Thermodynamic analyses of biomass post-firing and co-firing combined cycles

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Outline

1. Introduction and literature review
2. System Description
3. Thermodynamic Modeling
4. Results and Discussions
5. Conclusions

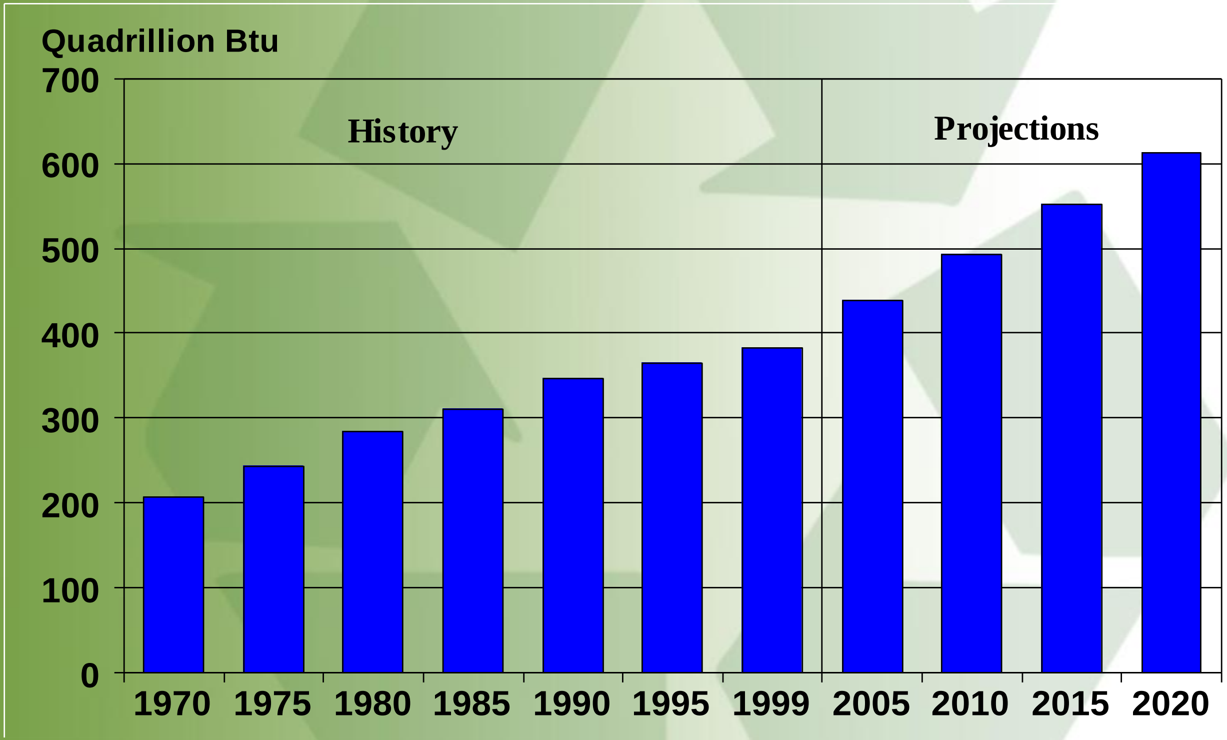
1. Introduction

The possibility / likelihood of global warming is disturbing …

… but there may be a bigger problem!

1. Introduction

Consumption of Energy Increased by 85% Between 1970 and 1999



By 2020, Consumption will Triple

1. Introduction

What is biomass

- Biomass is a renewable energy source that is derived from living or recently living organisms.

- Biomass includes biological material, not organic material like coal.

- Energy derived from biomass is mostly used to generate electricity or to produce heat.

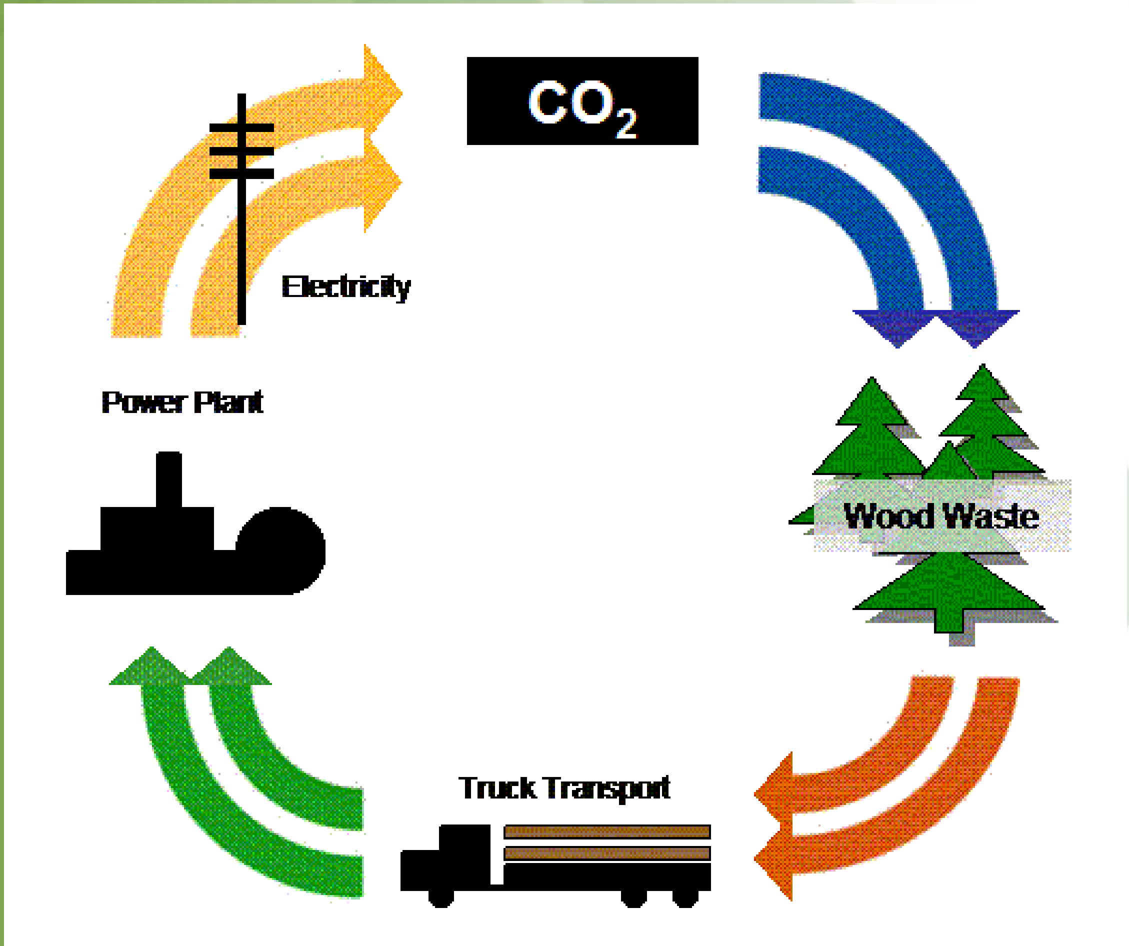
- Biomass can be chemically and biochemically treated to convert it to a energy-rich fuel.

