Thermochemical Power Group

Sustainable Energy

Mod.1: Fuel Cells & Distributed Generation Systems

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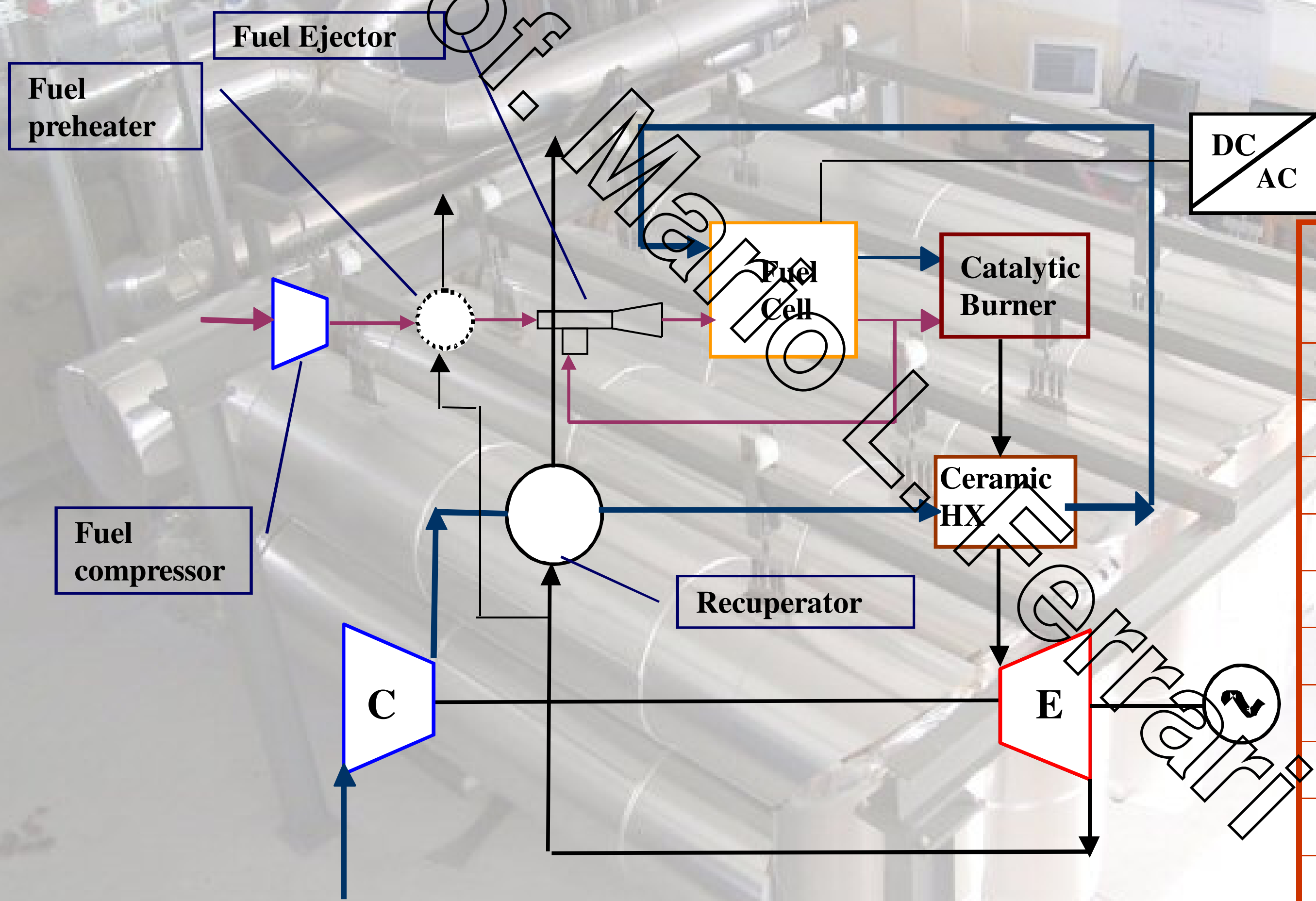
Lesson XII: fuel cell systems (alternative fuels)

