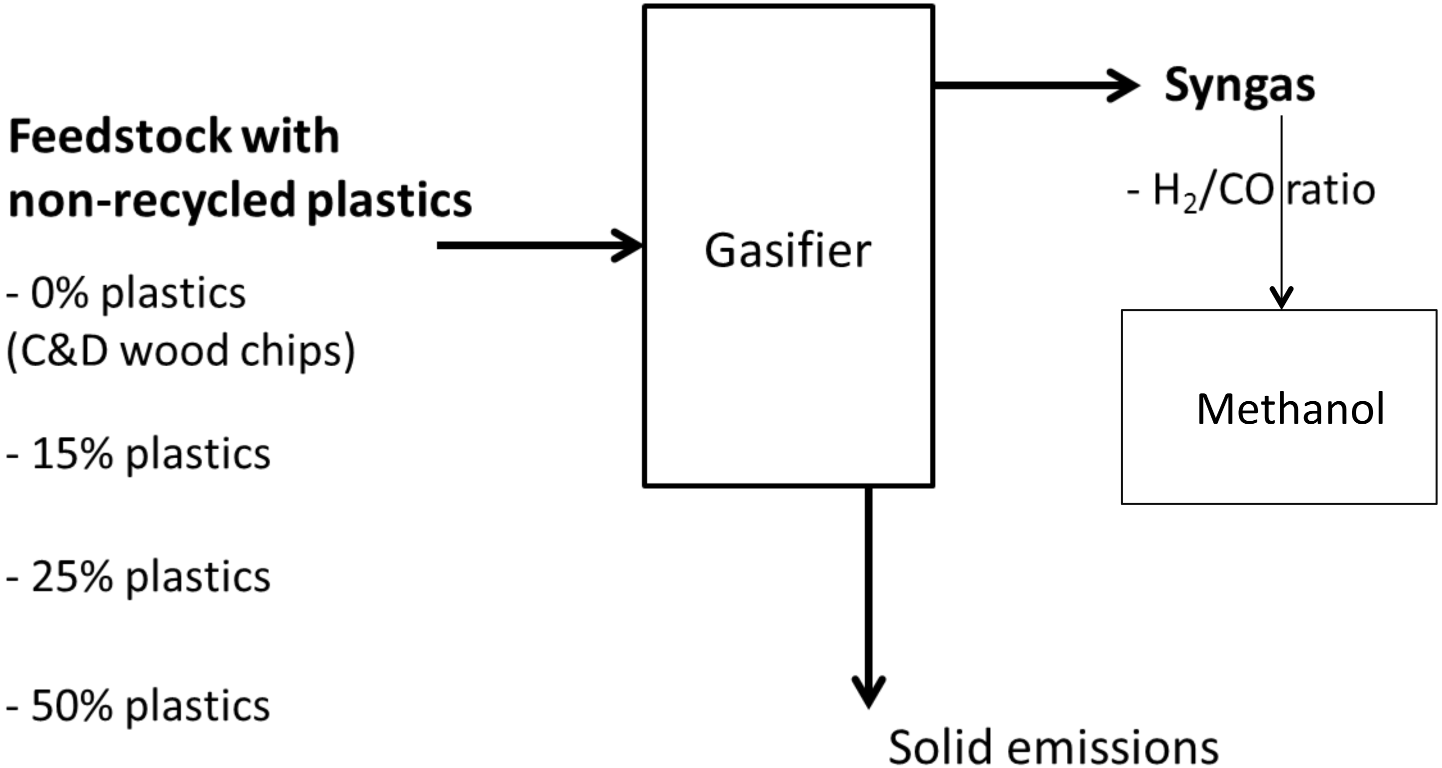
Enerkem's Waste to Fuels and Chemicals Process (WTFC)

Process flow diagram:



