Prediction of gas composition in biomass gasifiers

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Content

1. Motivation and objective
2. Background: Existing evidence in gasification
3. Modelling
4. Experiments and application
5. Conclusions

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1. **Motivation and objective**
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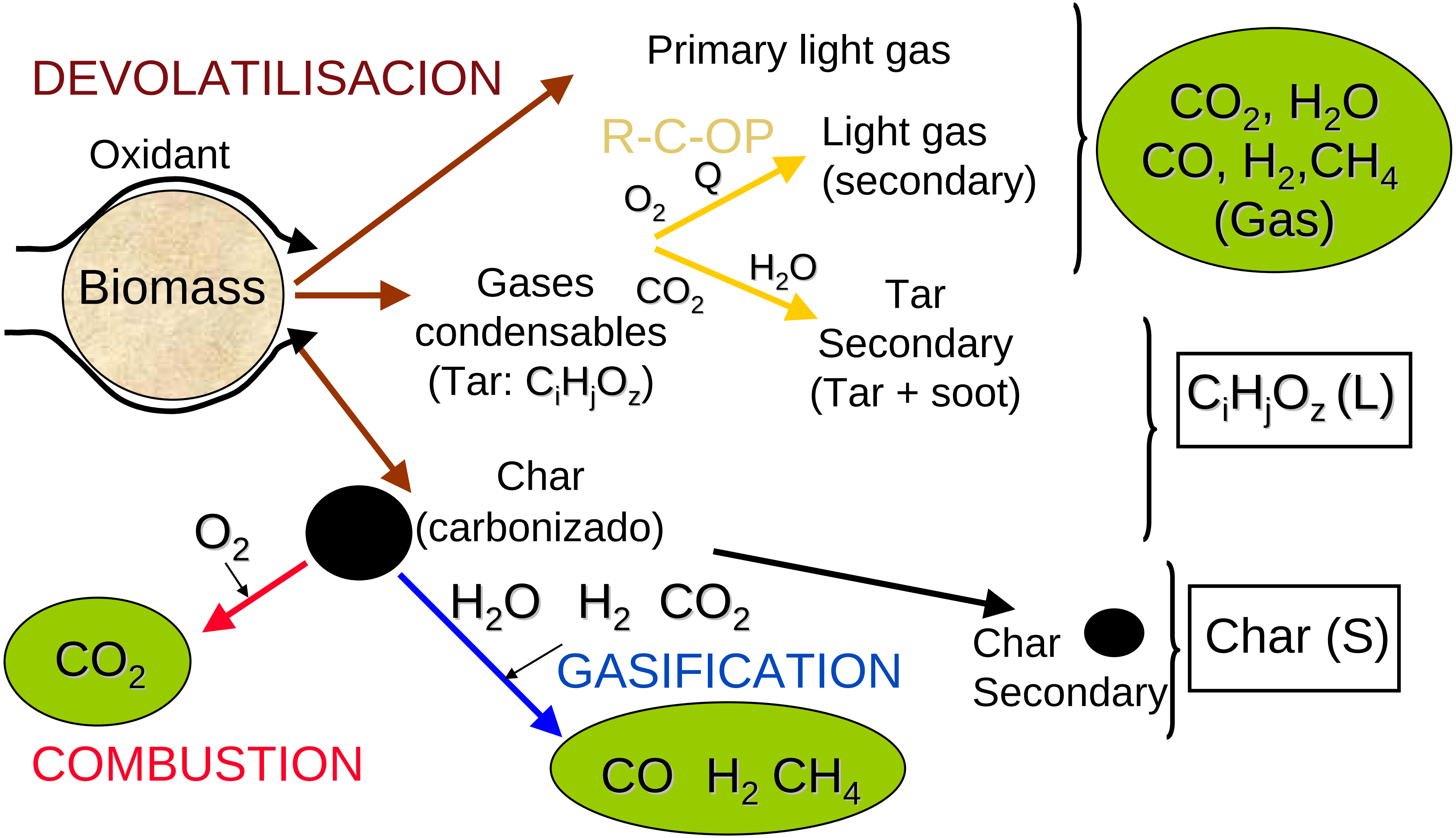
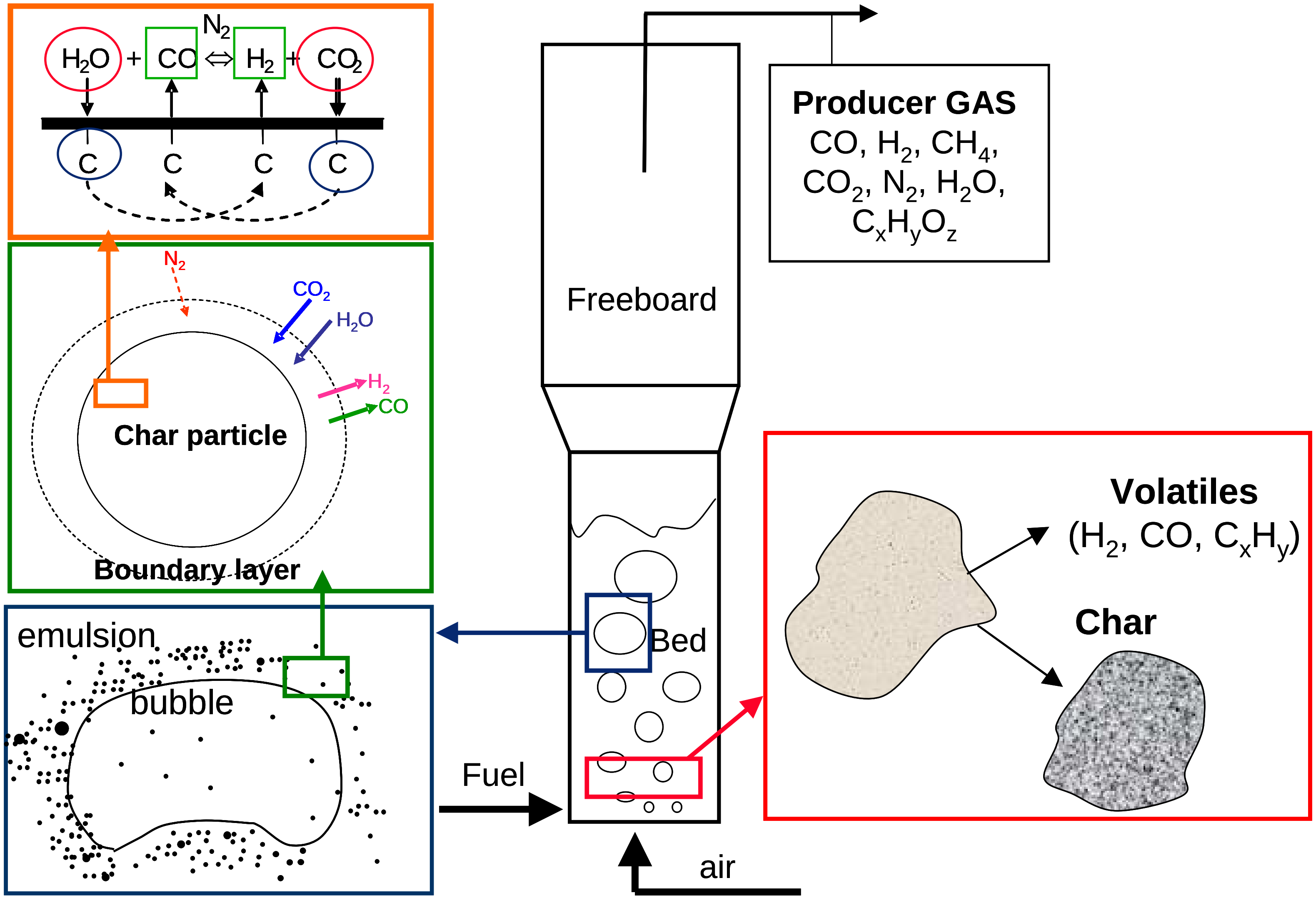
Motivation for a new method