Objectives

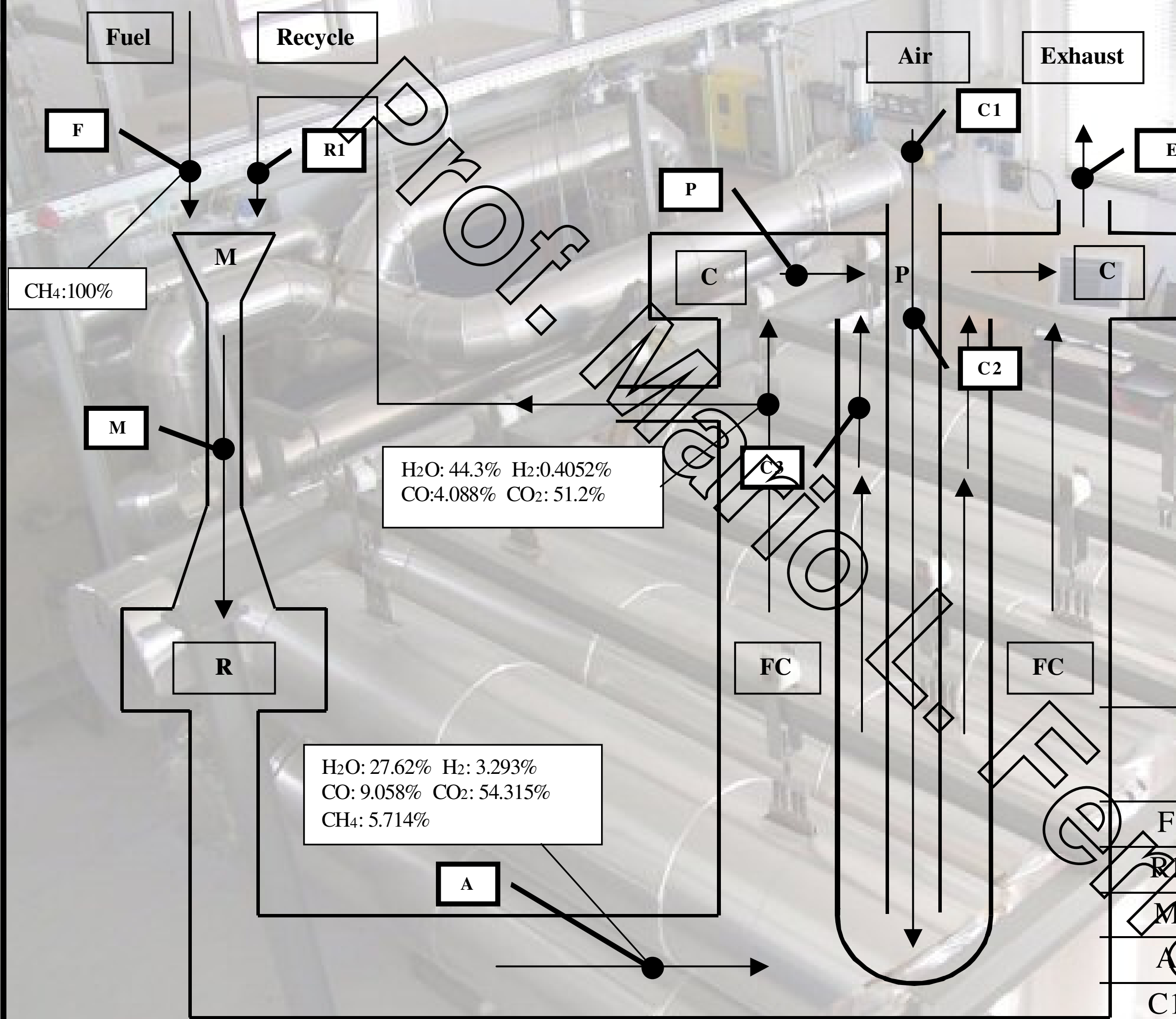
- Alternative fuels such as biomass or coal gasification-derived ones, could potentially further increase SOFC hybrid systems market.
- The feasibility of alternative fuels employment in a SOFC-GT hybrid system was investigated.
- Gasification process and gas cleanup were not analysed in this lesson.

SOFC-GT Hybrid System: Plant Layout



Methane-Operation Design Point

m_{fuel} [kg/s]	0.0185
i [A]	1.34
m_{air} [kg/s]	1.170
β_C	4.50
F [$=m_{sec}/m_{prim}$]	7.1
STCR	2.4
$m_{fue}\cdot$LHV [kJ/s]	925
FC Power [kW]	484
HS Power [kW]	581
FC Efficiency %	52.3
HS Efficiency %	62.8



$$STCR = \frac{nH_2O}{nCO + nCH_4}$$

If STCR<1.8-2.5

Carbon deposition

$$CH_4 \leftrightarrow 2H_2 + C$$

	Mass flow rate [kg/s]	Temperature [°C]
F	0.0094	400
R1	0.0663	984
M	0.0757	873.8
A	0.0757	538.6
C1	0.476	605.5
C2	0.476	783
C3	0.4409	984
PC	0.0851	1050
EX	0.0851	899