1. Introduction

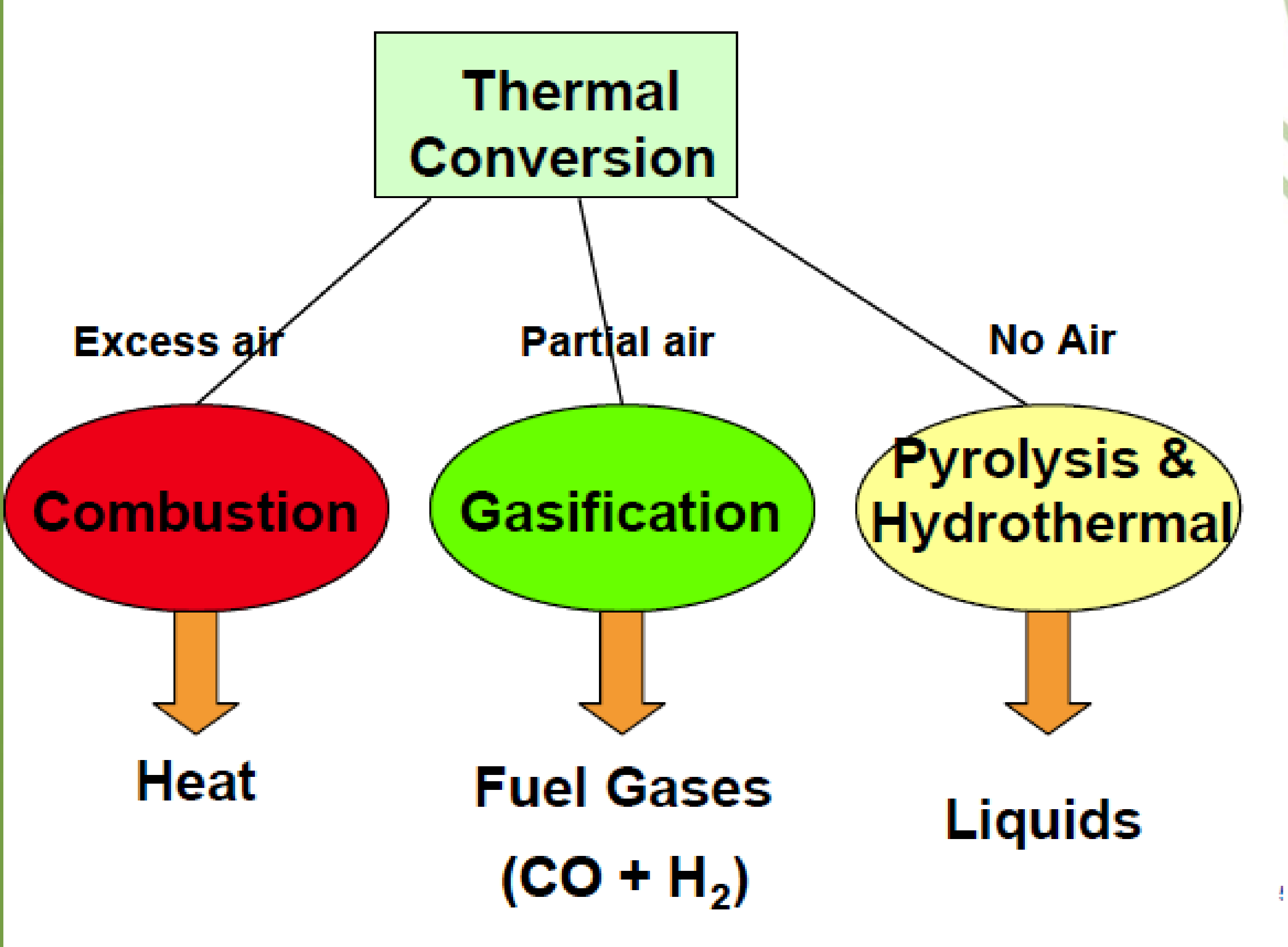
What makes it green (ideally)?

- CO_2 emissions/per energy produced is similar to petroleum.
- However, CO_2 released is recaptured by next years crops. So, there is no net CO_2 added.

1. Introduction



1. Introduction



1. Introduction

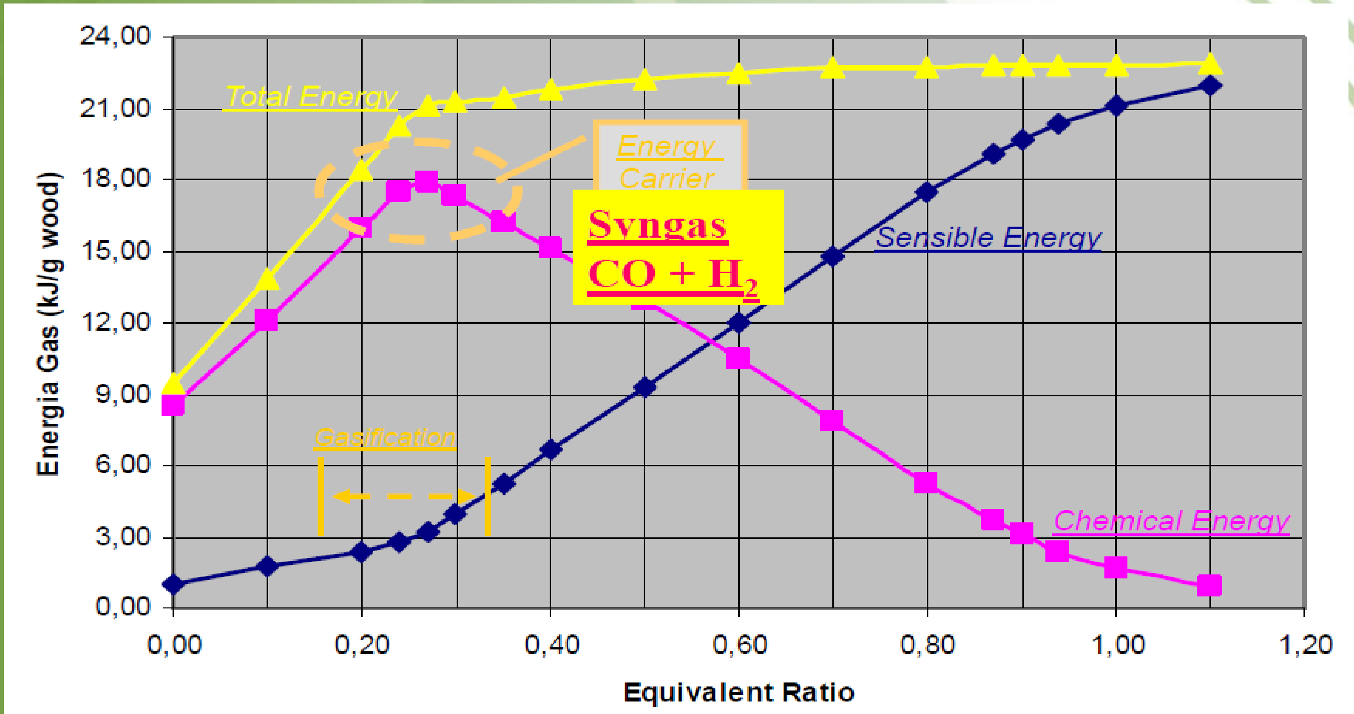
What is Biomass Gasification?