- In the preliminary design of a FBG, the knowledge of the main components of the gas produced in the gasifier is a key factor
- Advanced models for FBG exist but require physical and kinetic inputs difficult to estimate and sometimes are not available to industrial applications
- Simple and reliable semi-empirical methods to predict gas composition and reactor performance are not common in literature, and there is a need for such modelling tools

Difficulty in modelling
(complex Chemestry and transport phenomena at particle level)



Difficulty in modelling
(complex flow pattern and transport phenomena at reactor level)



Past trials for simple modelling of FBG

- Equilibrium models (EM)
- Quasi-Equilibrium models (QEM)
- Empirical models

Equilibrium models (EM)

Advantages

– Simple to apply

– Independent of gasifier design

– Widely used

Failures

– Overestimates yields of H_2 and CO

– Underestimates the yield of CO_2

– Prediction of gas nearly free of CH_4 and tar

– No char in the gas phase over 1000 K

Quasi-Equilibrium models (QEM) (Gumz, 1950)

Advantages

- Improvement of EM
- Simple to apply

Failures

- Need correlations
- Dependent of gasifier design
- Most cases do not predict tar and/or char
- Sometimes recommendations can avoid correlation but this make QEM non-predictive

Empirical models

Advantages

- Simple to apply
- The best predictions

Failures

- Needs a lot of experimental data
- Only valid for a given facility and biomass

Example

- Maniatis et al (1994) ➔ Correlations based on one parameter (ER)

Objective

To develop a model (method):

- Based on QEM (simple)
- With predictive capability
- Free from correlations
- Able to estimate tar and char
- Based on established evidences

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Existing evidence for corrections

- **Heterogeneous or homogeneous equilibrium?**
  - In EM no solid carbon in the gas phase over 1000 K

- **Steam Reforming of Methane (SRM) in equilibrium?**
  - Steam reforming of methane is kinetically limited below 1300 K
  - methane in the exit stream of the gasifier ~ that formed in devolatilisation

Existing evidence for corrections

- **Water Gas Shift Reaction (WGSR) in equilibrium?**
  - Equilibrium for the WGSR reached at 1273 K and residence time about 1 s
  - Between 1073 K and 1273 K the attainment of equilibrium has to be confirmed
  - This confirmation depends on the use of catalysts and steam presence:
    - Synthetic (Ni) vs. minerals (dolomite, olivine, etc) catalyst
    - Steam vs. air gasification

Conclusions from the existing evidence for the model

- Homogeneous equilibrium is enough for practical applications
- Modified equilibrium based on WGSR and SRM is convenient
- Kinetic rates of SMR should be included in the model
- CH_4 in the exit is nearly that formed during devolatilisation (air gasification without catalyst)
- Equilibrium of WGSR is nearly attained: an approach to equilibrium method based on T, t_{res}, type of catalyst and the presence of steam seems to be convenient

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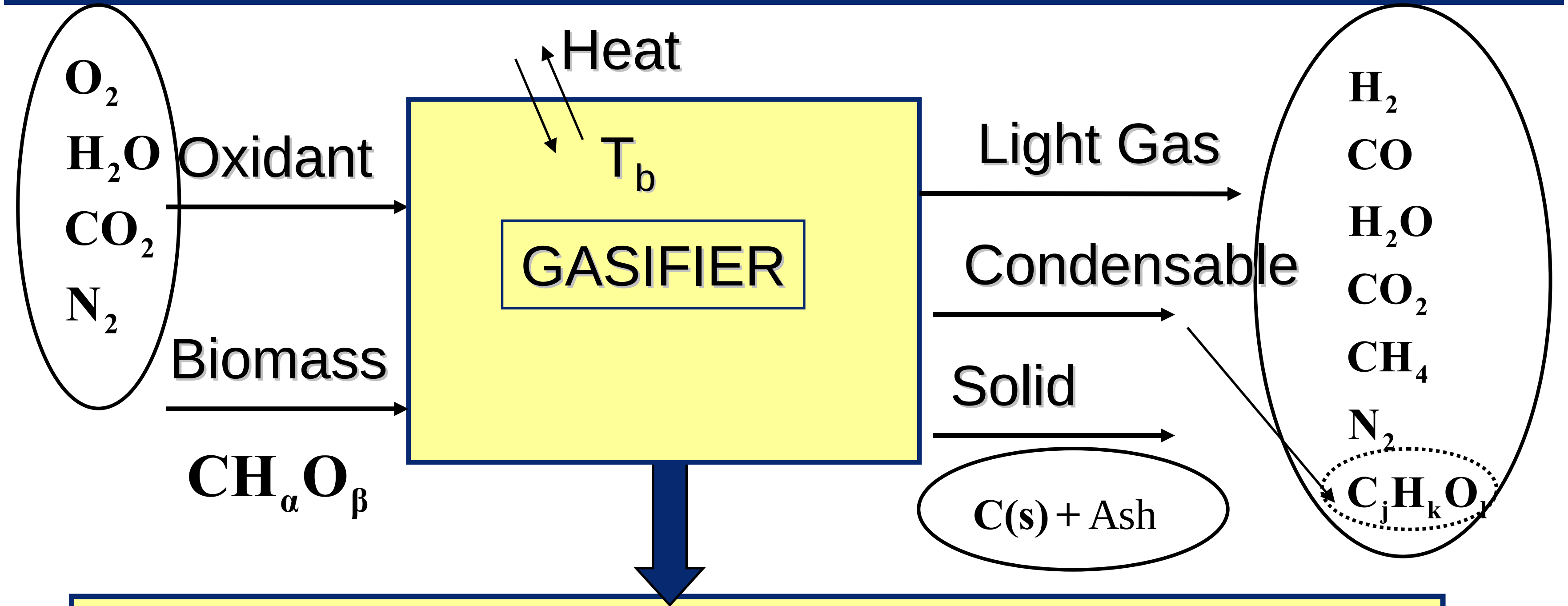
Aim: Overall model