M : Mixing
R : Sensible Heat Reforming
FC : Fuel Cell
C : Combustion
P : Air Pre-Heater

Syngas- Biofuel Compositions

	Syngases		Biofuel
% vol	#1	#2	
H_2	26.83	52.20	7.38
CO	46.47	29.49	8.90
CH_4	3.85	4.40	6.62
CO_2	2.94	5.60	15.60
H_2O	16.54	5.09	24.00
N_2	3.37	3.22	37.50
LHV [kJ/kg]	11708	17091	3777
LHV/LHV_{CH4} %	23.40	32.20	7.60

Biofuel

Very low LHV (3777 [kJ/kg])

Lower fuel flow rate:
m_f = 0.26 [kg/s]

Fuel Cell too cold:
Inefficient or off in some region

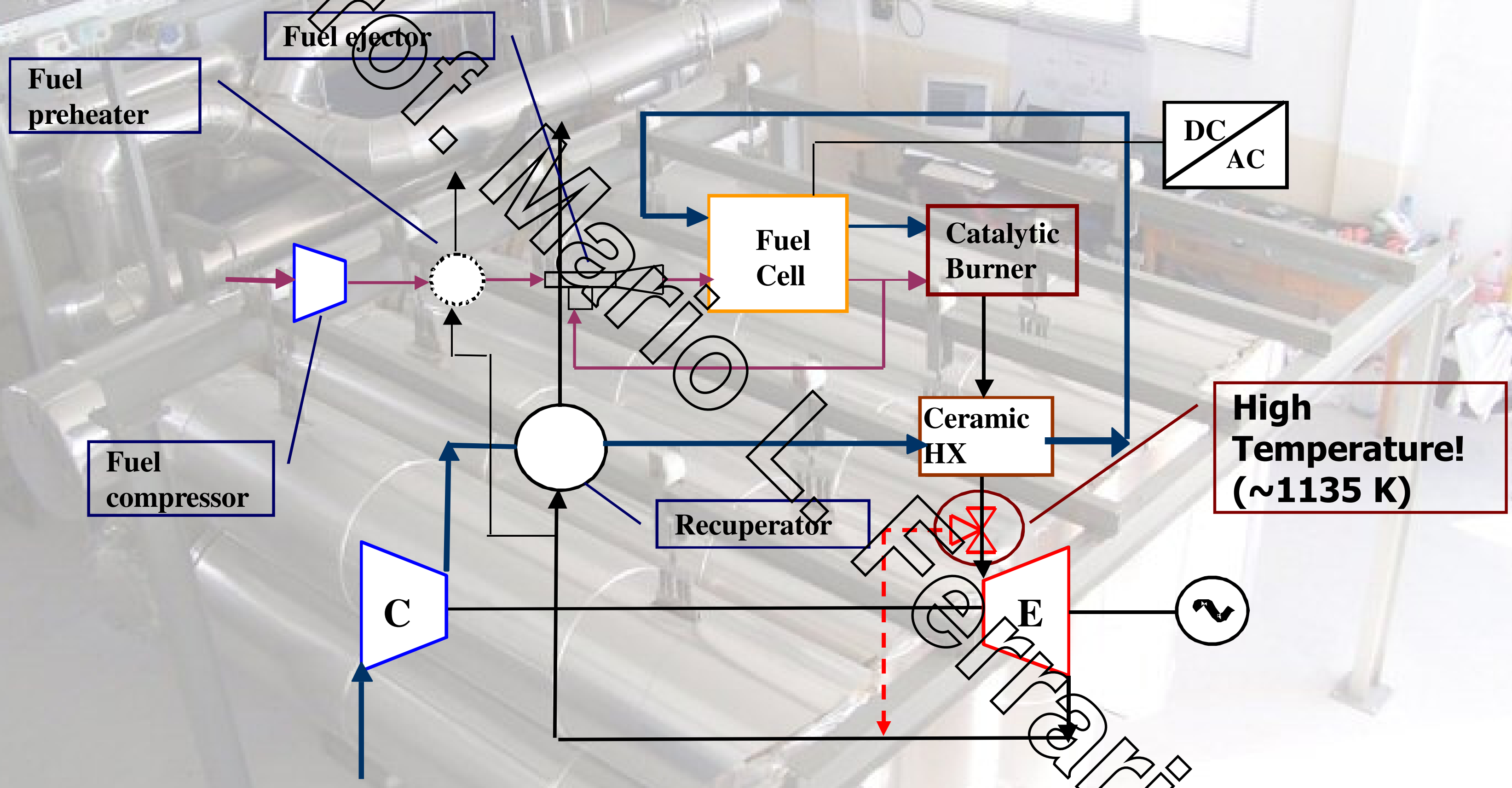
Ejector Dimensions Much Higher

Optimization Needed

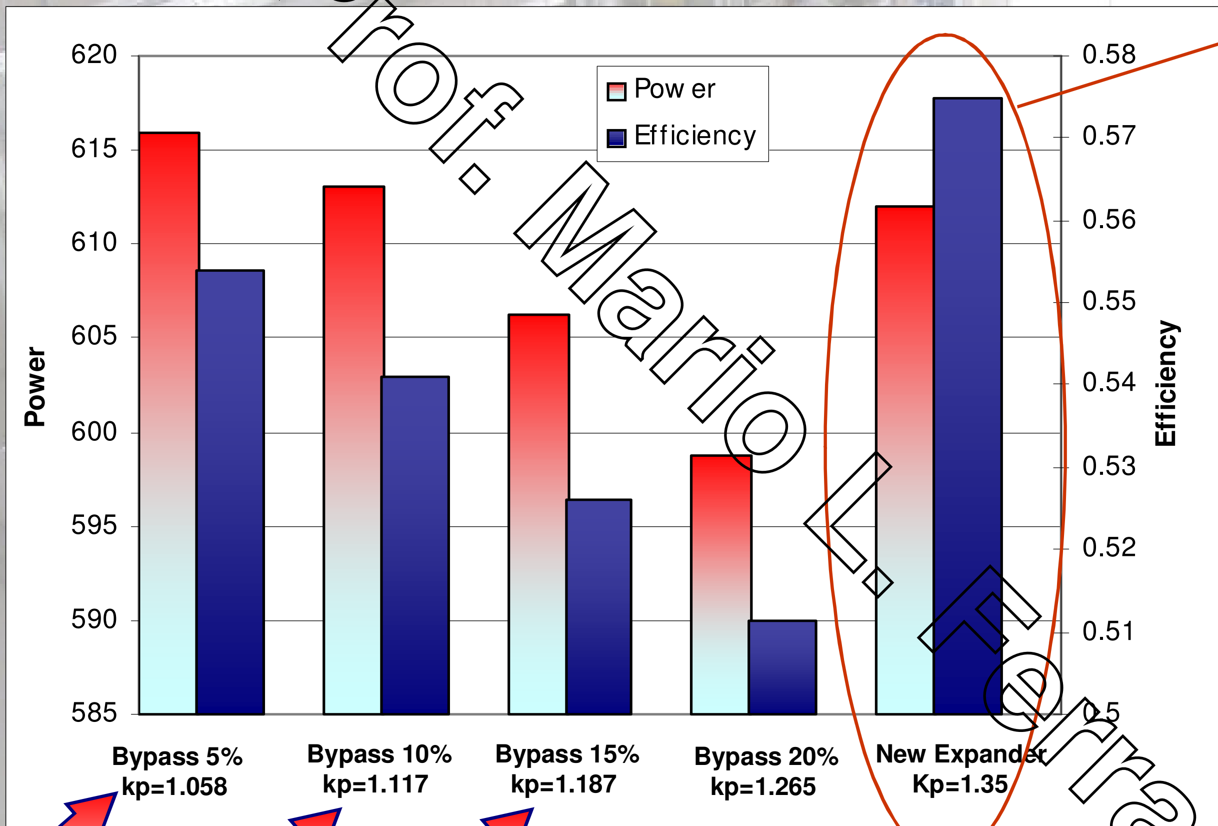
Right fuel flow rate:
m_f = 0.28 [kg/s]