Basic Process Chemistry

- Conversion of solid fuels into combustible gas mixture called producer gas ($CO + H_2 + CH_4$)
- Involves partial combustion of biomass
- Four distinct process in the gasifier viz.
  - Drying
  - Pyrolysis
  - Combustion
  - Reduction

1. Introduction

Why gasification



It maximize the Chemical Energy in the produced gases

1. Literature review

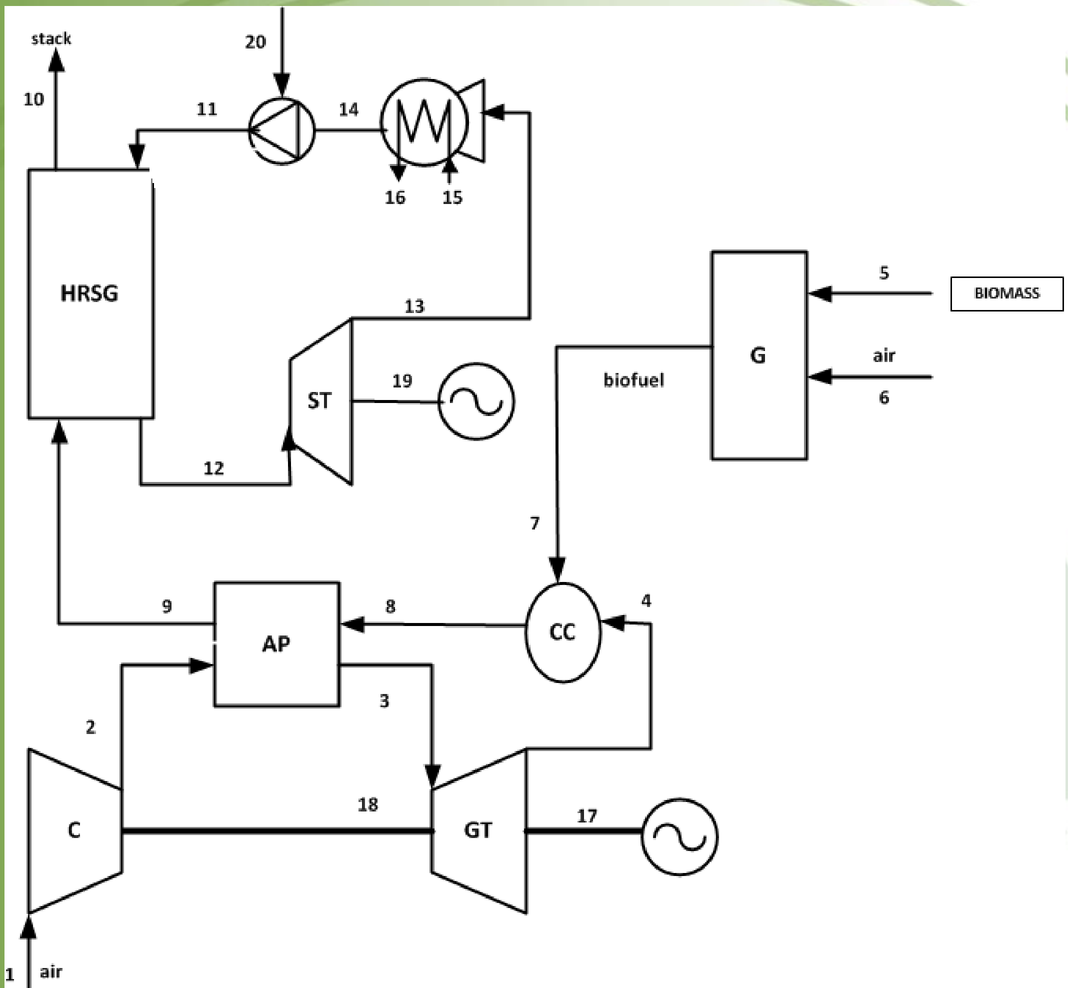
- ✓ Biomass gasification and influence of different gasification parameters on the gasification
- ✓ Thermodynamic analysis of gasification process
- ✓ Power producing systems integrated with gasifiers

1. Literature review

Influential parameters have been investigated:

- ✓ *Humidity of biomass*
- ✓ *Equivalence ratio*
- ✓ *Temperature*
- ✓ *Biomass type*
- ✓ *Biomass size*
- ✓ *Pressure*
- ✓ *Gasification medium*

