THE MICRO TURBINE RENEWABLE ENERGY COMBUSTOR (MITREC[1]): CHALLENGES IN DESIGN AND MODELLING OF A BIOGAS COMBUSTOR IN A MICRO TURBINE GENERATOR (MTG)

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2nd EUROPEAN MICRO GAS TURBINE FORUM
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[1] MiTREC project (2017-2019) has been funded by Innovate UK under the Energy Catalyst Round 4 call, Mid-Stage Technology Development

About me …

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Prof Hamidreza Gohari Darabkhani

- Professor of Low Carbon & Renewable Energy Systems
- 18 years of Industrial/Academic Experience
- University Project PI in the Innovate UK funded project (MiTREC, total £1.2m)
- MSc Scheme Award Leader in Engineering
- Module Leader in a dual MSc course "Sustainable Smart Cities" with the University of Alabama in the US
- UG & PG studies in Mechanical Engineering (Thermo-fluids & Energy Conversion Systems), PhD from The University of Manchester, UK
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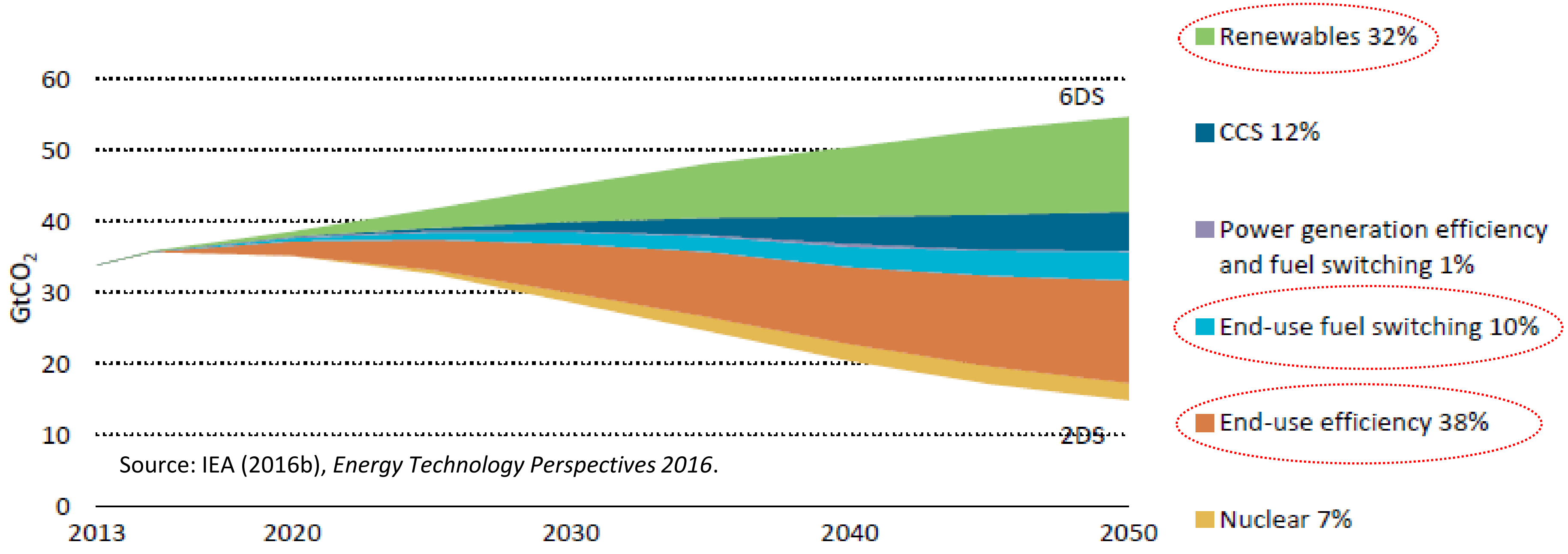
Outline of presentation

- Key contributors to global CO_2 emissions reductions
- Decentralised Micro combined heat and power (m-CHP) systems
- Biogas as a renewable fuel
- Pros and cons of burning Biogas fuels in MT
- Micro combustor design procedure for biogas
- CFD analysis of the micro combustor and comparison with two conventional fuels
- Resolving the biogas issues with combustor design optimisation
- Eco-exo-energy analysis of the combustor in a standard Bryton cycle
- Concluding remarks on biogas fuels and it operability in MT

Key contributors to global emissions reductions

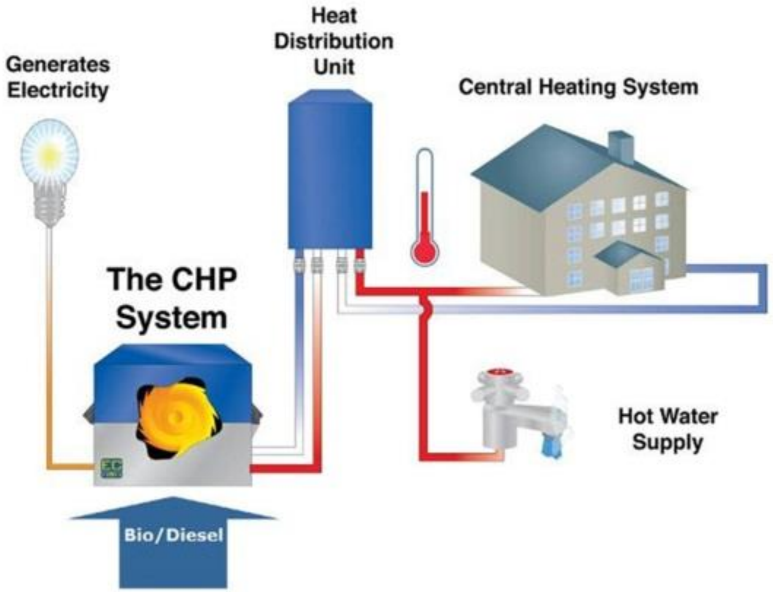
- In the International Energy Agency (IEA) 2°C scenario (2DS), 94 $GtCO_2$ is captured and stored between 2013 and 2050.
- The power sector accounts for the majority of CO2 captured, at 52 GtCO2 or 55% of the total CO2 captured through 2050 in the 2DS.
- There are increased roles for Renewables + End-use fuel switching and End-use efficiency
- Almost 14 Gt of this is “negative emissions” from bioenergy with CCS (BECCS) which act to compensate for emissions elsewhere in the energy system.