$$CH_{\alpha}O_{\beta} + a\,O_2 + b\,H_2O + c\,CO_2 + d\,N_2 \rightarrow$$

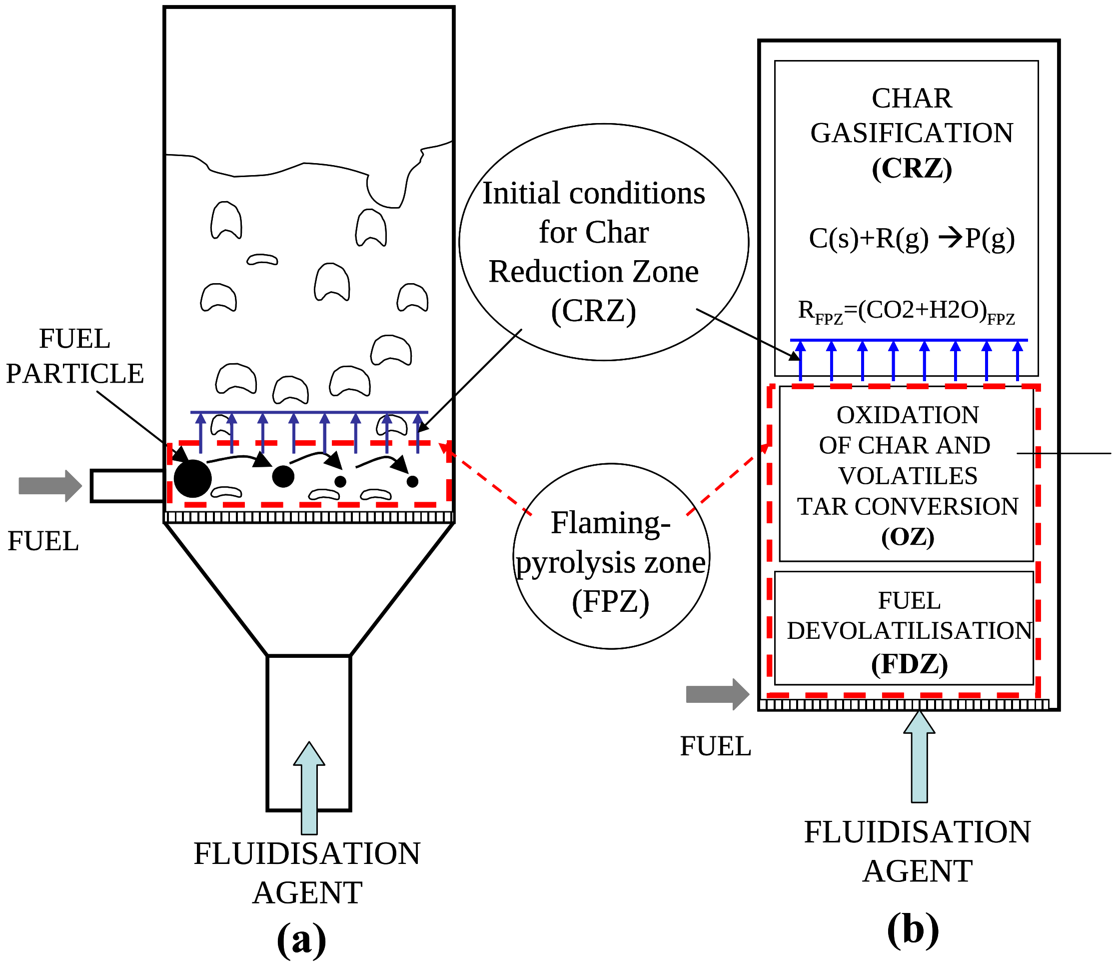
$$x_1\,C(s) + \text{ash (Solid)}$$

$$+x_2H_2 + x_3CO + x_4H_2O + x_5CO_2 + x_6CH_4 + x_7N_2 \quad \text{(Gas)}$$

$$x_8C_jH_kO_l\,\text{(Gas condensable)}$$

Simplified model of a FB gasifier (N_{seg}>>1)

N_{seg} = segregation time / devolatilisation time



