# High Efficient Hydrogen-Air Solid Oxide Fuel Cell

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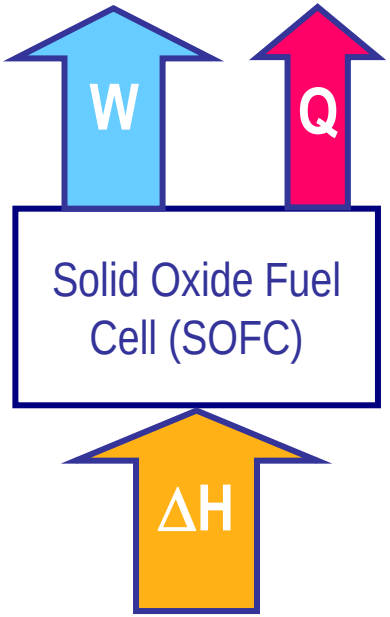
# Energy transformation in an SOFC




Kinds of energy

**Chemical energy of fuel ΔH**

**Electrical energy W**

**Heat Energy Q**

# SOFC efficiency (1)

$$\eta = \frac{\text{Produced energy}}{\text{Spent energy}}$$

Produces energy in the SOFC is electrical energy; A = qU

Spent energy in the SOFC is chemical energy of a fuel; $-\Delta H_{298}$

$$\eta_{SOFC} = \frac{qU}{-\Delta H_{298}}$$

$\eta_F = \frac{q}{zF}$ – коэффициент использования топлива

$U_{tn} = \frac{-\Delta H_{298}}{zF}$ – термонейтральное напряжение

$U_{tn,298}$ = 1,48 V (HHV), $U_{tn,298}$ = 1,25 V (LHV)

$\eta_{SOFC}^{max} = \eta_F \frac{E_{av}}{U_{tn,298}}$ $E_{av}$ – average value of an EMF