Expander mass flow rate too high:
Very high surge risk

Expander Bypass System



Biofuel-Fed Operation

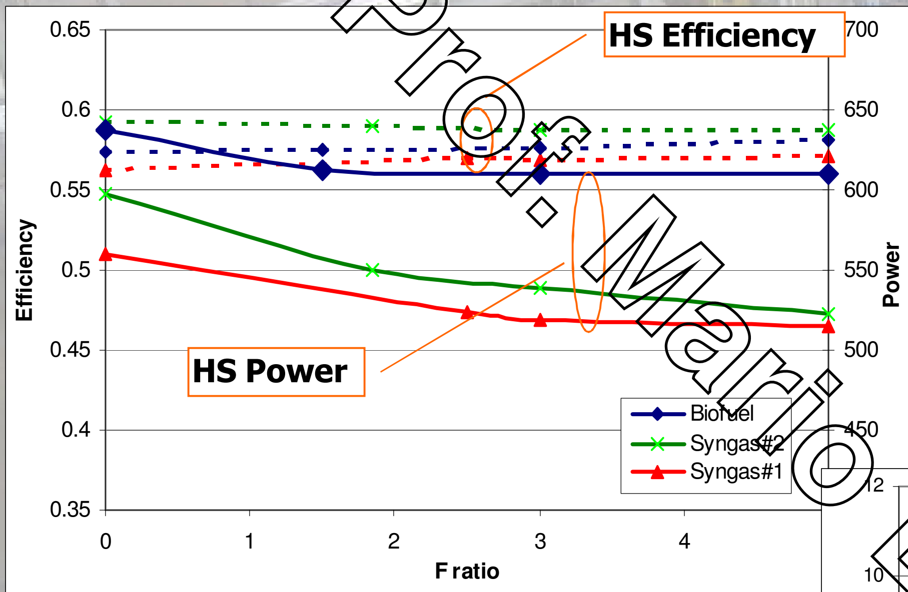


m_f [kg/s]	0.282
m_{air} [kg/s]	0.900
m_{air} / m_f	3.19
Tit [K]	1127
P_{FC} [kW]	430
η_{FC} %	40.4
P_{HS} [kW]	612
η_{HS} %	57.5
$P_{FuelCompr.}$ [kW]	88.5
η_{HSnet} %	49.2

U_f = 0.85
F = 1.5
LHV = 3777 [kJ/kg]
$T_{max\ FC}$ = 1255 [K]

$$kp = \frac{(\beta/\dot{m})_{surge}}{(\beta/\dot{m})_{o.p.}}$$

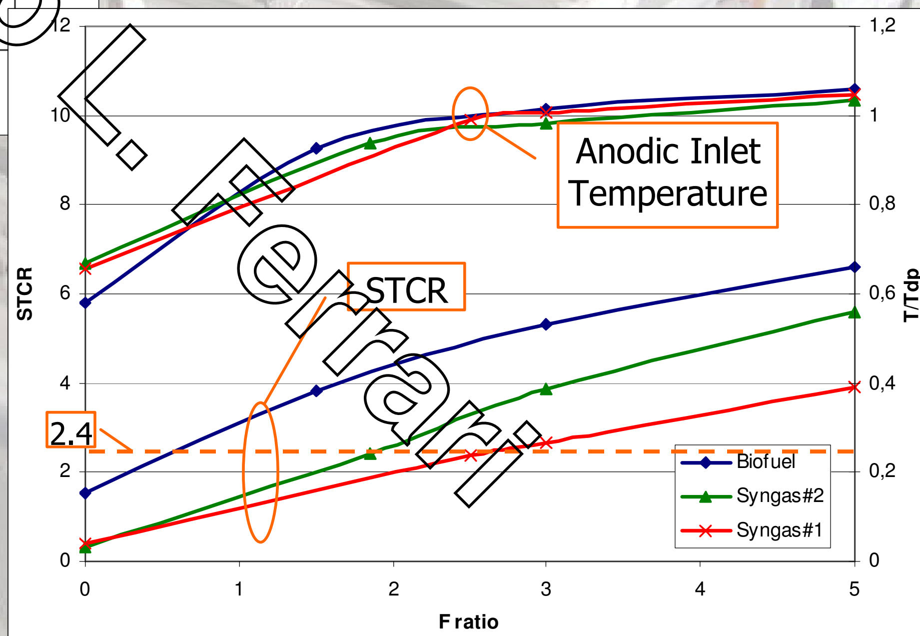
Anodic Recirculation Influence



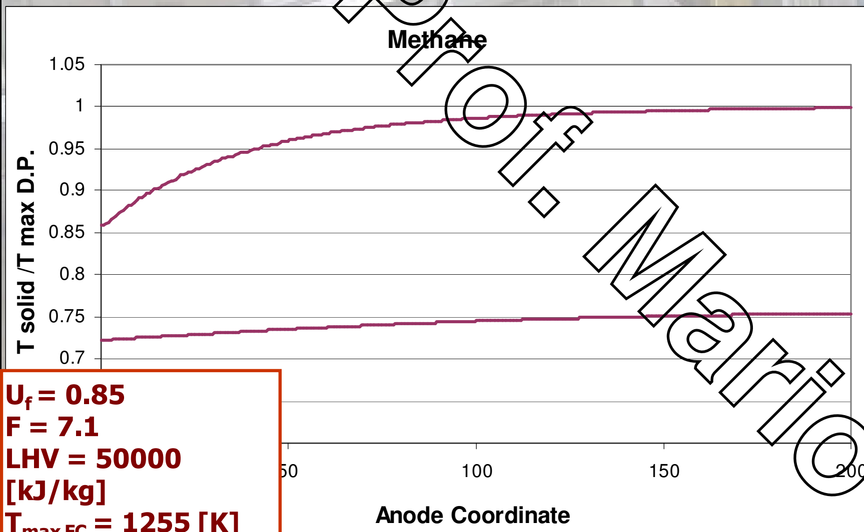
System efficiency remains more or less constant while power decreases due to the fuel flow rate reduction.