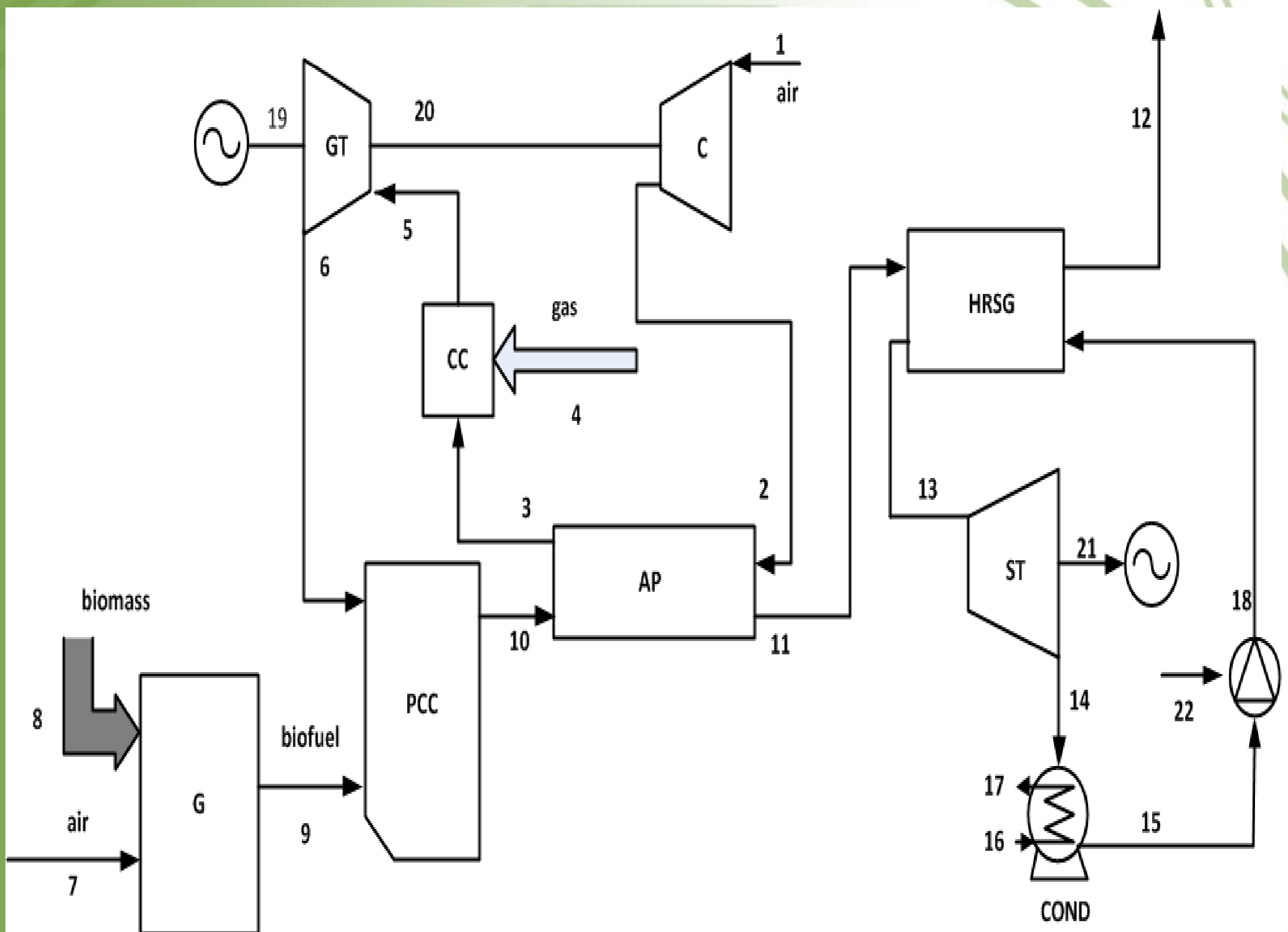
2. System Description



10 MW

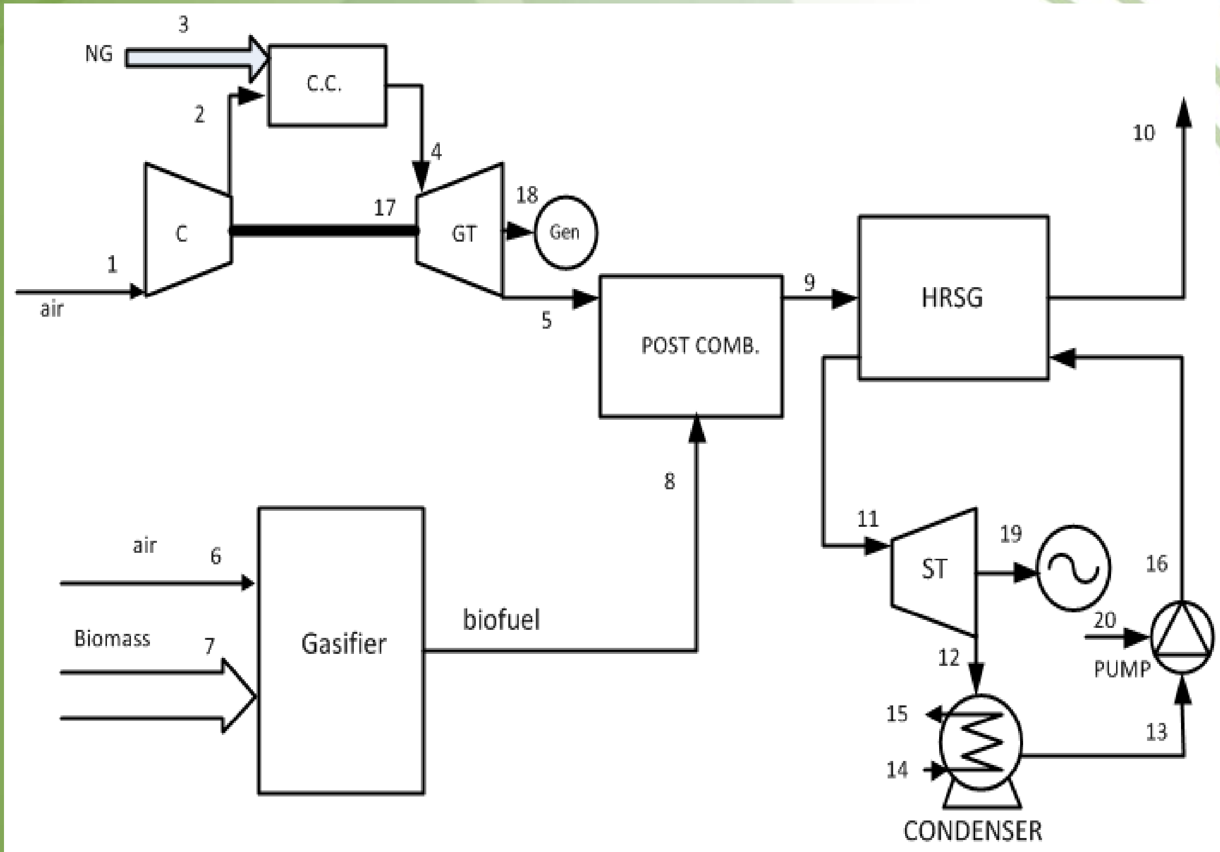
Externally fired combined cycle

2. System Description



10 MW
Biomass integrated co-fired combined cycle

2. System Description



10 MW

Biomass integrated post-firing combined cycle

3. Thermodynamic Modeling

Equilibrium model[1]

$$C + CO_2 \Leftrightarrow 2CO$$

$$C + H_2O \Leftrightarrow CO + H_2$$

$$CO + H_2O \Leftrightarrow CO_2 + H_2 \quad K_2 = \frac{P_{CO_2} P_{H_2}}{P_{CO} P_{H_2O}}$$

$$C + H_2 \Leftrightarrow CH_4 \quad K_1 = \frac{P_{CH_4}}{(P_{H2})^2}$$

K_i: equilibrium constants for methane formation and shift reaction

Global gasification process can be expressed as the global reaction:

$$C_xH_yO_z + w\,H_2O + m\,O_2 + 3.76m\,N_2 = x_1\,H_2 + x_2\,CO + x_3\,CO_2 + x_4\,H_2O + x_5\,CH_4 + 3.76m\,N_2$$

3. Thermodynamic Modeling

Constituent	Present model	Experiment	Zainal equilibrium model
Hydrogen	18.01	15.23	21.06
Carbon monoxide	18.77	23.04	19.61
Methane	0.68	1.58	0.64
Carbon dioxide	13.84	16.42	12.01
Nitrogen	48.7	42.31	46.68
Oxygen	0.00	1.42	0.00

3. Thermodynamic Modeling

Thermodynamics

- The First Law
  - The energy of the universe is constant
- The Second Law
  - The Entropy of the universe is constantly increasing.

3. Thermodynamic Modeling

Energy-based methods are not suitable for answering some questions because the only thermodynamic inefficiencies identified by energy-based methods are the transfer of energy to the environment. However, *the inefficiencies caused by the irreversibilities within the system* being considered are, in general, by far the most important thermodynamic inefficiencies and are identifiable with the aid of an exergetic analysis.

Exergy-based methods reveal the location, the magnitude and the sources of inefficiencies and costs impact and allow us to study the interconnections between them.

3. Thermodynamic Modeling

Exergetic Variables: E_P and E_F

Exergy of product: $\dot{E}_P$

The desired result, expressed in exergy terms, achieved by the system (the *k*-th component) being considered.

Exergy of fuel: $\dot{E}_F$

The exergetic resources expended to generate the exergy of the product.

The concepts of product and fuel are used in a consistent way not only in *exergetic analyses* but also in the *exergoeconomic* and *exergoenvironmental* analyses.

3. Thermodynamic Modeling

Exergetic Variables: E_D and E_L

Exergy destruction: $\dot{E}_D$

Exergy destroyed due to irreversibilities within a system (the k-th component).

Exergy loss: $\dot{E}_L$

Exergy transfer to the system surroundings. This exergy transfer is not further used in the installation being considered or in another one.