# SOFC efficiency (2)

$$P = UI = \frac{U(E_{av} - U)}{r}$$ - SOFC power

$$P_{max} = \frac{E_{av}^2}{4r}$$ - maximum SOFC power

$$P_r = \frac{P}{P_{max}}$$ - relative power

$$U_r = \frac{U}{E_{av}}$$ - relative volage

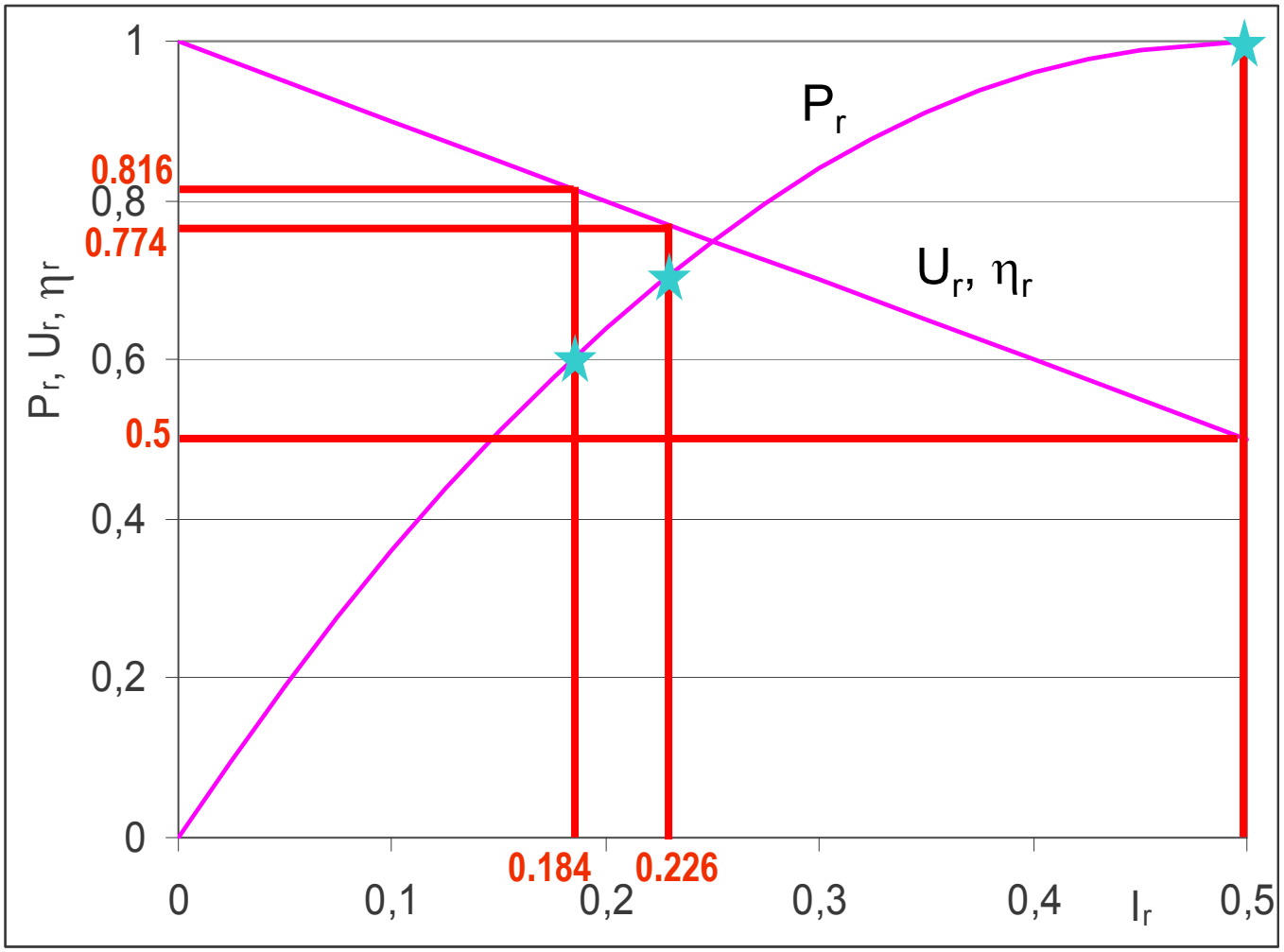
$$\eta = \eta_F U_r$$

$$P_r = 4U_r(1 - U_r)$$

$$\eta = 0,5\eta_{max}\left(1 + \sqrt{1 - P_r}\right)$$

$$\eta_r = \frac{\eta}{\eta_{max}}$$ - relative efficiency $\Rightarrow$ $\eta_r = 0,5\left(1 + \sqrt{1 - P_r}\right)$