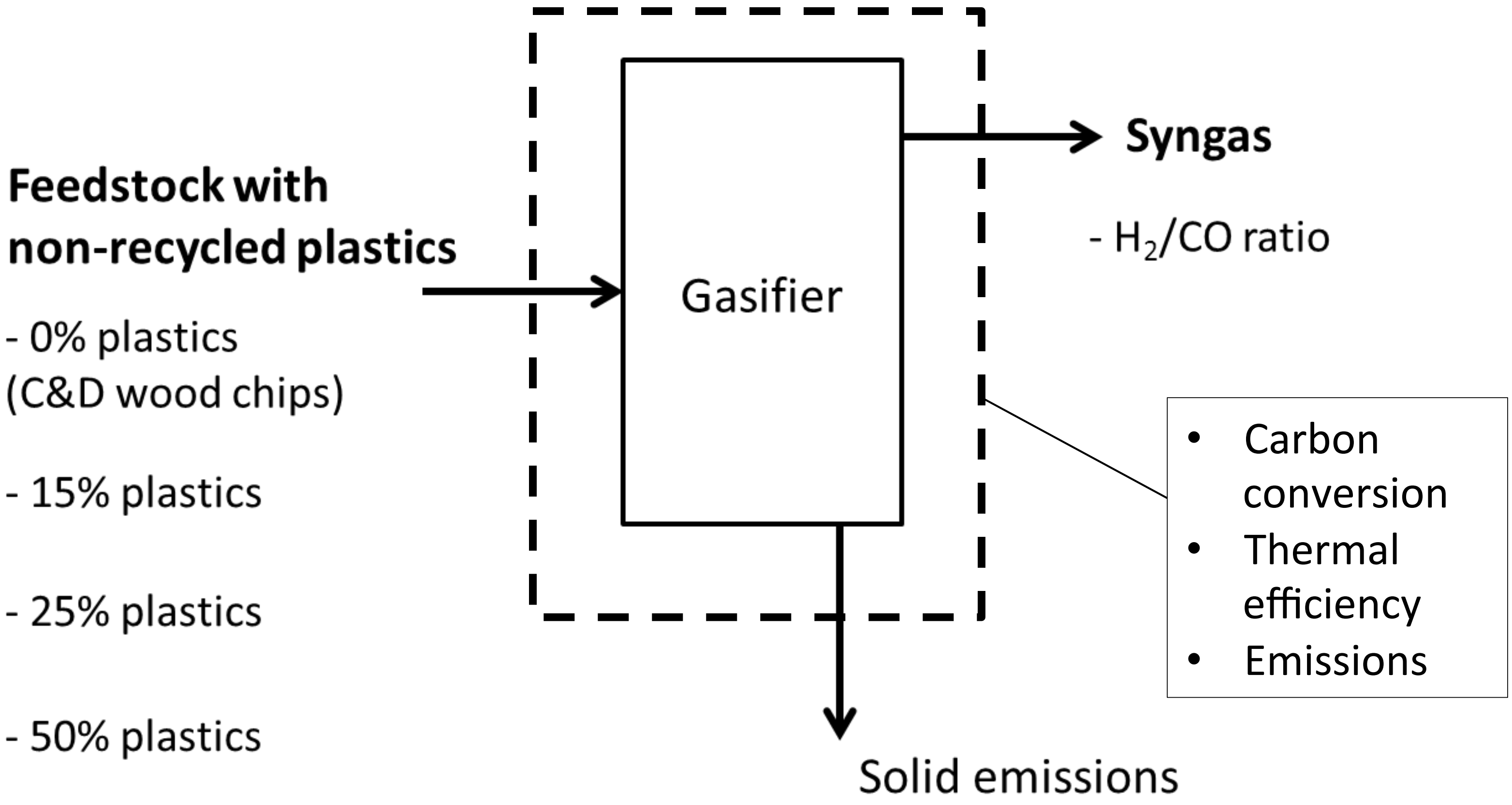
Scope of Pilot Study

1. **Measure syngas composition for waste feedstock with varying plastic concentrations**



Scope of Pilot Study

2. Perform mass and energy balances to determine impact of plastics on gasifier efficiencies, emissions, and final product yields



Pilot tests: October 2013 to September 2014

- **Pilot tests conducted at WTFC pilot facility in Edmonton**
  - Housed in the Advanced Research Energy Facility of EWMC
  - Operating capacity: approx. 300 kg/hr
- **Waste feedstock provided by EWMC**
  - C&D wood chips from Integrated Processing & Transfer facility
  - Non-recycled plastics residue from Material Recovery Facility
- **Results presented are from Apr. and Sept. 2014 pilot tests**