Steps in modelling

1. Estimation yields of light gases, char and tar from FPZ (CH_4, tar and char are estimated as function of T)
2. Estimation tar, methane and char conversion in CRZ by application simple kinetic models
3. QE model:

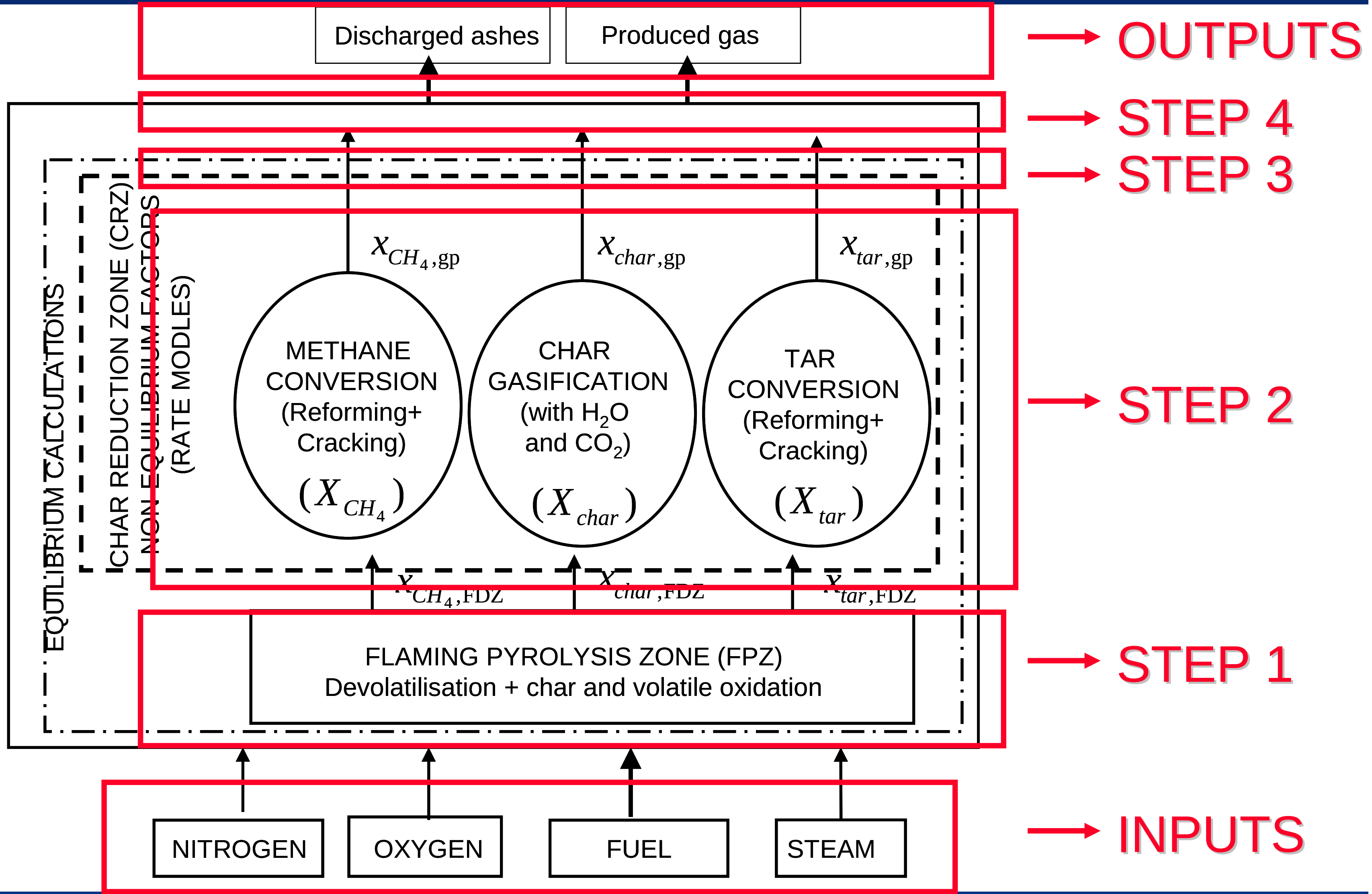
   - Unconverted CH_4, tar and char are removed from this analysis formulation of C-H_2-O_2-N_2 mass balances