# Relationship between the main SOFC parameters




$$P_r = \frac{P}{P_{max}}$$

$$U_r = \frac{U}{E_{av}}$$

$$\eta_r = \frac{\eta}{\eta_{max}}$$

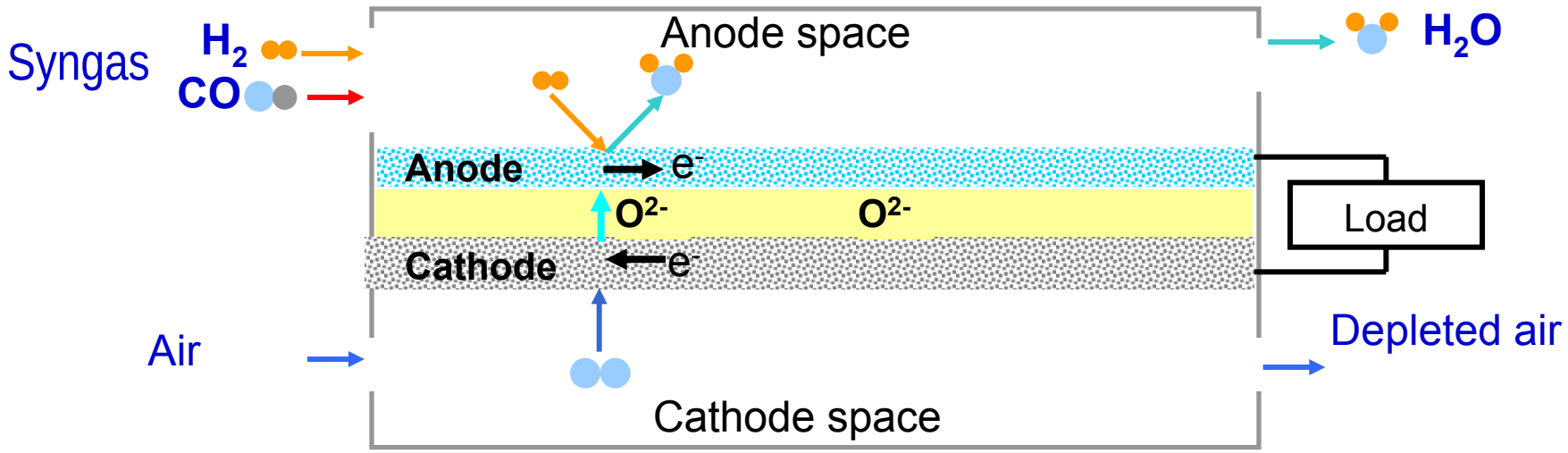
$$I_r = \frac{I}{I_{max}}$$