Exergy balance:

$$\dot{E}_F = \dot{E}_P + \dot{E}_D \left(+ \dot{E}_L \right)$$

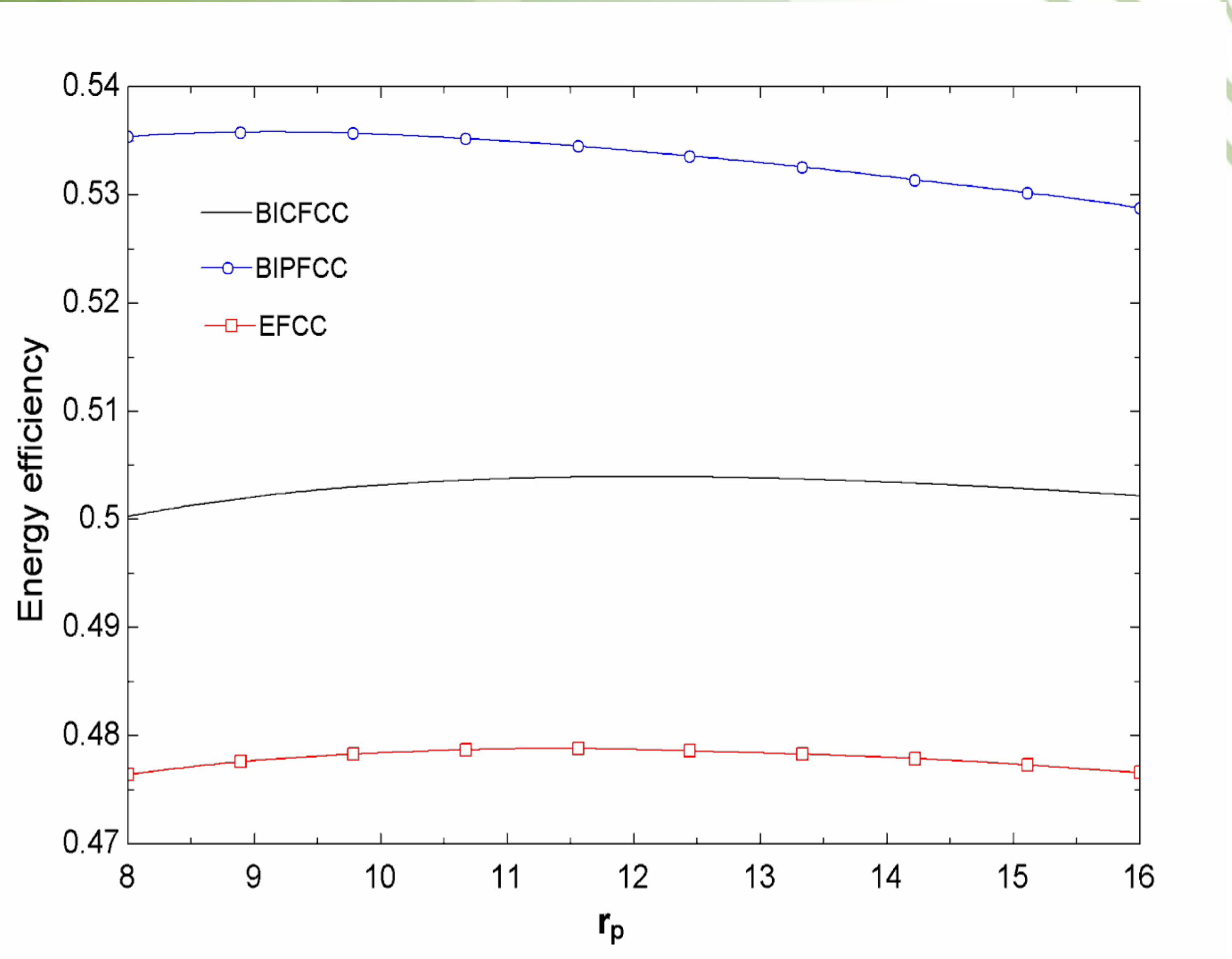
$\dot{E}_D$ and $\dot{E}_L$ are absolute measures of the thermodynamic inefficiencies.

3. Thermodynamic Modeling

$$\eta = \frac{\dot{W}_{net,cycle}}{\dot{m}_{fuel} LHV_{fuel}}$$

$$\varepsilon = \frac{\dot{W}_{net,cycle}}{\dot{E}_{in,cycle}}$$

4. Results and discussions



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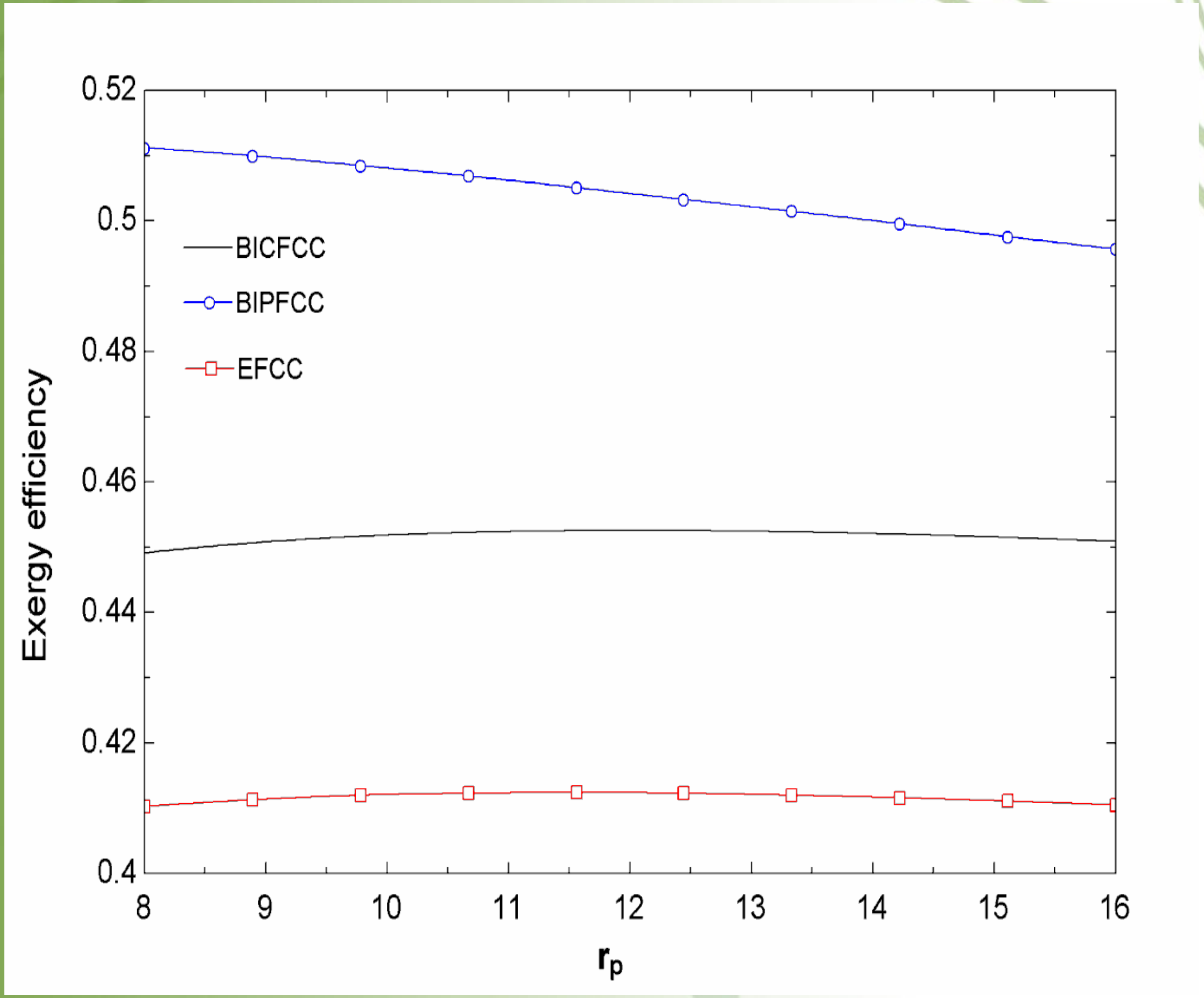