STCR too low without recirculation.

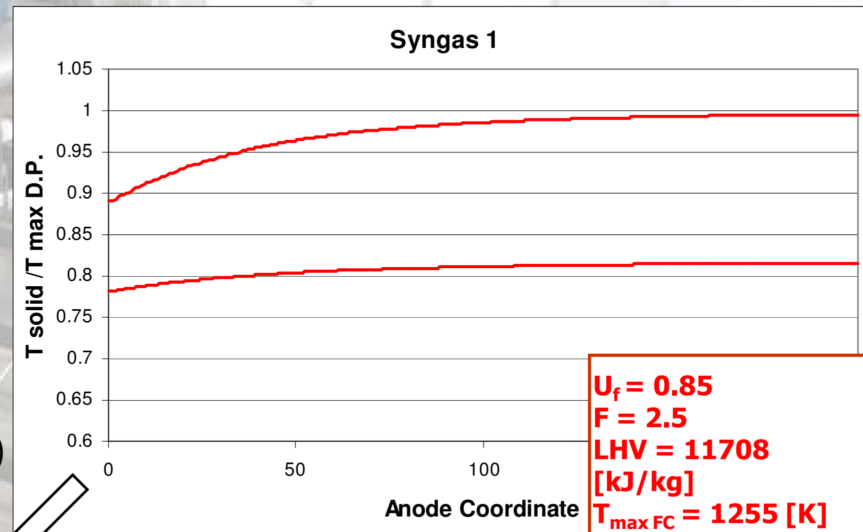
Anodic inlet temperature is biofuel key parameter to define F value.



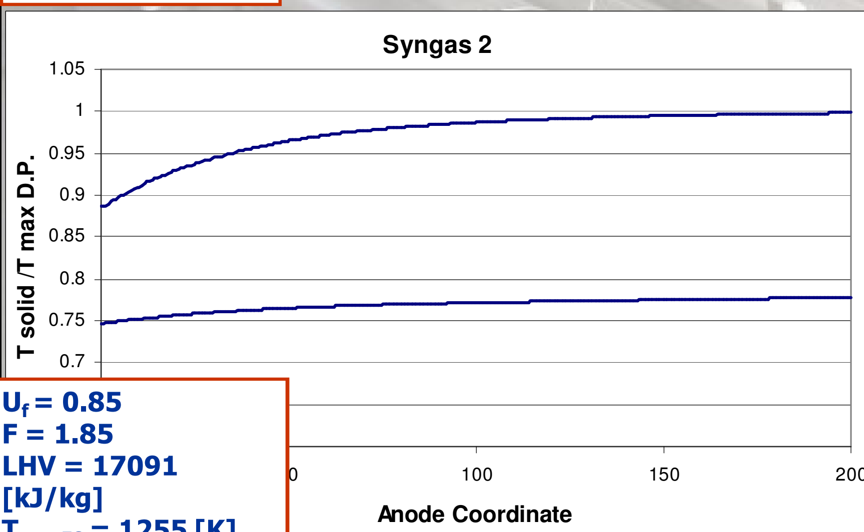
Stack Thermal Management



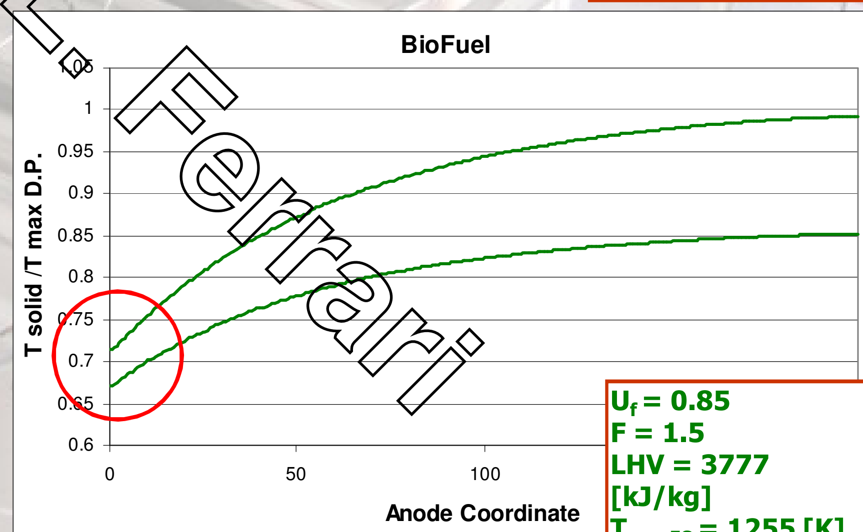
U_f = 0.85
F = 7.1
LHV = 50000 [kJ/kg]
$T_{max\ FC}$ = 1255 [K]