Feedstock Characterization: April 2014 pilot test

- Mixture of C&D wood and MRF residue (source of NRP)
- EEC conducted calorimetry and C-14 testing of MRF residue to determine mixing ratio for feed:

MRF Residue
(plastics and paper)

Average biogenic content (%)	33.5
Lower heating value (Btu/lb)	10,900 -17,000

Feedstock Characterization: Sept. 2014 pilot test

- Mixture of C&D wood and segregated plastic fluff
- Separated NRP stream from MRF residue:
  - No paper in feedstock
  - Ensure better control of desired plastic concentration in feed
- Segregated plastic fluff was a 50/50 mixture of:
  - Rigid plastics (i.e. water bottles, margarine tubs)
  - Film plastics (i.e. plastic bags)

Ultimate Analysis of Plastic Mixtures

	C&D Wood Waste	15% Plastic Mixture	25% Plastic Mixture	50% Plastic Mixture
Carbon (%)	45.97	51.36	55.28	59.13
Hydrogen (%)	5.78	7.19	7.86	8.72
Nitrogen (%)	0.59	0.5	0.5	0.5
Oxygen (%)*	40.26	31.11	28.34	23.54
Sulfur (%)	0.12	0.09	0.08	0.07
H/C ratio	0.126	0.140	0.142	0.147

*Oxygen calculated by difference

Sample Name	% ASH	% Moisture
C&D wood waste	8.4	12.9
15% plastic mixture	8.7	11.4
25% plastic mixture	6.9	11.1
50% plastic mixture	6.6	7.8

Predicted Syngas Compositions: Based on Thermodynamic Equilibrium Model

- Dutta et. al. model:

$$CH_xO_yN_z + wH_2O + m(O_2 + \cancel{3.76N_2}) = n_{H_2}H_2 + n_{CO}CO + n_{CO_2}CO_2 + n_{H_2O}H_2O + n_{CH_4}CH_4 + (\frac{z}{2} + \cancel{3.76m})N_2$$

where w = kmol of moisture/kmol of feedstock   m = kmol of oxygen/kmol of feedstock

Assumptions of model:

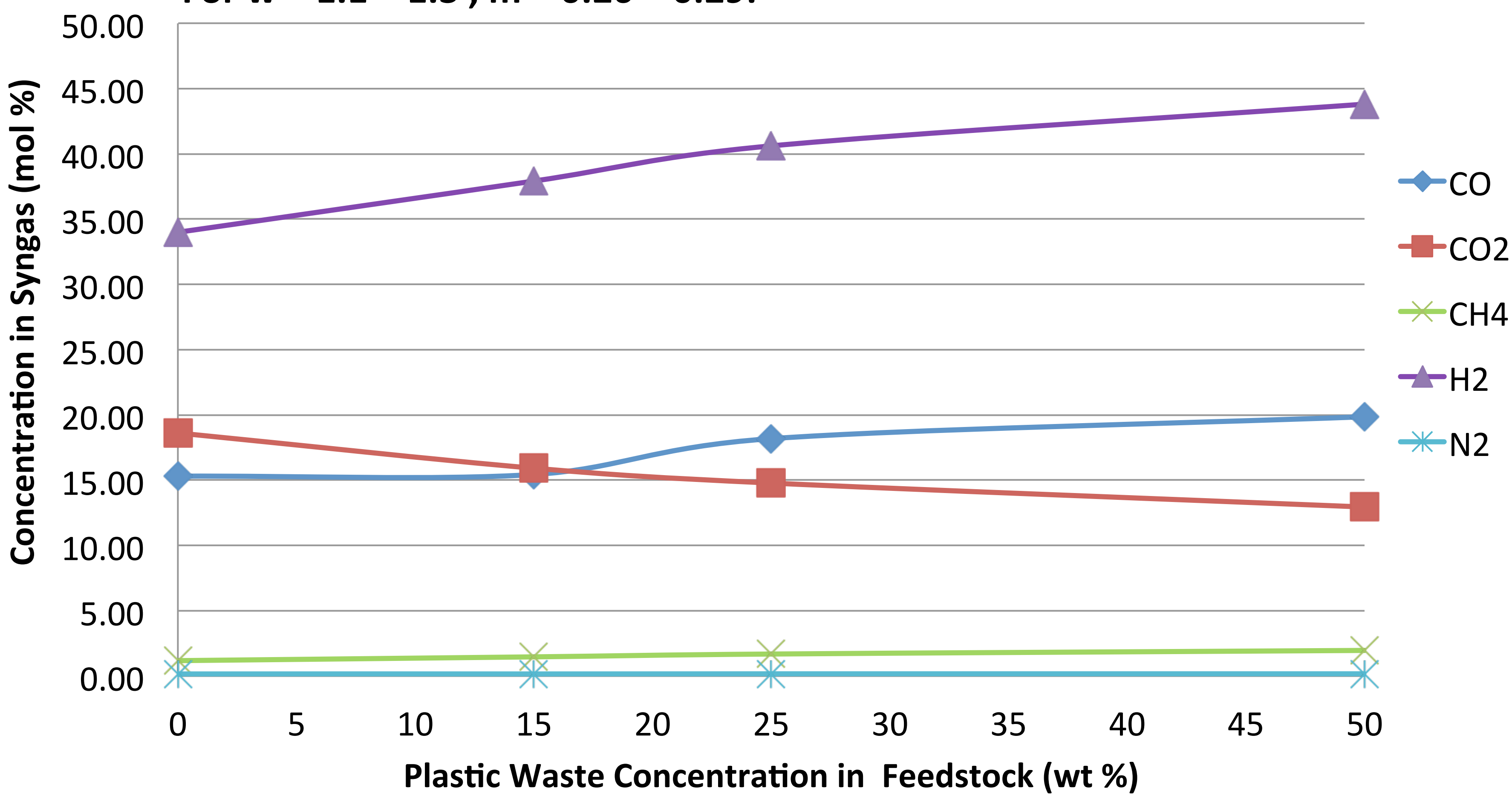
- Thermodynamic equilibrium based on minimization of Gibbs free energy
- Theoretical syngas composition represents equilibrium composition of an autothermal gasifier where all the heat requirements are provided by the partial oxidation