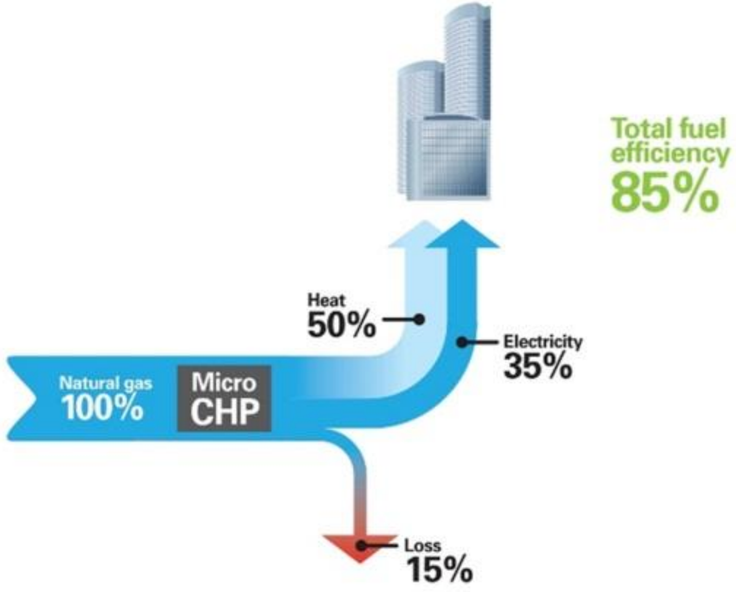


CCS is a key contributor to global emissions reductions

Decentralised Combined Heat and Power (CHP) Systems

Cogeneration (CHP) is a well-proven technology, recognised worldwide as a cleaner alternative to traditional centralised generation. Its long-term future in the global energy markets is secured by CHP's ability to provide a multitude of financial, operational, environmental and legislative benefits from a single unit of fuel.



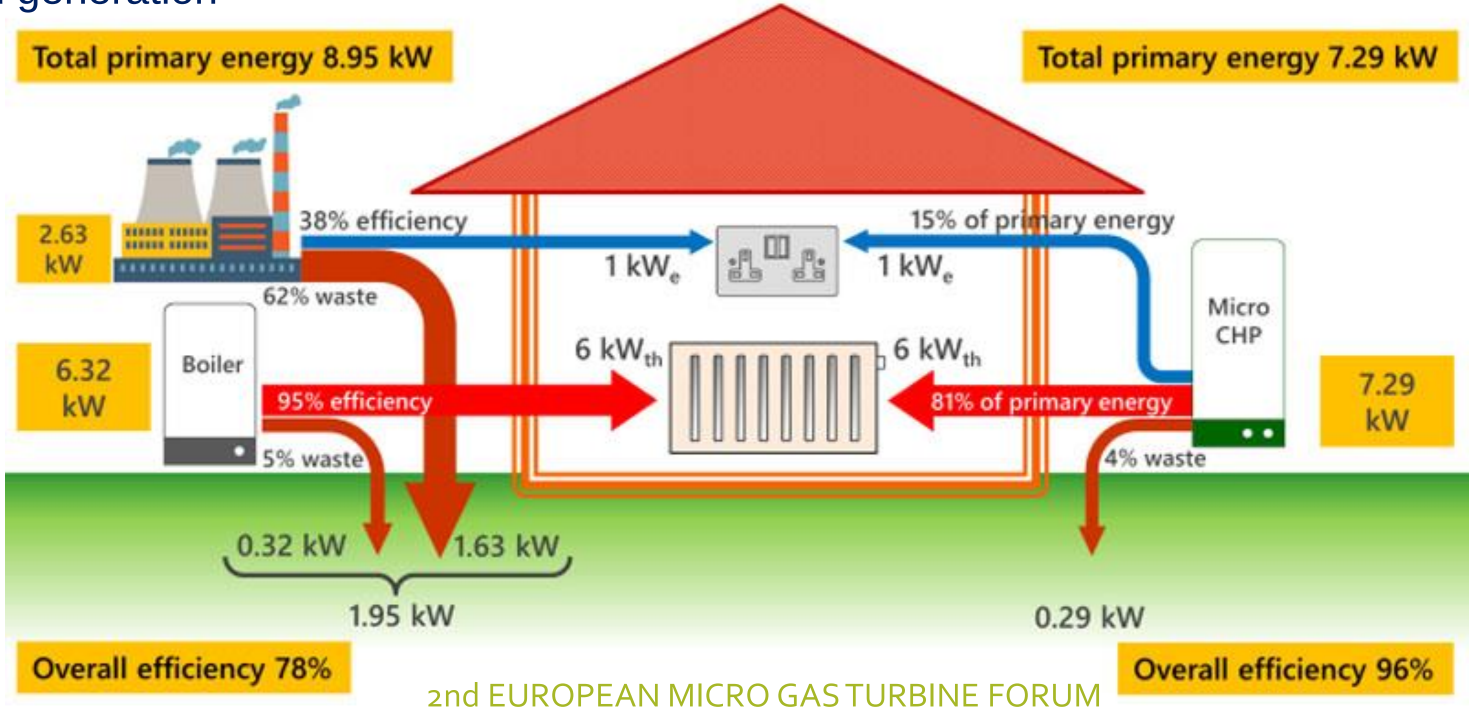


Combined Heat & Power (CHP) system
(A. Moghaddam - 2012)

Micro-CHP Systems for Smart Building

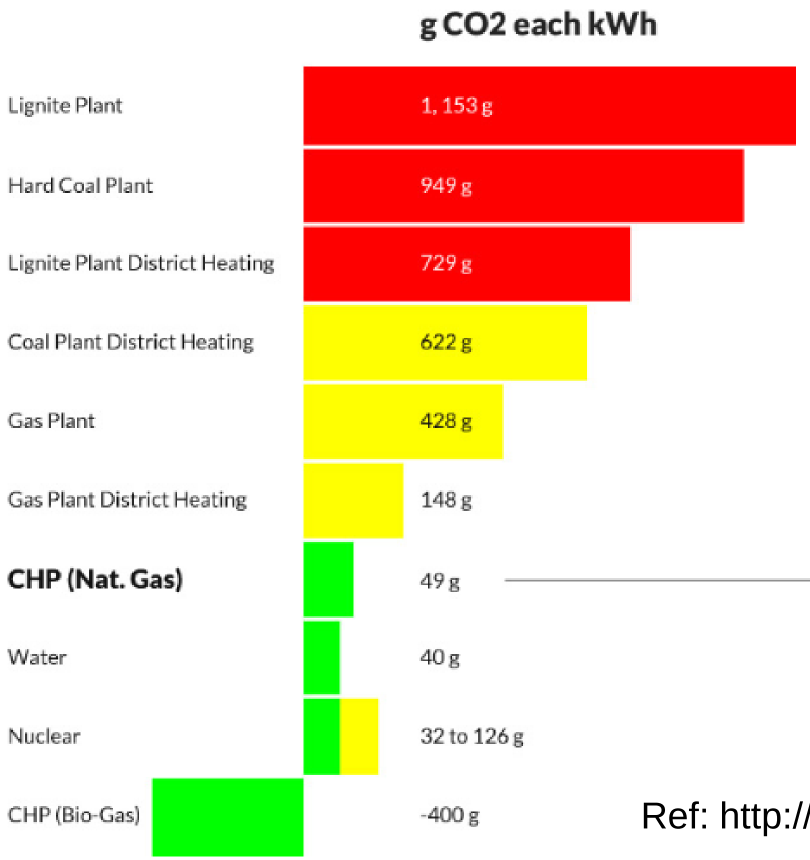
Micro combined heat and power (micro-CHP or mCHP) is a technology which:

- generates heat and electricity simultaneously (< 50 kWe),
- from the same energy source,
- in individual homes or buildings,
- the main output is heat, with some electricity generation as by-product,
- typical ratio of heat to electricity is about 6:1 for domestic appliances
- At least 20% higher efficiency (in cogeneration) by avoiding the transmission losses compared to centralised generation



Greenhouse Gas Emissions & Generation Options

Micro-CHP makes an active contribution to environmental protection, as its excellent efficiency not only results in lower energy costs, it also preserves fossil fuel resources and, at the same time, significantly reduces CO_2 emissions.