   - Mass balances with corrected C-H-O inputs

   - two equilibrium (or approach to equilibrium) relationships (WGSR and SRMR)
4. Restoration of unconverted CH_4, tar and char

   Application of heat balance over the corrected exit streams

Model concept adopted



Char conversion sub-model

- Based on a recent simple method for non-catalytic gas-solid reactions for one reaction

- Reaction: Char + R → P,

  being R = H_2O + CO_2 and P = H_2 + CO

- Population balance and any kinetic models with any structural behavior and n^{th} order kinetics respect to R is solved in one-envelope calculation

Tar and CH_4 conversion sub-model

- Calculated by single-flow kinetic models (CSTR, PFR)
  - Initial conditions established by solution of FPZ

- Adequate selection of tar and methane model could be challenge:
  - Tar: mainly depends on the biomass nature, operating conditions (T, t), presence of catalyst
  - Methane: The use of catalyst and the presence of steam

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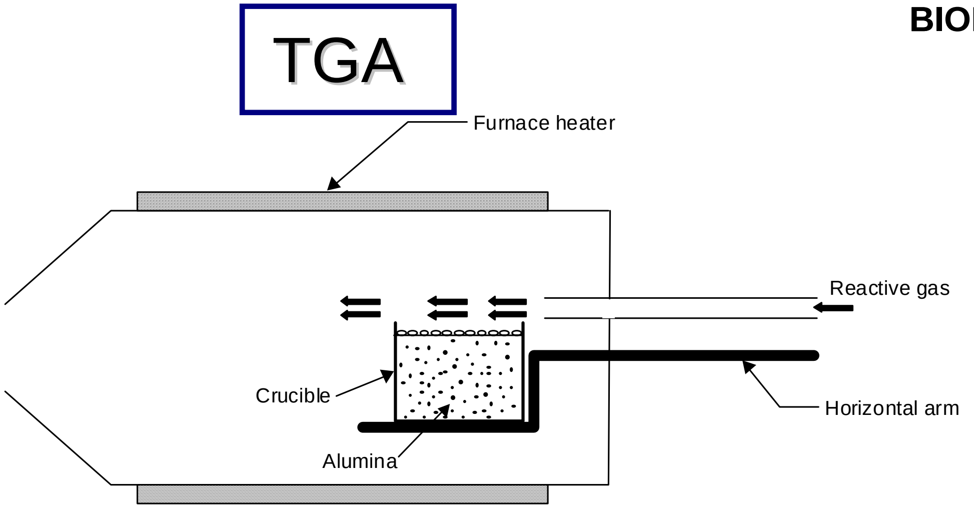
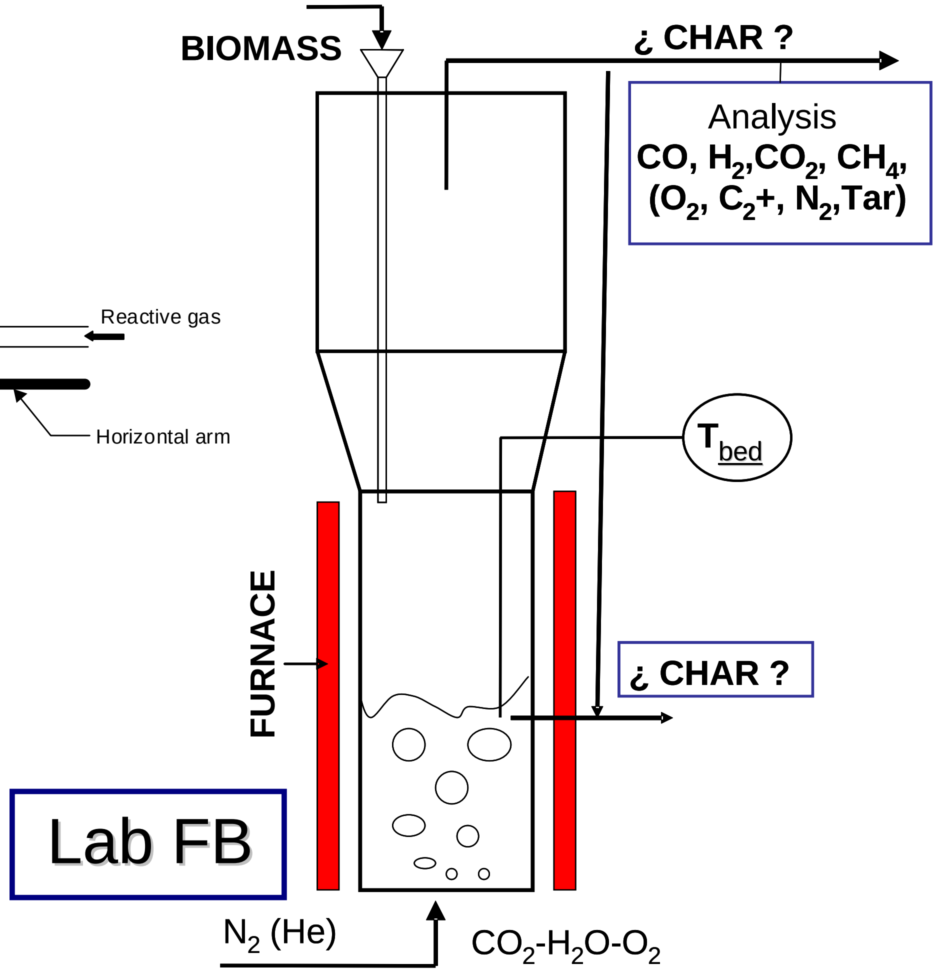
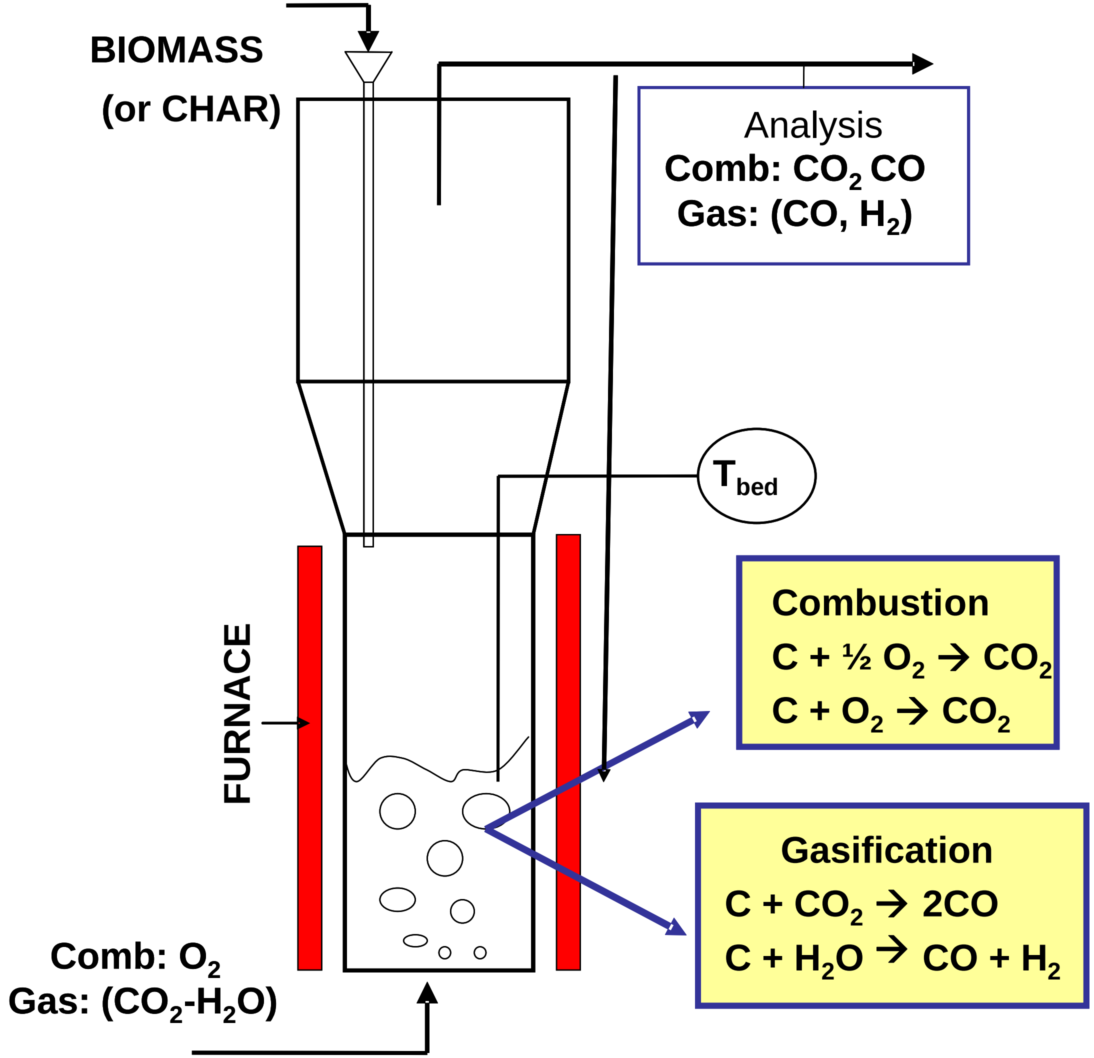
10 kW$_{th}$ Lab and pilot scale experiments