Applications of model:

- Modified for oxygen gasification
- Based on ultimate analysis of mixtures
- Based on feed rates and co-reactant flow rates from pilot tests

Predicted Syngas Composition for Increased Plastic Concentration in Feedstock

For w = 1.1 – 1.3 , m = 0.26 – 0.29:



Predicted H2/CO Ratios in Syngas for Increased Plastic Concentration in Feedstock

- Methanol Formation:

$$CO + 2H_2 \rightarrow CH_3OH$$

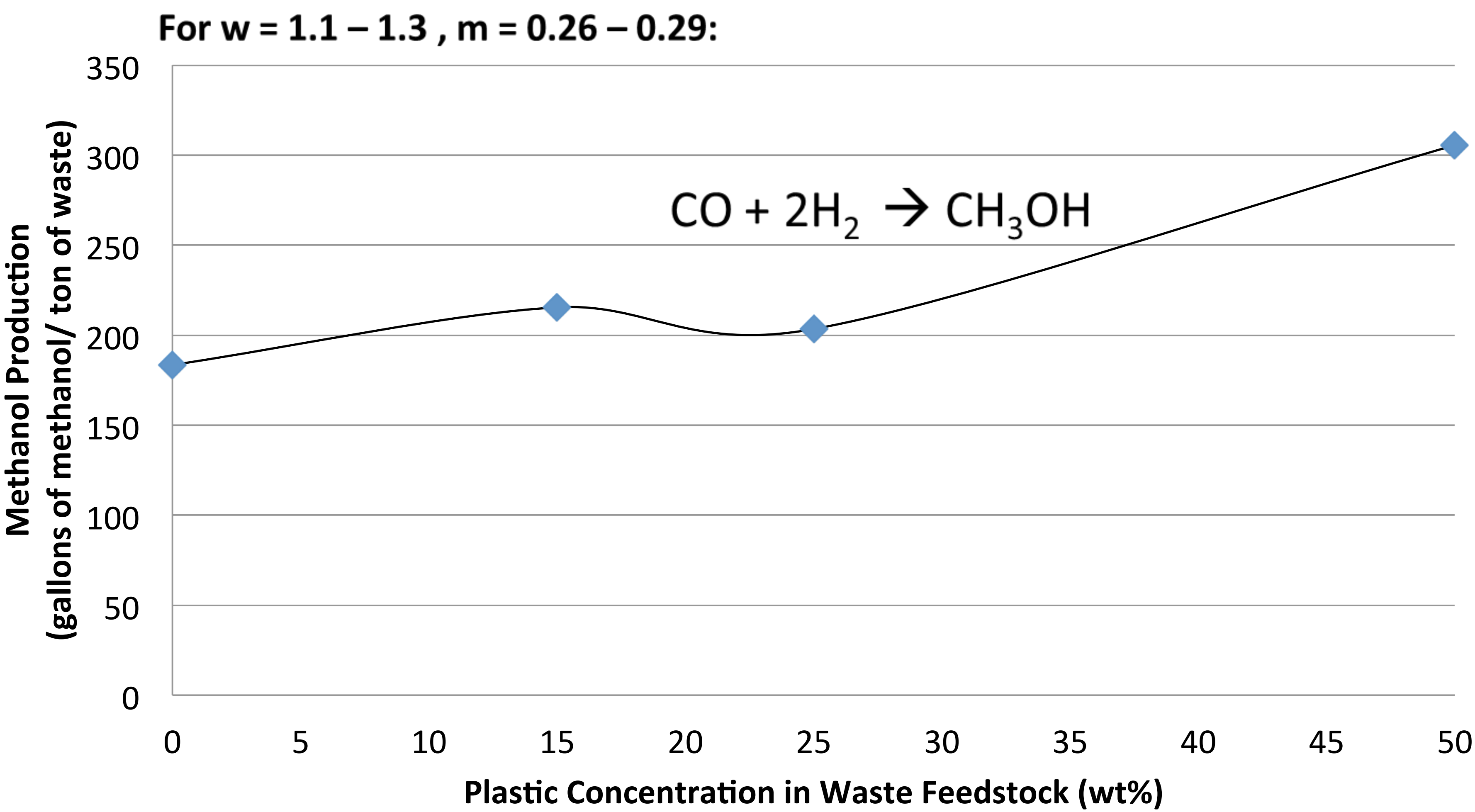
  - Ideal H_2/CO ratio = 2:1

For w = 1.1 – 1.3 , m = 0.26 – 0.29:

Plastic Concentration in Waste Feedstock (%)	H_2/CO
0	2.22
15	2.46*
25	2.23
50	2.21