Ref: http://www.ecpowermchp.com/why-chp.php

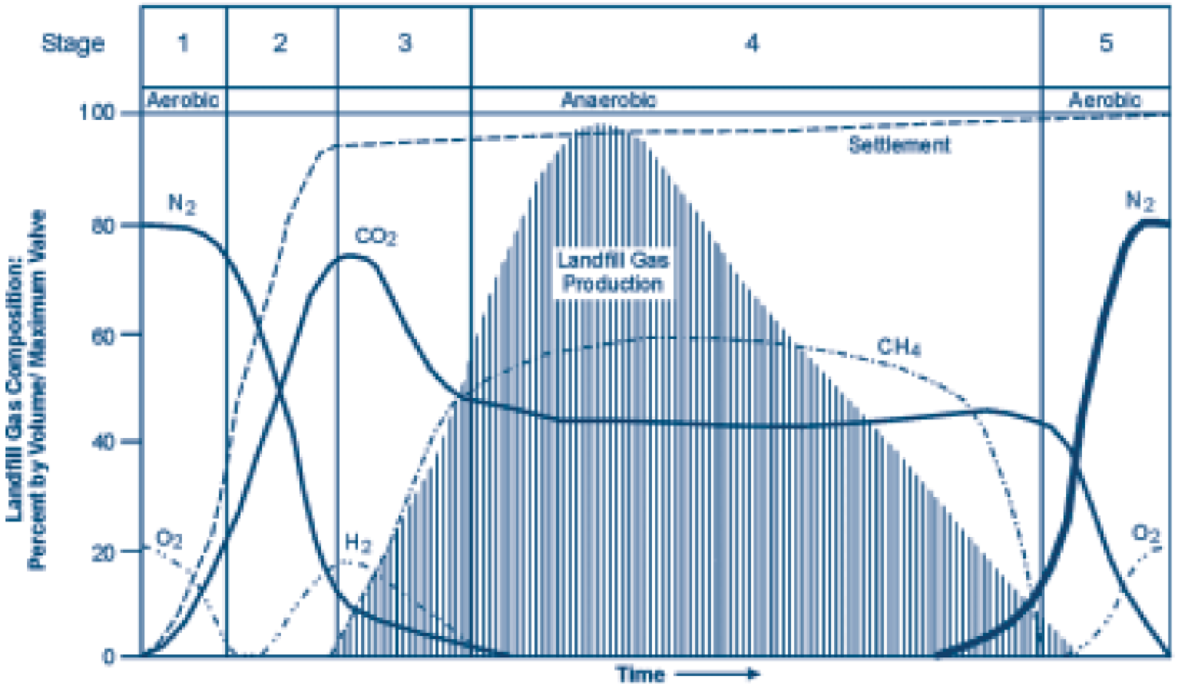
MiTREC Project (2017-2019)

- ✓ The Micro Turbine Renewable Energy Combustor (MiTREC) project has recently been funded a total budget of £1.2m by Innovate UK under the Energy Catalyst Round 4, Mid-Stage Technology Development call.
- ✓ The project consortium will develop a micro-turbine generator (MTG) powered by renewable biogas fuel based on an existing Bladon MT recuperated micro-turbine generator architecture
- ✓ Staffordshire University is responsible for the design of this micro-combustor to develop this unit renewable MTG system for the first time in the energy market.

Biogas as a fuel

Biogas is mainly produced from breakdown of organic matters in absence of oxygen.

- ✓ **Feedstocks** (waste material: agricultural waste, animal waste, municipal and household waste, plant material, sewage, green waste or food waste)
- ✓ **Similarity to methane**: Low gaseous emissions (CO, NO_X, PAH, and VOC)
- ✓ **Energy security:** No dependency on the foreign supplies
- ✓ **Renewability:** Carbon neutral (no net carbon emission)



Source: UK EA, LFTGN 03

Biogas challenges

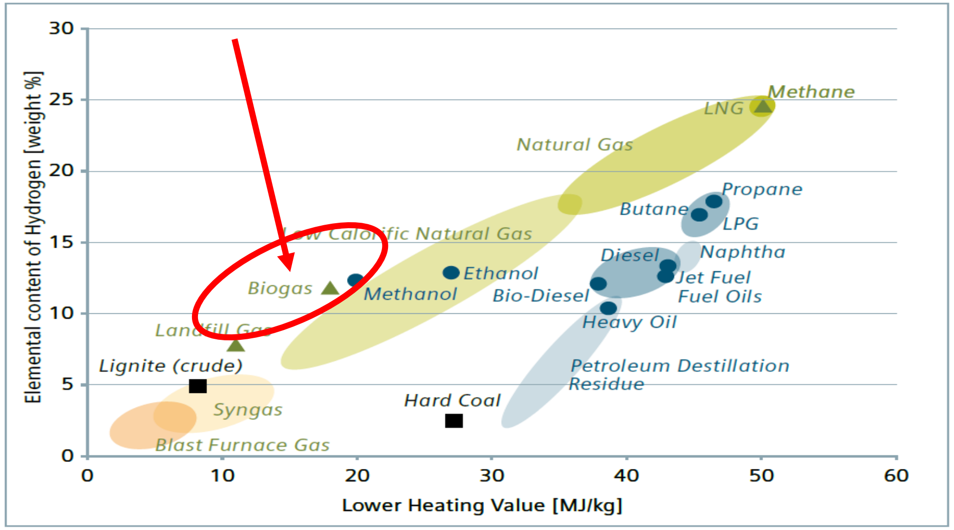
Impurities
- Carbon dioxide
- Hydrogen sulphide
- Moisture and siloxanes

Components	Concentration (v/v)	Properties
CH_4	50 - 75%	Energy carrier.
CO_2	25 - 50%	Decreases heating value. Corrosive, especially in the presence of moisture.
H_2S	0 - 5 000 ppm	Corrosive and toxic. Sulphur dioxide emission during combustion.
NH_3	0 - 500 ppm	NO_x – Emissions during combustion.
N_2	0 - 5%	Decreases heating value
Water vapour	1 - 5%	Facilitates corrosion in the presence of CO_2 and sulphur dioxide (SO_2).

Production scales
- Limited Biogas feedstocks
- Only in rural and suburban areas

Limitation conditions
- Digestion temperature of = 37 °C
- Limitation in cold climate

Low calorific value
- Accompanying gas CO2 with high Cp



Biogas interaction with MT components

Biogas possible issues for MT

Issue

Corrosion

Erosion

Flashback

Defects from Flashback
Hydrogen contents > 60%vol

Fouling

Prof H. Gohari & Dr B. Bazoyar

Design of a Micro biogas combustor

- The purpose is to show how biogas challenges in design of micro combustor is counteracted.

Design pathway:

I. Type of combustor
II. Dimension of combustor parts (liner, casing, openings)
III. Swirler type and dimensions
IV. Fuel nozzle design
V. Orientation of combustor parts

- The possible problems associated with burning the biogas fuel include: flashback, high thermal stress on combustor walls, soot formation and flame impingements.