Devolatilisation studies





Char reactivity studies



150 kW$_{th}$ pilot scale experiments

Scaling-up

3 MW_{th} BFB Gasifier

Applications

- Optimisation for gasification with wood and orujillo at 150 kW_{th} pilot scale
- Test programme for the 3 MW_{th} BFB gasifier
- Preliminary design of BFB gasifier for processing MBM
- The tool developed improves significantly the capability of equilibrium

Validation: Gasification of wood pellets at 150 kW_{th} pilot gasifier (ER=0.28)

	Units	This method	Equilibrium	Pilot results
CO	% vv	15.0	24.5	14.3
CO_2	% vv	17.2	7.1	18.5
H_2	% vv	12.5	25.5	11.9
H_2O	% vv	12.5	5.5	11
CH_4	% vv	4.5	0.0	5.1
N_2	% vv	51	40	52
$C_kH_lO_m$ (tar)	g/Nm^3	12	0.0	12.5
$F_{gp,d}$ (Gas yield)	mole gas/kg fuel daf	2.1	2.4	2.1
$x_{C,ash}$	kg_C/kg_{da}	0.32	–	0.28
CC (tar included)	%	91.5	100	92.5

Summary and Conclusions

1. The development of a model based on QEA with predictive capability and easy to apply
2. Used as tool for design and optimisation: improves significantly equilibrium predictions
3. Valid for preliminary design
4. Yields of char, methane and tar during devolatilisation steps need to be estimated
5. Proper selection of kinetic parameters for tar and CH_4 may be critical

Thank you for your kind attention