$$\eta = 0{,}5\eta_{max}\left(1+\sqrt{1-P_r}\right)$$

# Processes in the SOFC

Anode reaction

$H_2 + O^{2-} = H_2O + 2e^-$



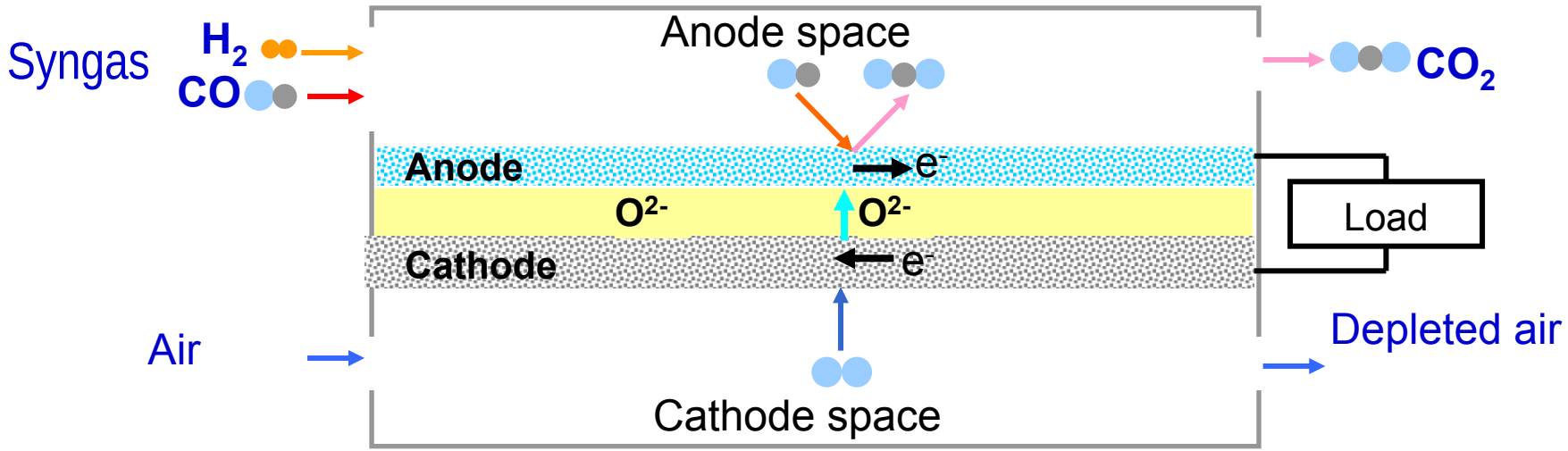

Cathode reaction

$0.5O_2 + 2e^- = O^{2-}$

# Processes in the SOFC

Anode reaction