*w = 1.3, w_{ave} = 1.1

Projected Methanol Production based on Predicted Syngas Compositions

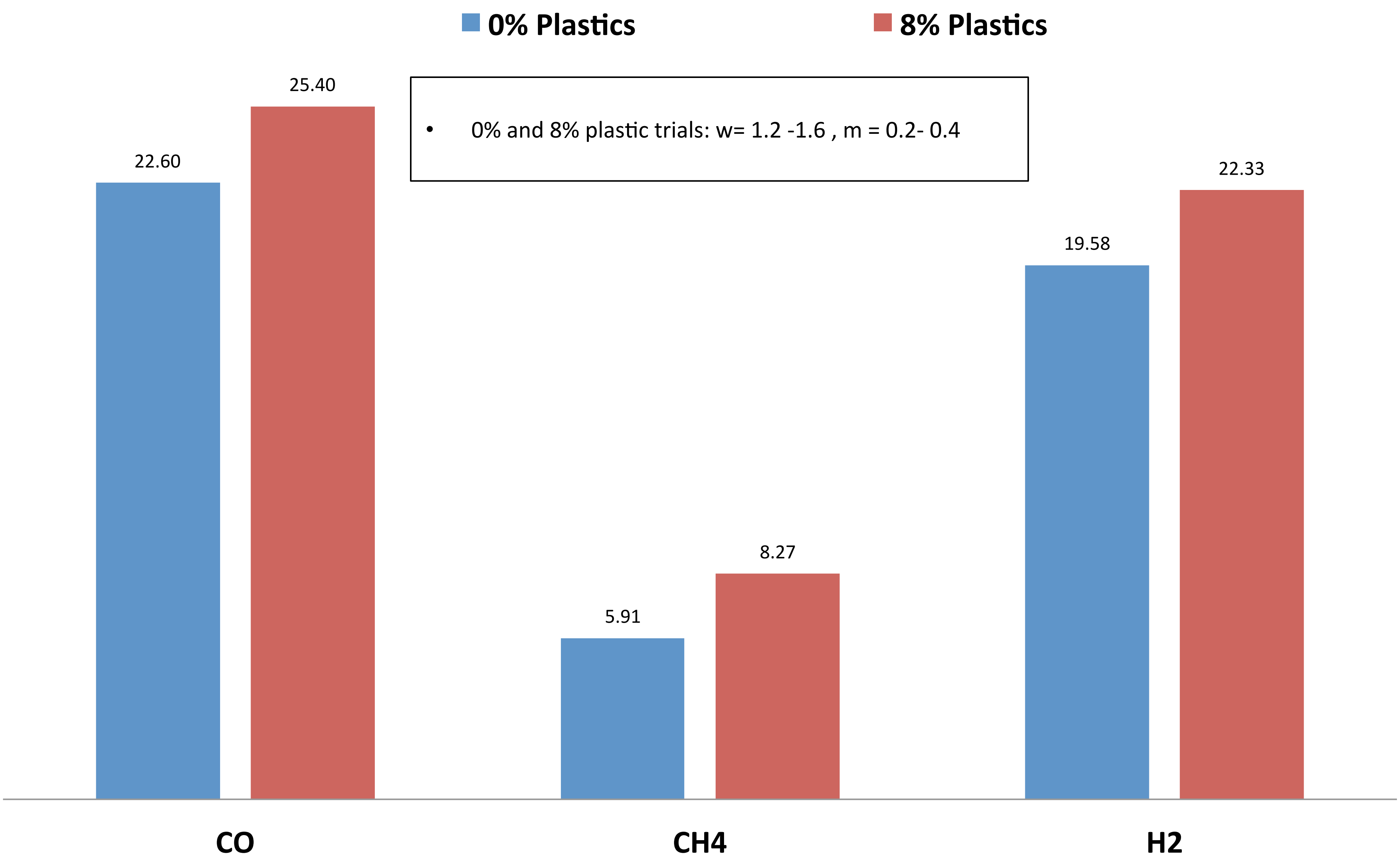


Preliminary results from Pilot Tests

Pilot Test	Plastic Composition (wt%)	H_2 (mol%)	CO (mol%)	CH_4 (mol%)	H2/CO
April 2014	0	19.6	22.6	5.9	0.87
April 2014	8	22.3	25.4	8.3	0.88
September 2014	15	Data analysis in progress			
September 2014	25				
September 2014	50				

- April 2014 pilot study: w= 1.2 -1.6 , m = 0.2- 0.4
- September 2014 pilot study; w= 1.1 – 1.3, m≈ 0.3

Comparison of Syngas Compositions from Pilot Tests



- 0% and 8% plastic trials: w= 1.2 -1.6 , m = 0.2- 0.4

Estimated Methanol Production from Plastic Trials

Plastic Concentration (wt %)	% Increase in Methanol Production Compared to Baseline Feedstock of 0% Plastics	
	Based on Theoretical Syngas	Based on Actual Syngas
0	0	0
8	2.5	16.5
15	16.0	TBA
25	10.0	TBA
50	63.1	TBA

Conclusions

- Increased plastic concentration indicates*:
  - ↑ H_2, CO in syngas
  - ↑ Methanol yield

  **For w = 1.2 to 1.6, m = 0.2 to 0.4*

- Future work includes:
  - Pilot tests with methanol production
  - Complete data analysis of pilot trials
  - Use mass and energy balances to determine impact on efficiencies
  - Economic and environmental assessment

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Questions?

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APPENDIX

Gasification Reactions

$C + 2H_2 = CH_4$	REACTIONS WITH CARBON
$C + H_2O = CO + H_2$	
$C + CO_2 = 2CO$	
$C + O_2 = CO_2$	
$CO + H_2O = CO_2 + H_2$	WATER-GAS SHIFT RXN
$CO + 3H_2 = CH_4 + H_2O$	STEAM REFORMING
$H_2 + CO = C_XH_Y + H_2O$	FISCHER TROPSCH
$CO + 2H_2 = CH_3OH$	METHANOL FORMATION