MT combustor types for biogas fuel

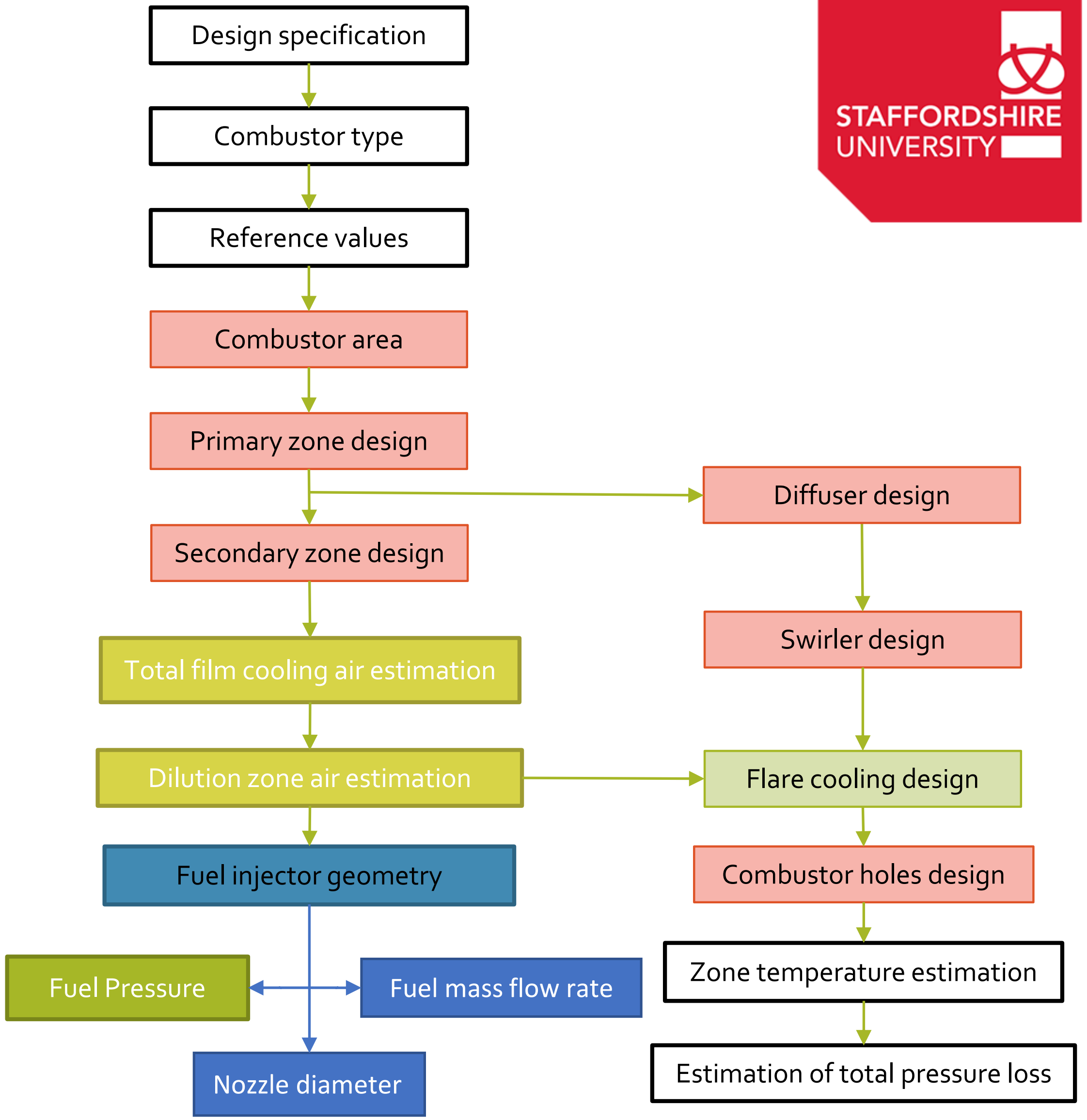
Types

- **Tubular**
  - Low cost
  - High mechanical strength
  - Cross and interconnector
  - Bulk design, and heavy weight
  - Inefficient at high pressure ratio
  - → Not effective in biogas
- **Annular**
  - Low pressure drop
  - Less captious: weight and space
  - Low mechanical strength
  - High loads on casing
- **Tubo-annular**
  - Operability at higher pressure ratios
  - Low weight and less bulky
  - High mechanical strength
  - Diffuser design problems
  - Inter-connectors
  - Inconsistent flow pattern

(Annular and Tubo-annular →) Biogas impurities
CO_2 problem

Design Procedure

- Combustion design pathway:
  - I. Type:
    - ➢ Fuel: biogas
  - II. Dimensions and position of holes:
    - ➢ pressure drop requirements
  - III. Swirler type and air distribution
    - ➢ Rough estimation
  - IV. Fuel nozzle design
    - ➢ Turbine energy requirement
  - V. Orientation of combustor parts in space
    - ➢ CFD optimisation



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Renewable micro combustor: CFD simulation using LES/PDF strategy

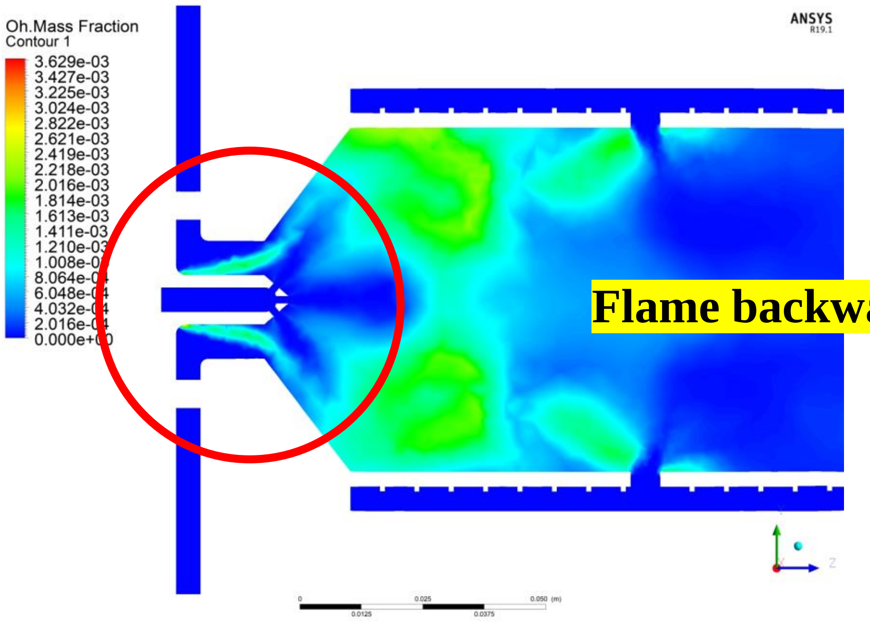
Modelling: LES/PDF strategy (Large Eddy Simulation/Probability Density Function)
Flamelet concept (32 diffusion flames)

Chemistry: GRI MESH III (52 species and 352 RXN)