$$CO + O^{2-} = CO_2 + 2e^-$$

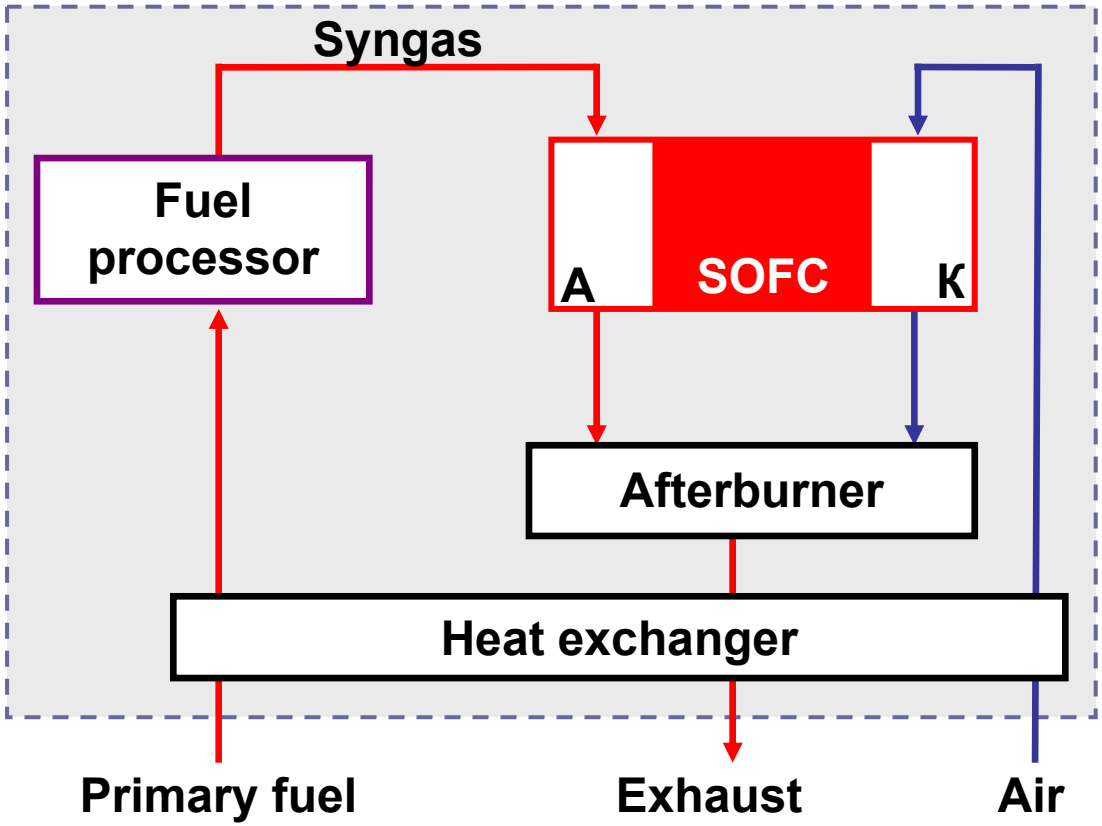



Cathode reaction

$$0.5O_2 + 2e^- = O^{2-}$$

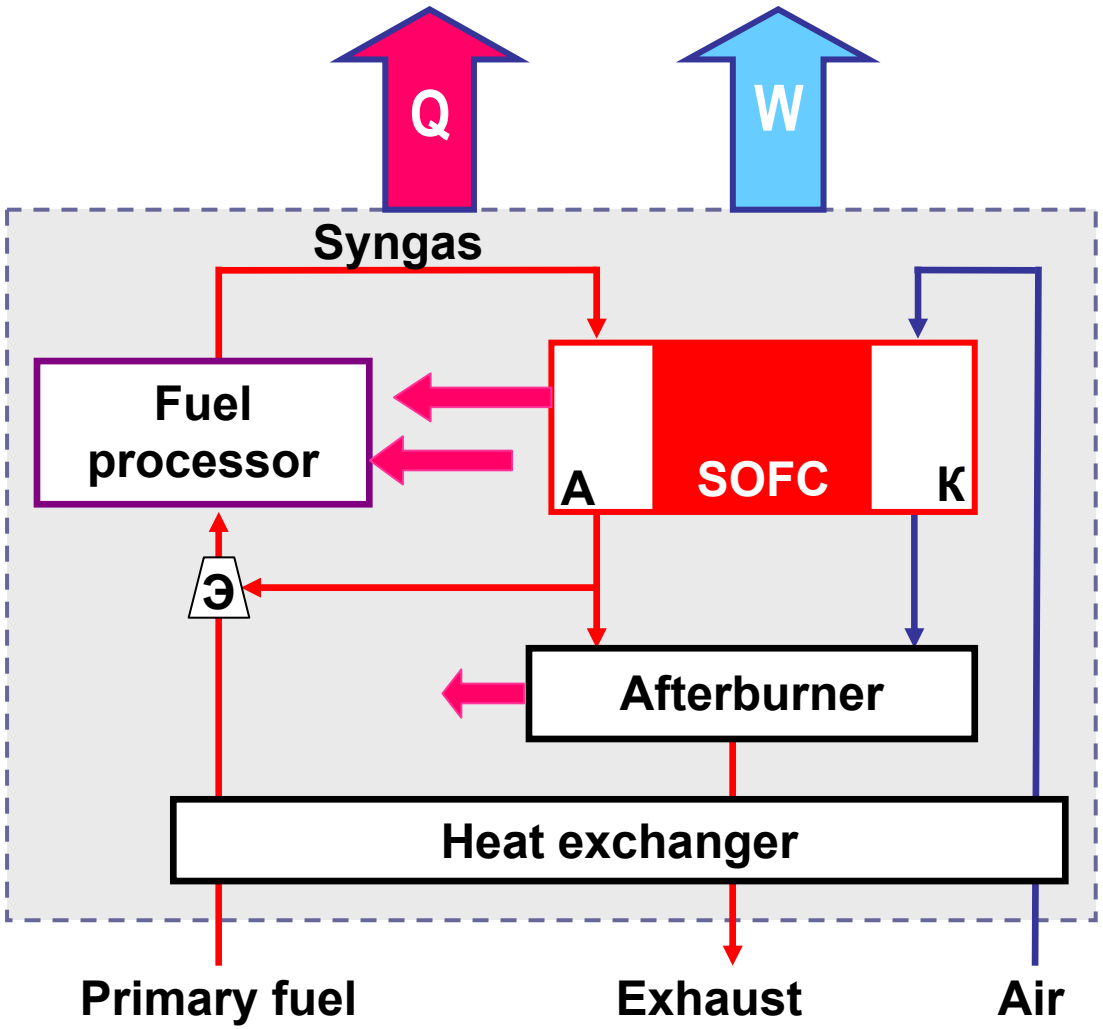
# SOFC system

## SOFC system fed by a hydrocarbon