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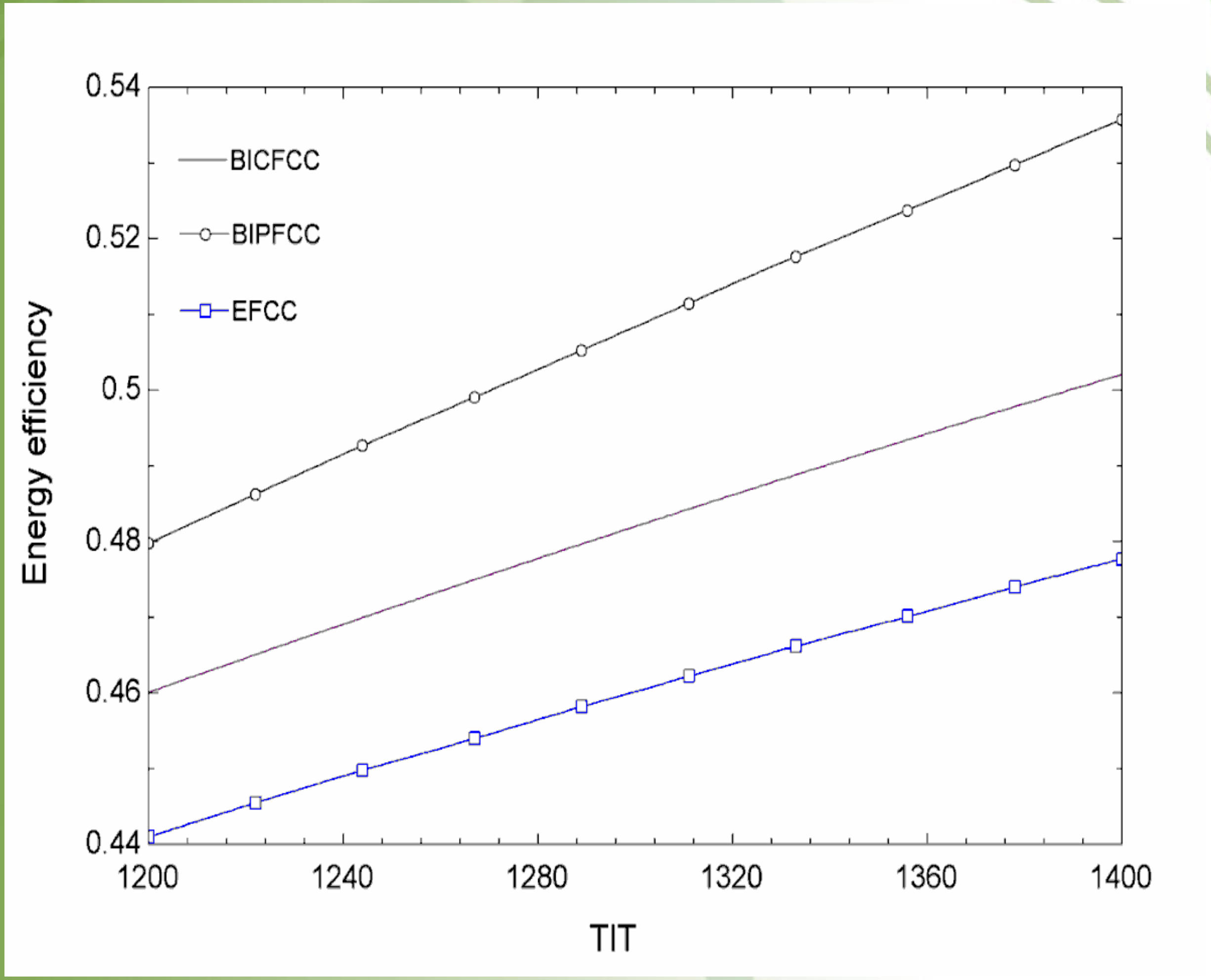

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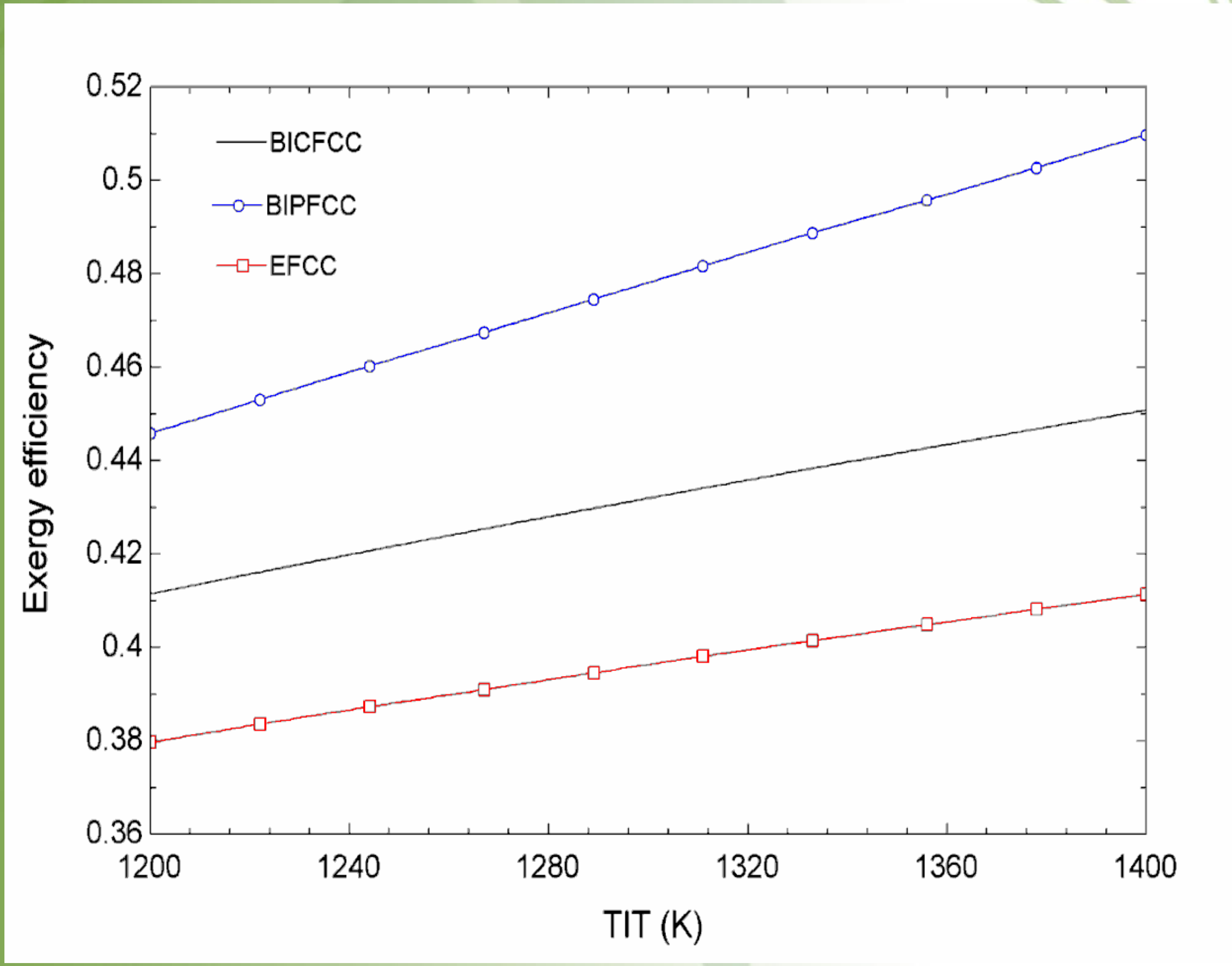