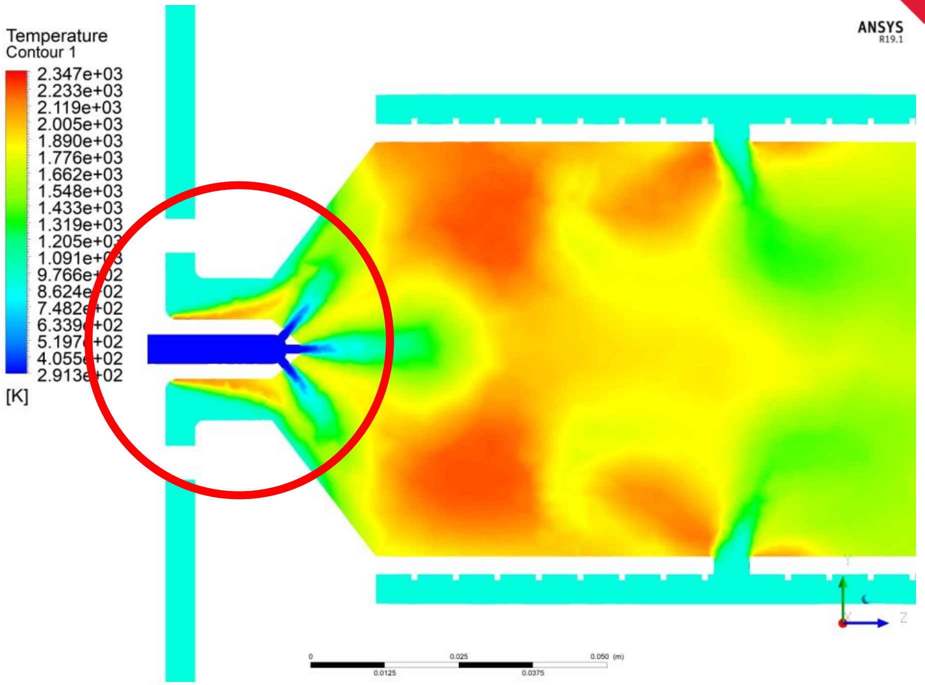
Governing equations:
- Continuity
- Turbulence kinetic energy
- Eddy dissipation
- Transport of mixture fraction
- Energy including heat radiation

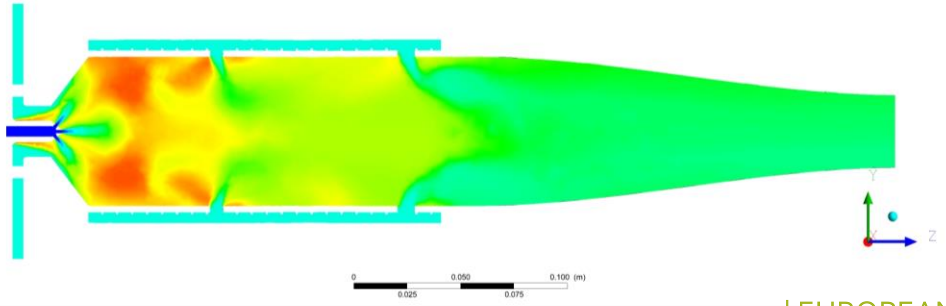
Computational costs: 20 hours/CPU with Intel Core i9 7980Xtreme, 64 GB Quadcore RAM