U_f = 0.85
F = 2.5
LHV = 11708 [kJ/kg]
$T_{max\ FC}$ = 1255 [K]



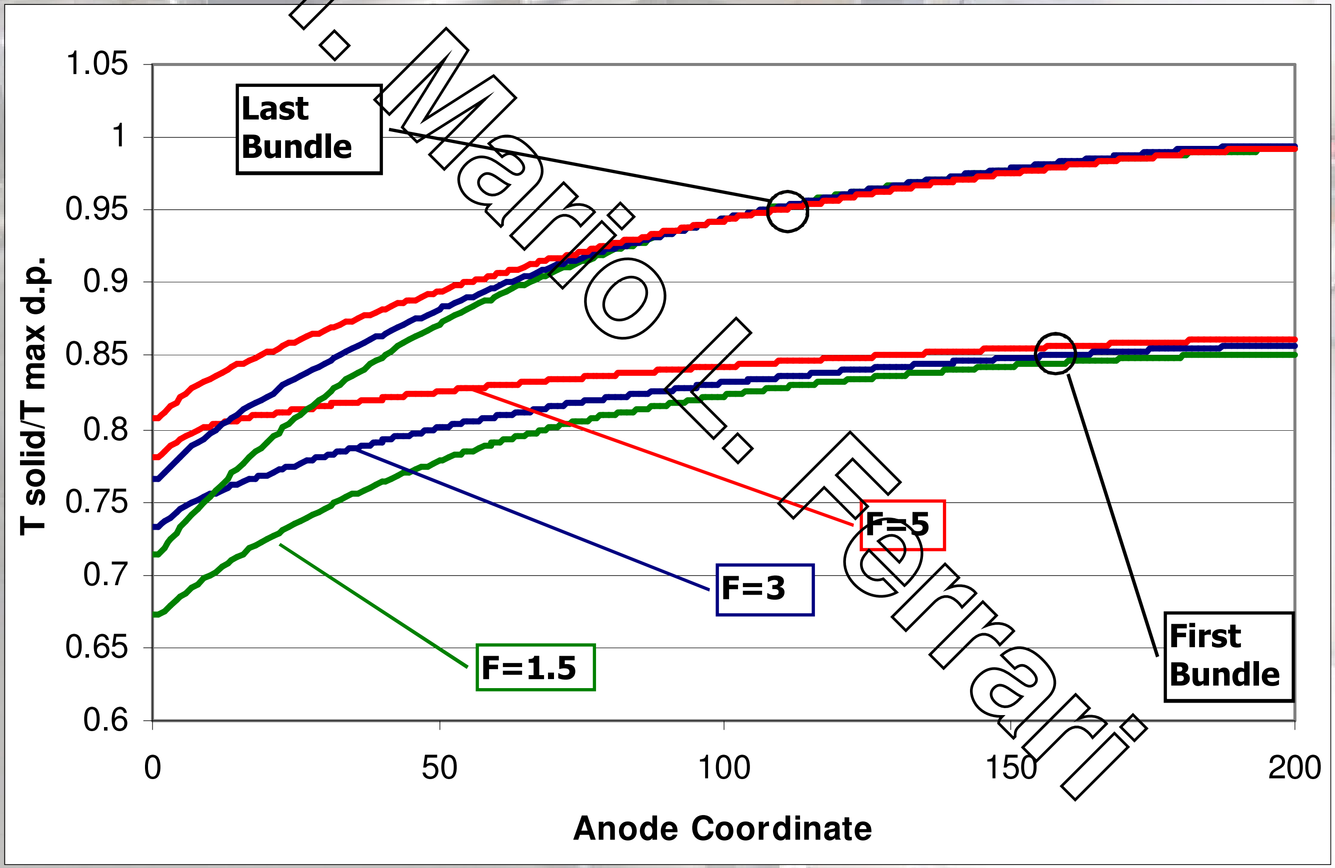
U_f = 0.85
F = 1.85
LHV = 17091 [kJ/kg]
$T_{max\ FC}$ = 1255 [K]