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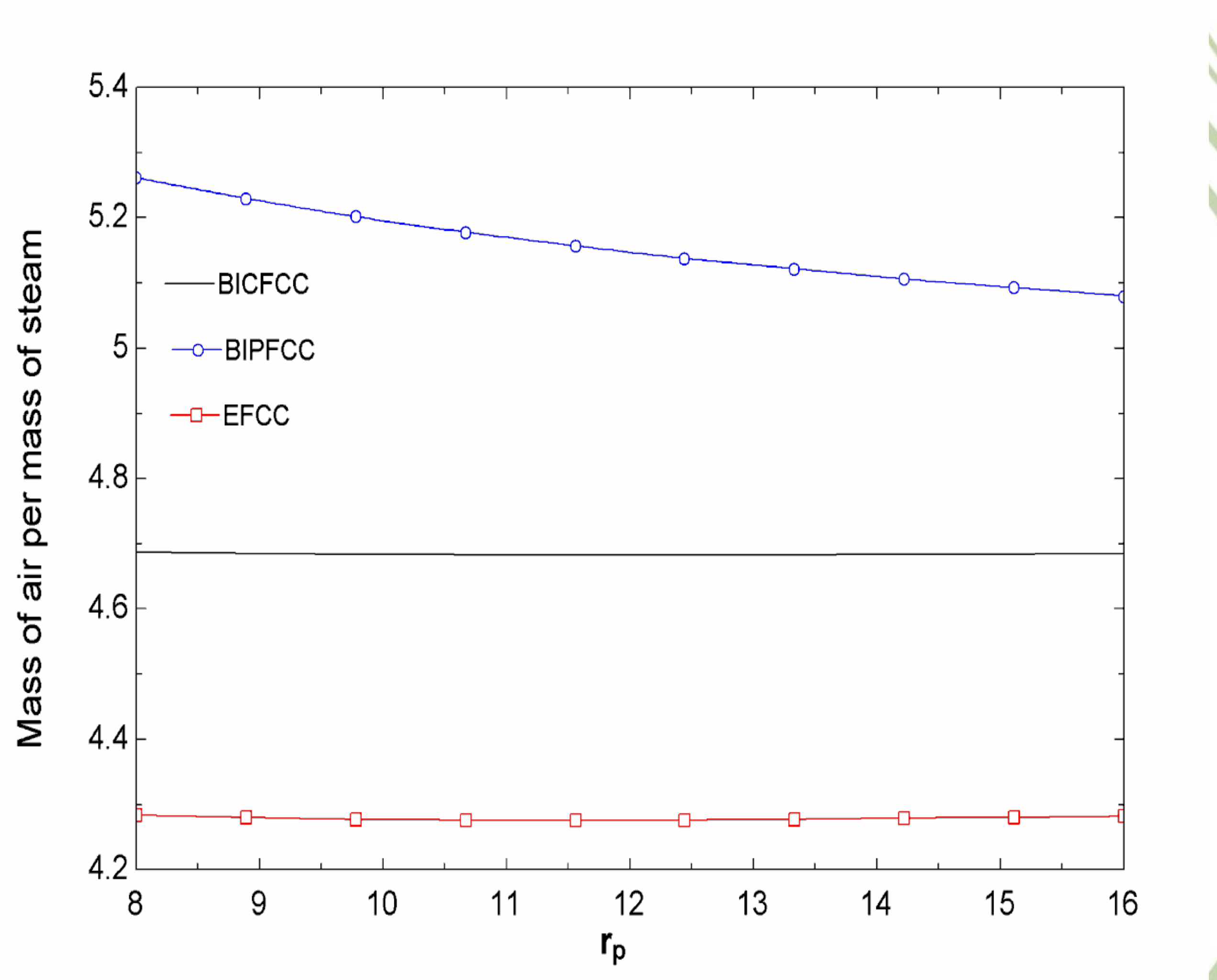