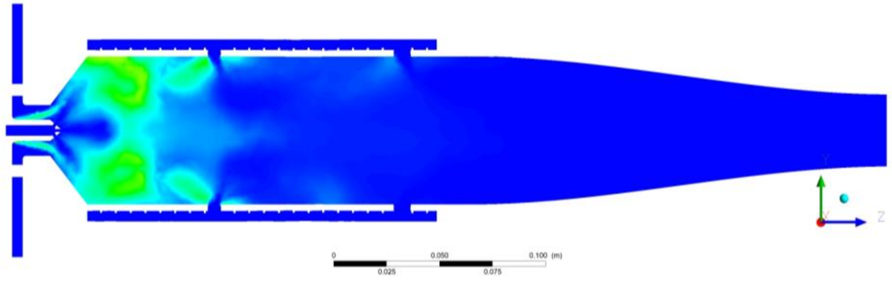
Combustor problems: Flashback



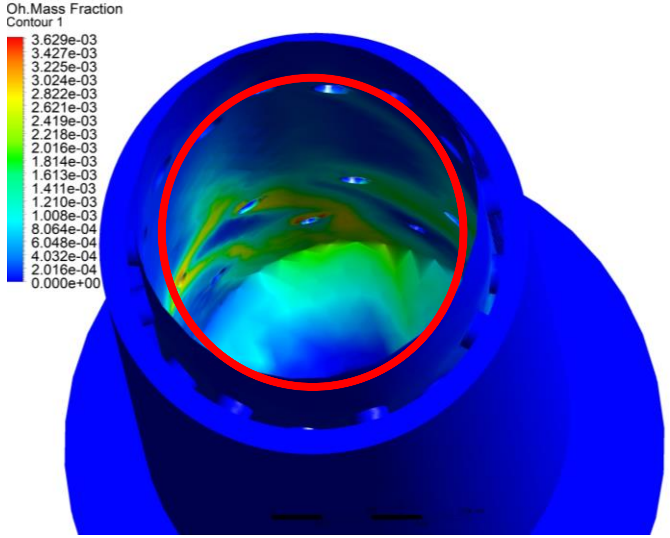
Flame backward movement



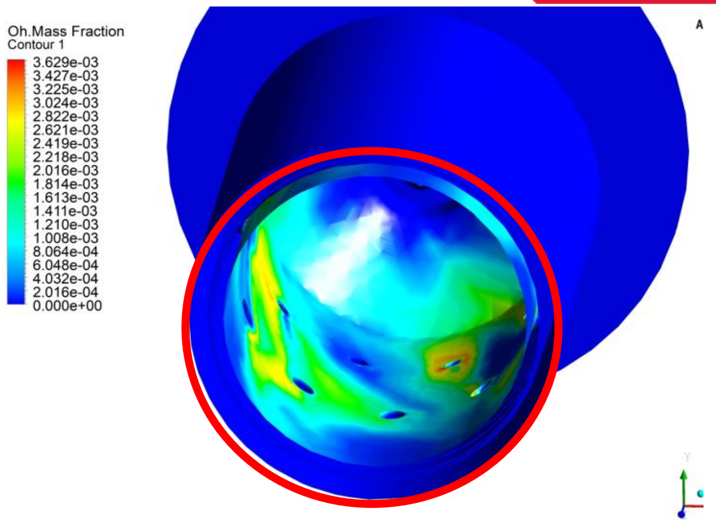


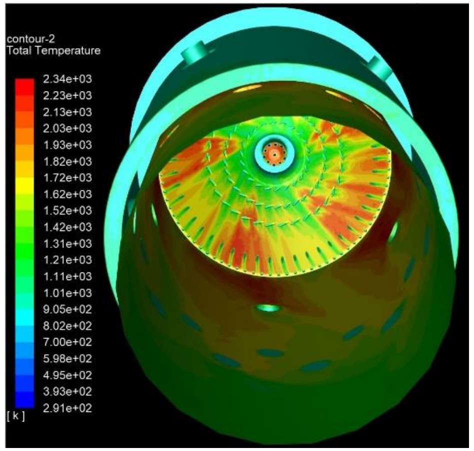


Combustor problems: Flame impingement

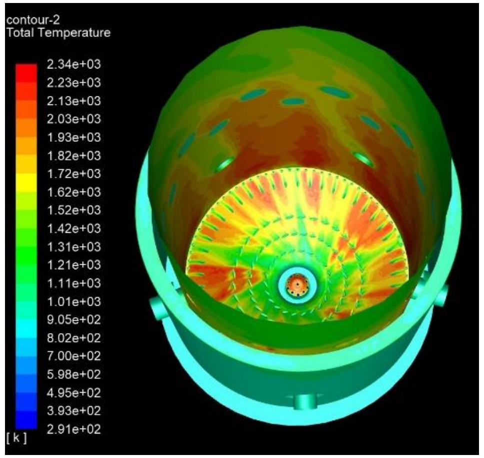


Flame impingement on the combustor rim

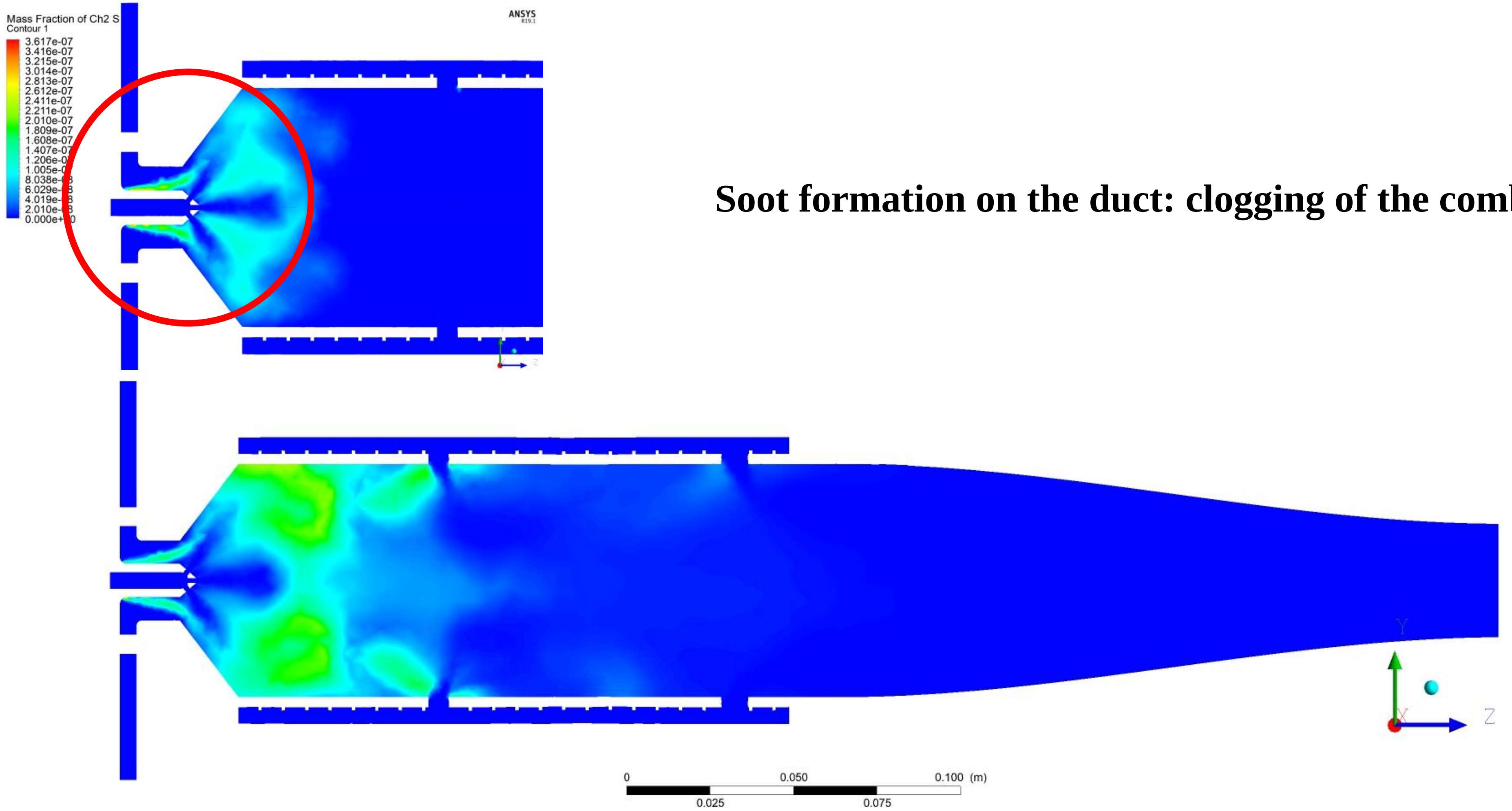




High temperature and temperature gradients



Combustor problems: clogging of duct



Soot formation on the duct: clogging of the combustor

Problem remediation

1) **Nozzle position**

2) **Nozzle cone angle**

3) **Swirler diameter**

4) **Swirler vanes**

5) **Introducing head cooling**

Analysis of the combustor in MT

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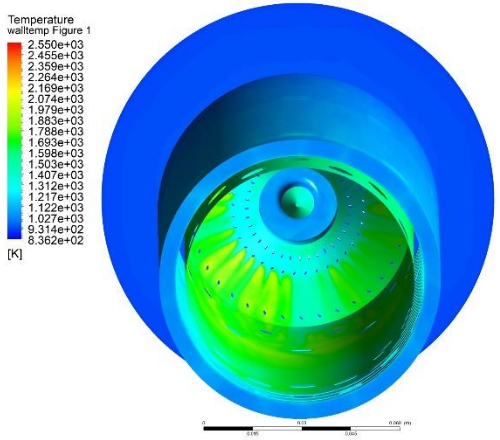
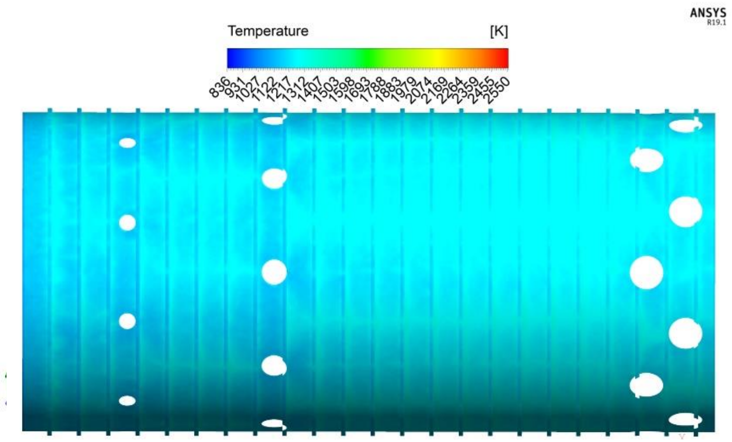
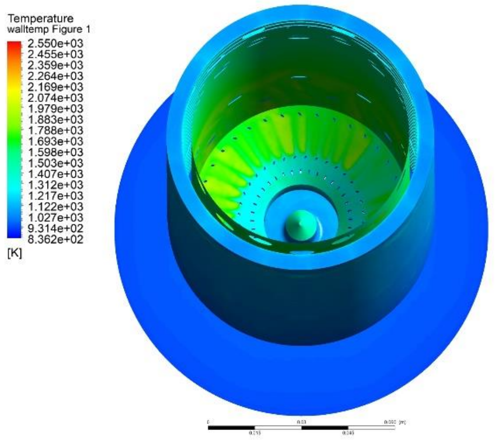
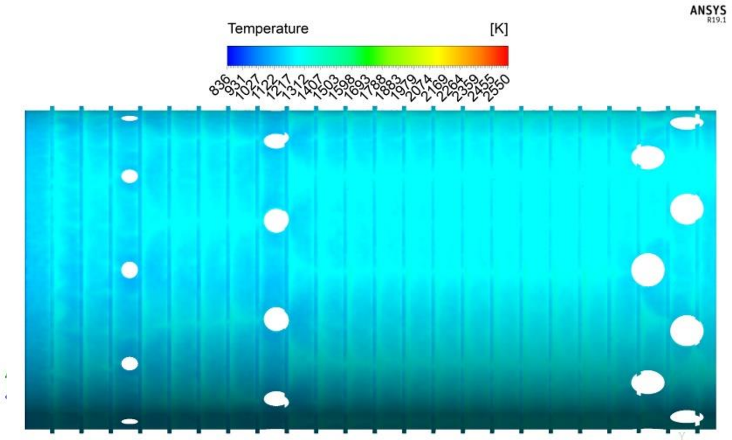
Temperature variation is mild without strong gradients