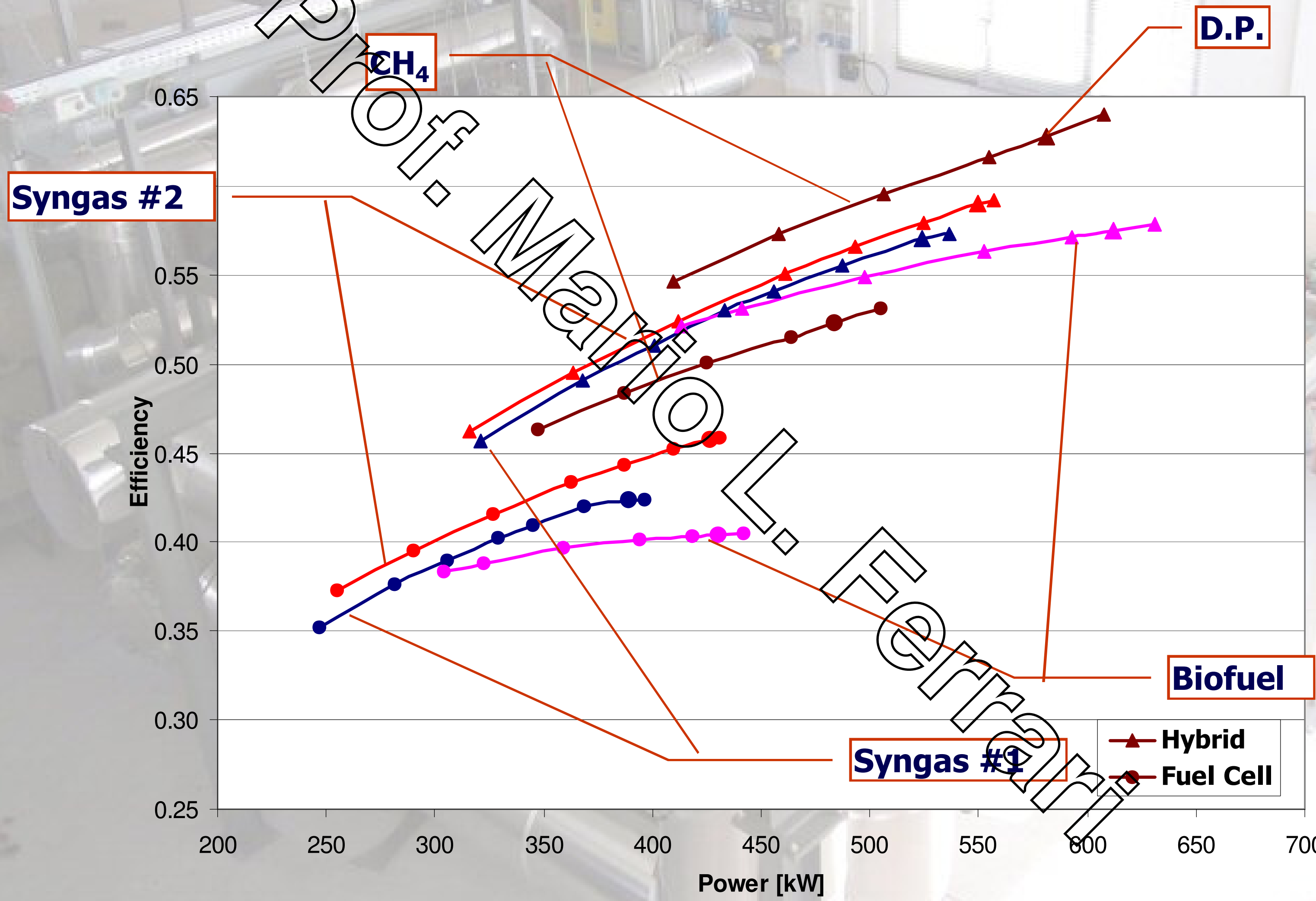
U_f = 0.85
F = 1.5
LHV = 3777 [kJ/kg]
$T_{max\ FC}$ = 1255 [K]

Stack Thermal Management

F influence on biofuel-fed stack



Part Load



CH4
D.P.
Syngas #2
Biofuel
Syngas #1
Hybrid
Fuel Cell
Efficiency
Power [kW]
0.65
0.55
0.50
0.45
0.40
0.35
0.30
0.25
200
250
300
350
400
450
500
550
600
650
700

Conclusions

- Fuel Cell can be fed with alternative fuels, thus extending fuel cells application field.
- Some layout modifications have to be considered:
  - Apt fuel compressor
  - Ejector redesign – optimization
  - No need for an external reformer
  - Apt Gas Turbine may be required for very low LHV fuels
- Efficiency and Power are quite good but fuel compression could deeply affect them (depending also on fuel pressure availability).
- A wider operating field Gas Turbine could fit both methane and biofuel requirements.
- A complete layout (including gasifier, gas clean-up etc.) will be investigated.