fuel



# Flow diagram of the SOFC system

## Reforming of fuel in the fuel processor by an exhaust anode gas




**Advantages:**

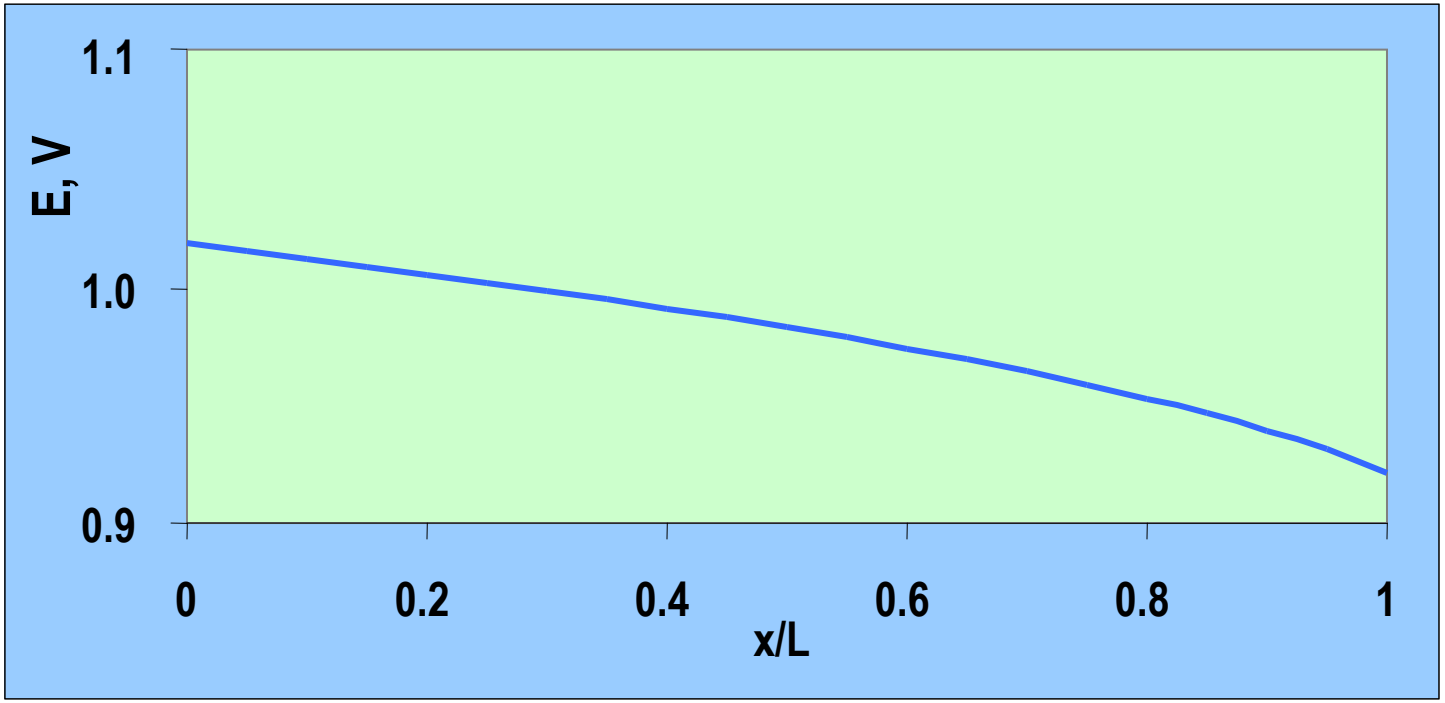
**High efficiency due to high fuel utilization and**