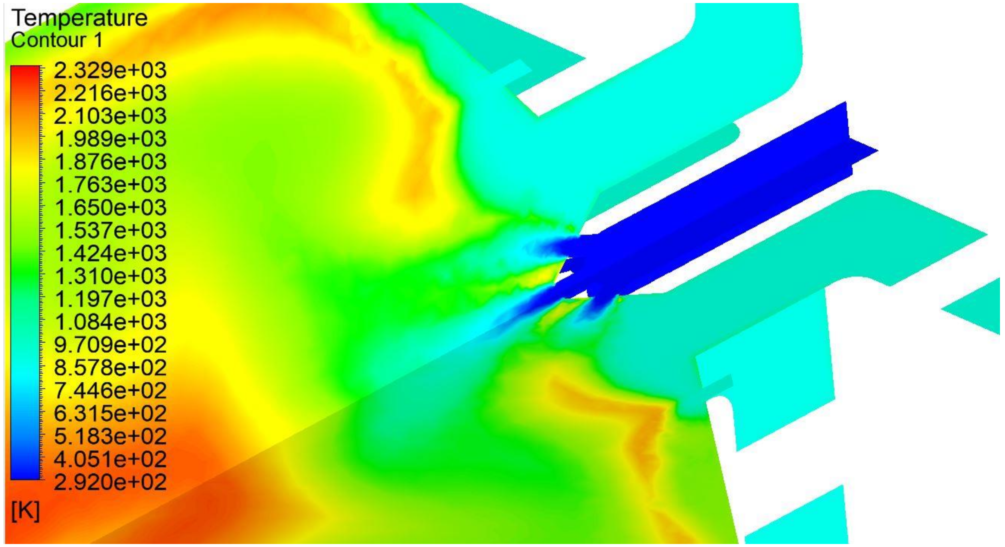




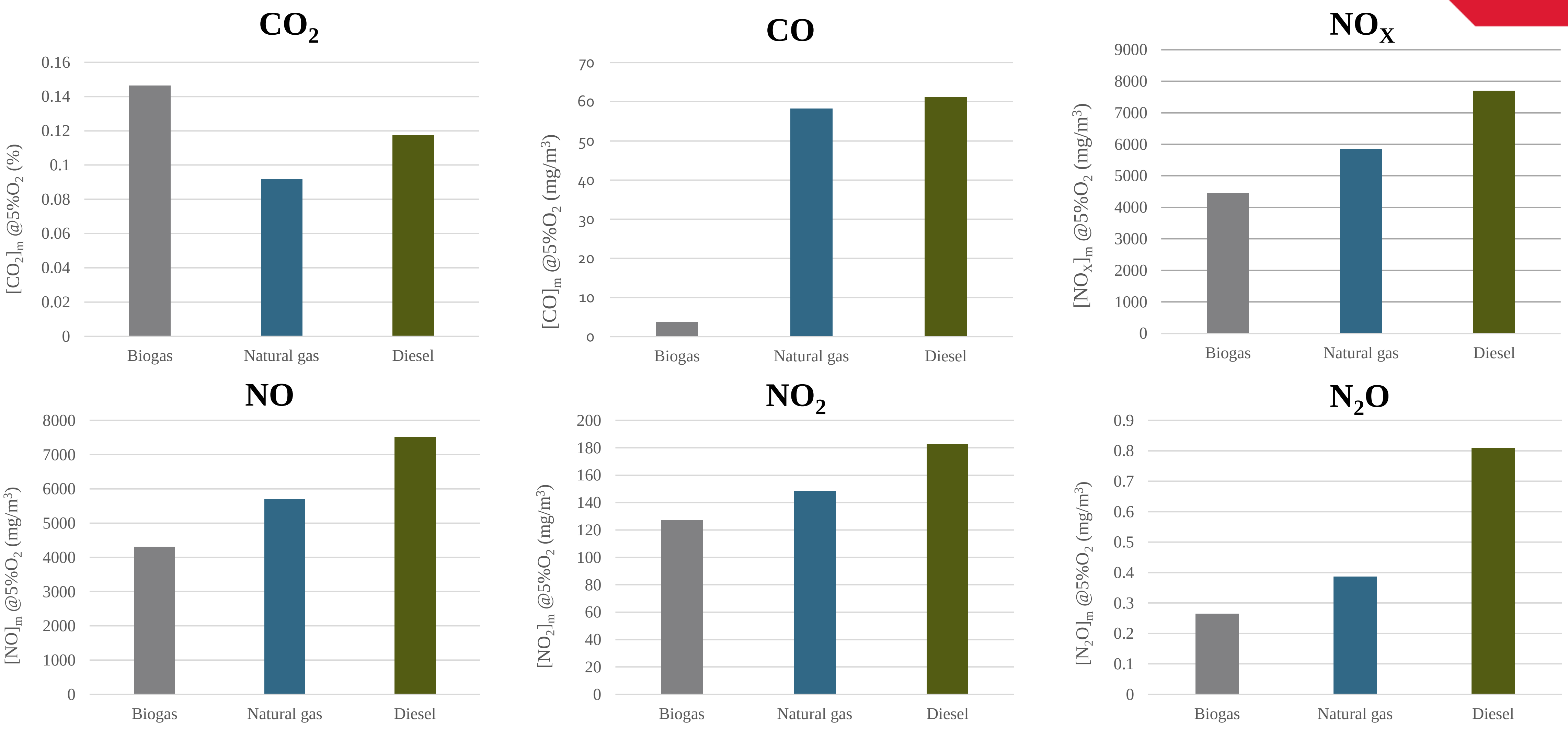




No flashback in combustor duct



Analysis of the combustor emission



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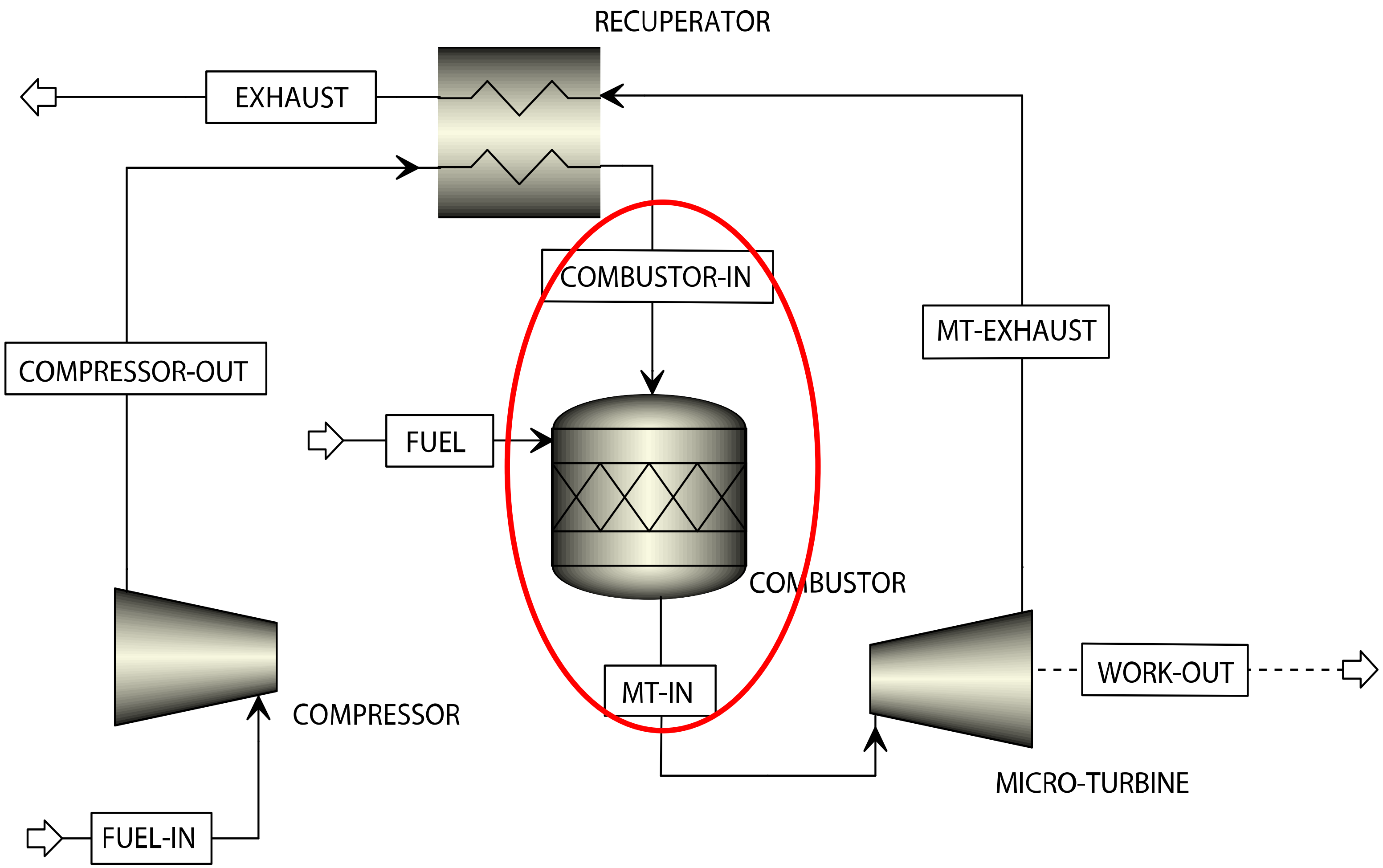
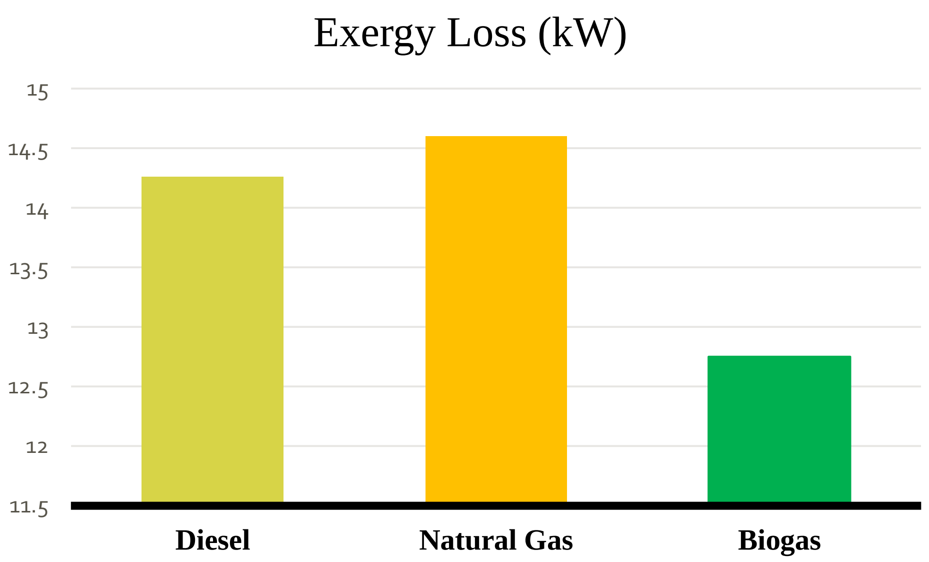
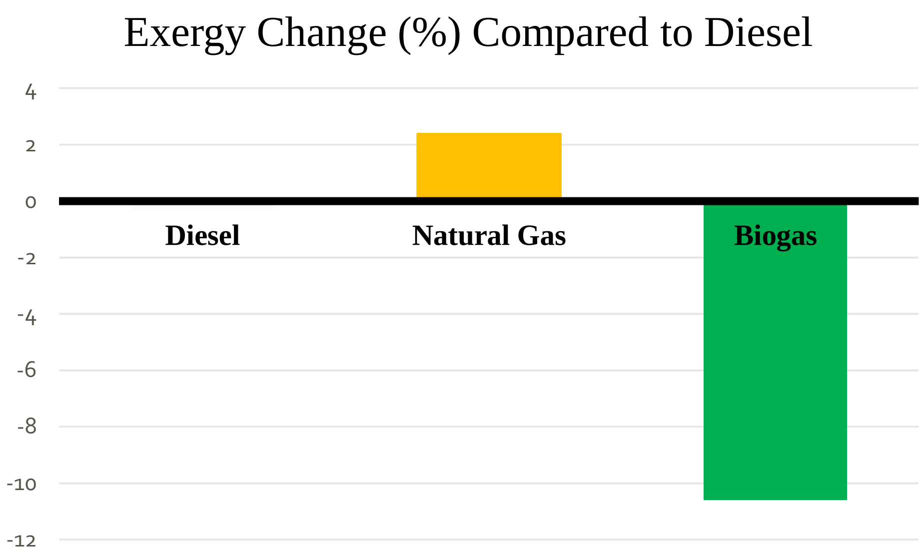
Analysis of the combustor in MT
(standard Bryton cycle)



Exergy Analysis (standard Bryton cycle)





Combustor conclusive remarks

- Burning renewable Biogas fuels in micro turbines is superior to other fuels if the design problems are addressed.
- Problems observed and resolved in the micro combustor
  1) Flame flashback
  2) Flame impingement and temperature gradients
  3) Sooty formation before the primary holes
- The combustor design is critical stage in solving the biogas issues in microturbines

Thank you for your attention

Any question?