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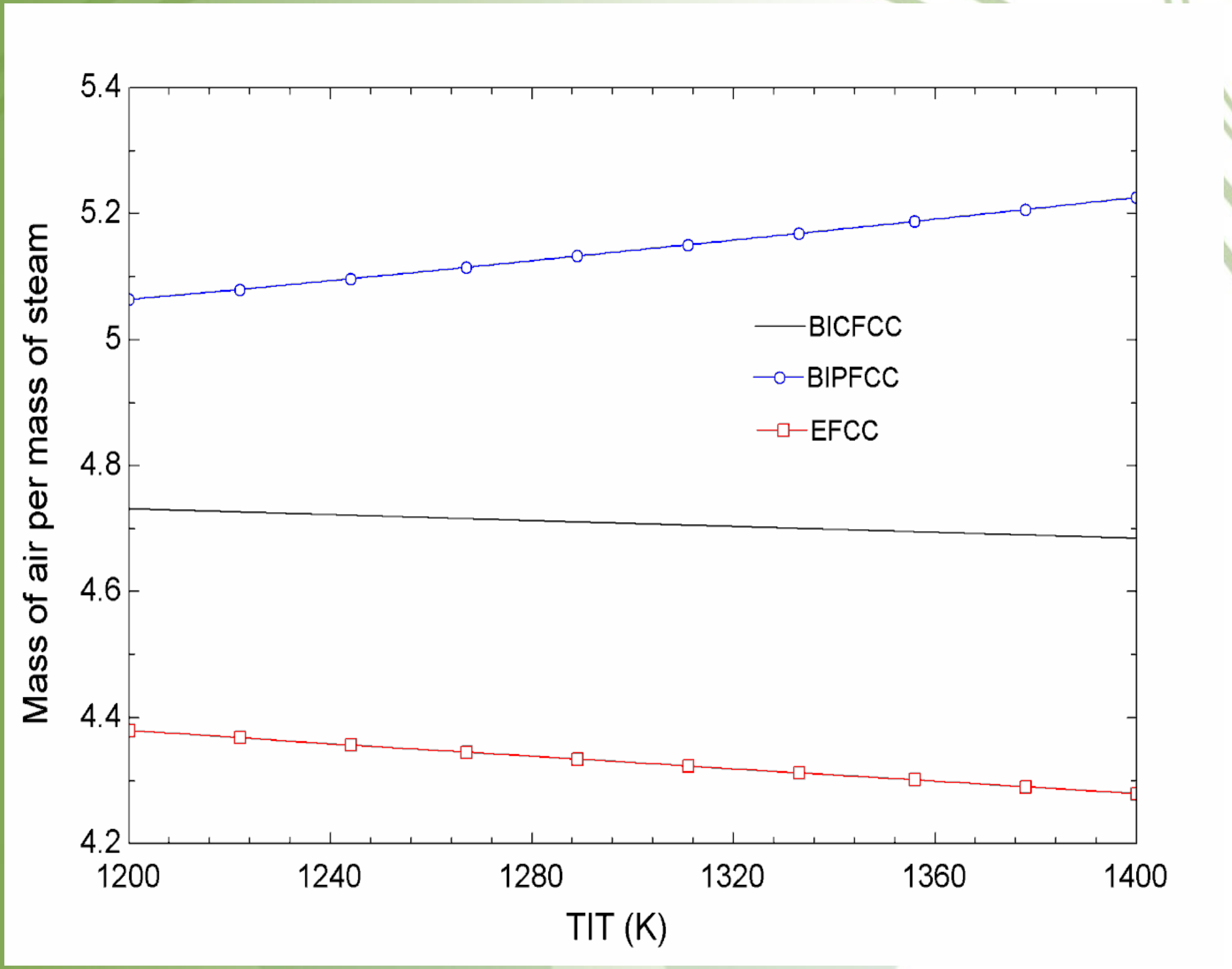
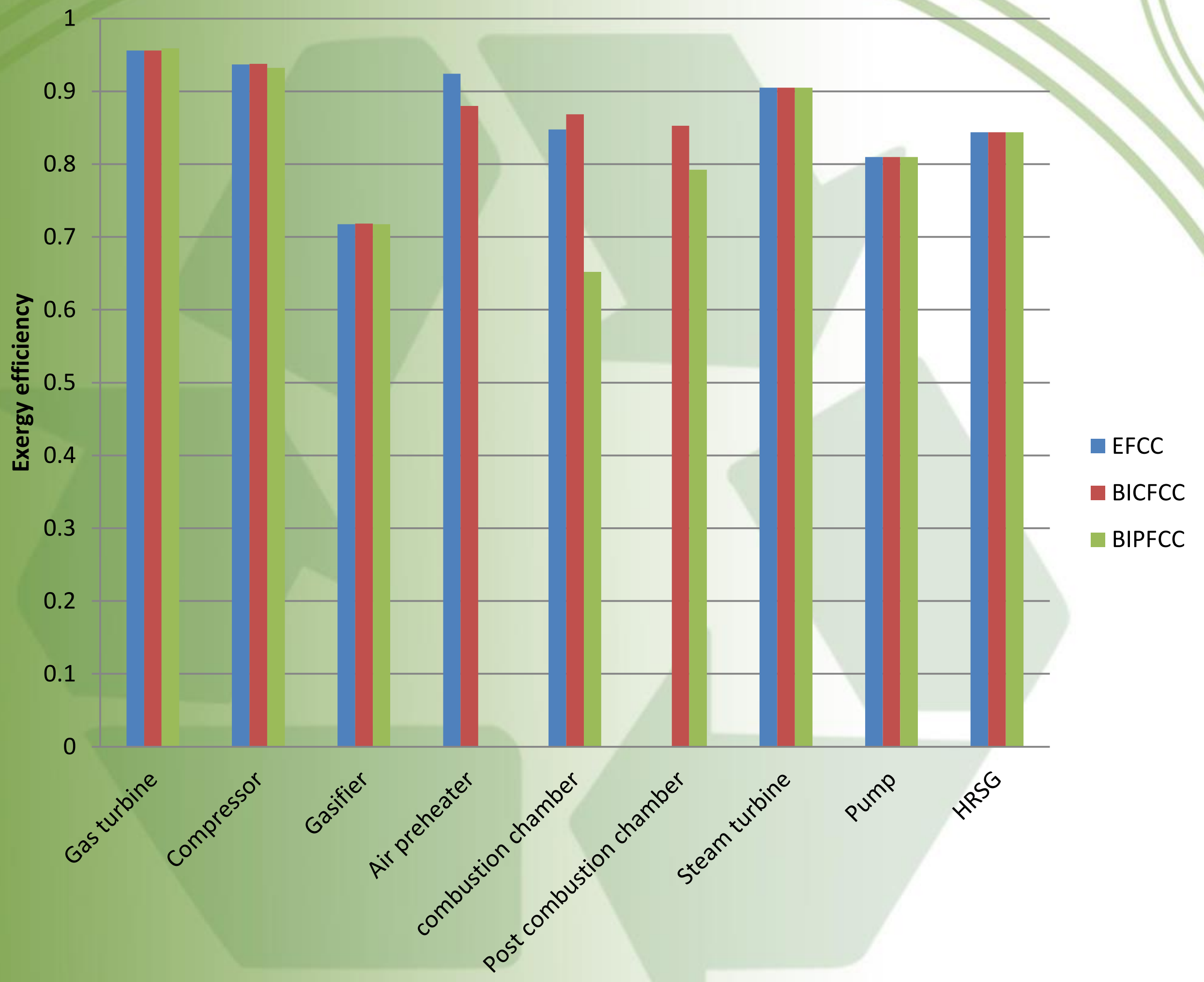


4. Results and discussions



5. Conclusion

- The BIPFCC energy efficiency is about 3% and 6% points higher than those of the BICFCC and EFCC, respectively. Correspondingly, the exergy loss in BIPFCC is lower relative to the BICFCC and EFCC. The energy and exergy efficiencies of the three biomass fired configurations are maximized at particular values of compressor pressure ratio, and increasing the TIT raises the energy and exergy efficiencies for the BIPFCC, EFCC and BICFCC.
- The mass of air per mass of steam is highest for the BIPFCC, but increasing the pressure ratio reduces this value for the BIPFCC and increases it slightly for the BICFCC and EFCC. Increasing TIT raises the mass of air per mass of steam for the BIPFCC and decreases it slightly for the other cycles.

5. Conclusion

- The exergy efficiencies for the components of the three configurations, determined for the maximum energy efficiency condition, indicate that the gas turbine exergy efficiency is the highest for three configurations, the BIPFCC exhibits the highest gas turbine exergy efficiency, the BICFCC combustion chamber has the highest exergy efficiency, and the lowest exergy efficiency is for the BIPFCC. The post combustion chamber of the BICFCC exhibits the highest exergy efficiency, while the heat exchanger exergy efficiency is highest for the EFCC.

5. Conclusion

The efficiencies of biomass plants are comparatively low, but their availability, renewability and environmental characteristics can justify their use. The results may prove beneficial for designers and engineers of such systems.

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Many thanks for your attention

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