**due to utilization of heat produced by SOFC stacks for providing operating regime of the fuel processor**

**Disadvantage:**

**operating temperature of the SOFC stacks must be higher than that of the fuel processor**

# EMF distribution along the SOFC




$$\eta_{SOFC}^{max} = \eta_F \frac{E_{av}}{U_{tn,298}} \qquad \eta_F = 0,9;\ E_{av} = 0,95 \Rightarrow \qquad \eta_{max} = 0,82\ (LHV)$$

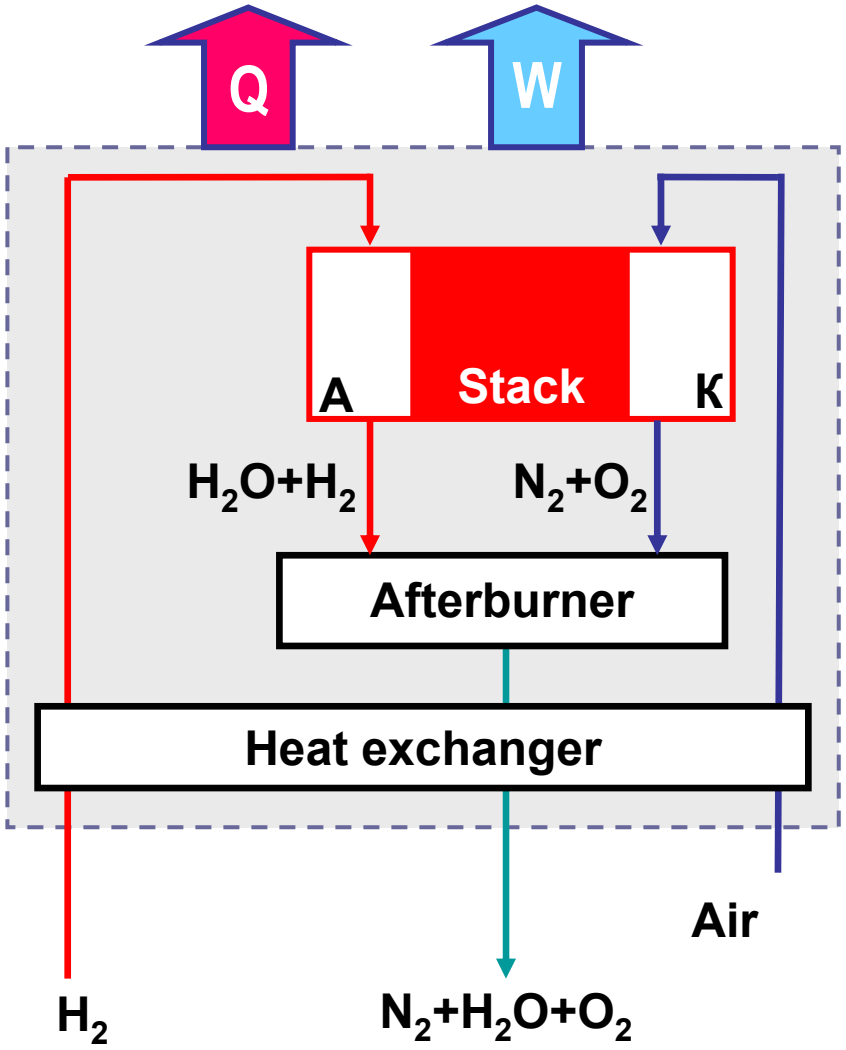
$$\eta_{max} = 0,74\ (HHV)$$

$$\eta = 0,5\eta_{max}\left(1+\sqrt{1-P_r}\right) \qquad P_r = 0,7 \Rightarrow \qquad \eta_{max} = 0,67\ (LHV)$$

$$\eta_{max} = 0,60\ (HHV)$$

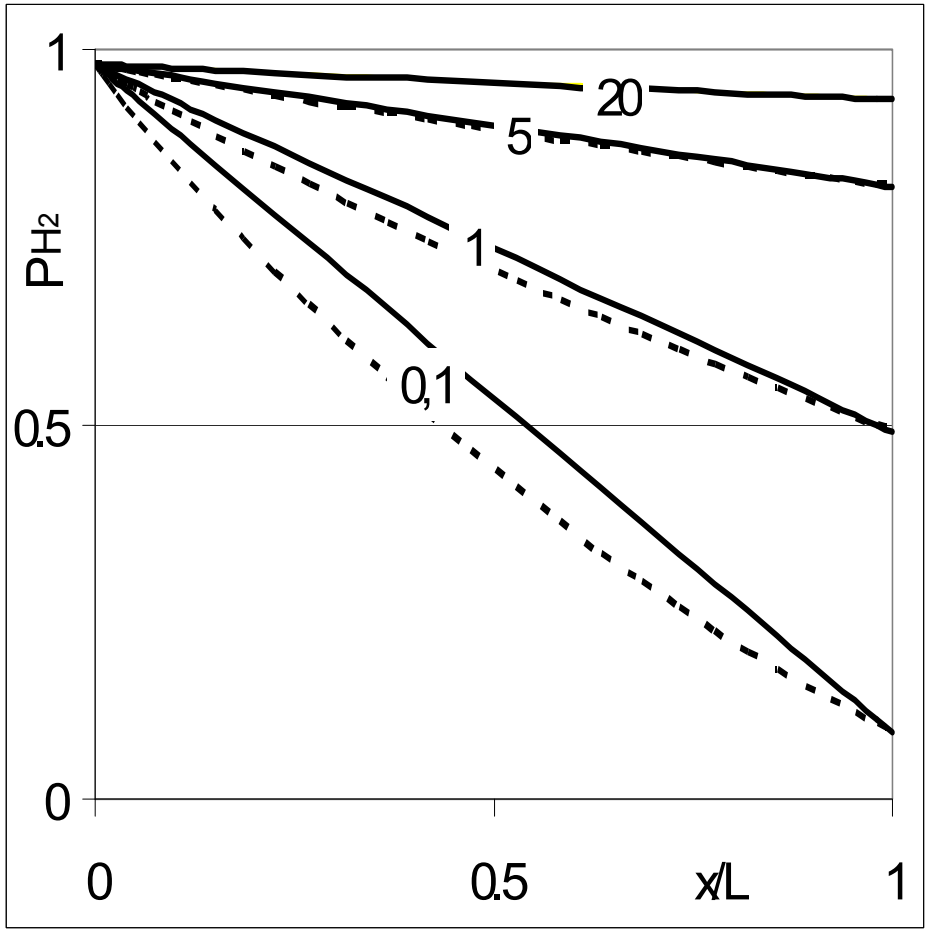
# Hydrogen-air SOFC system

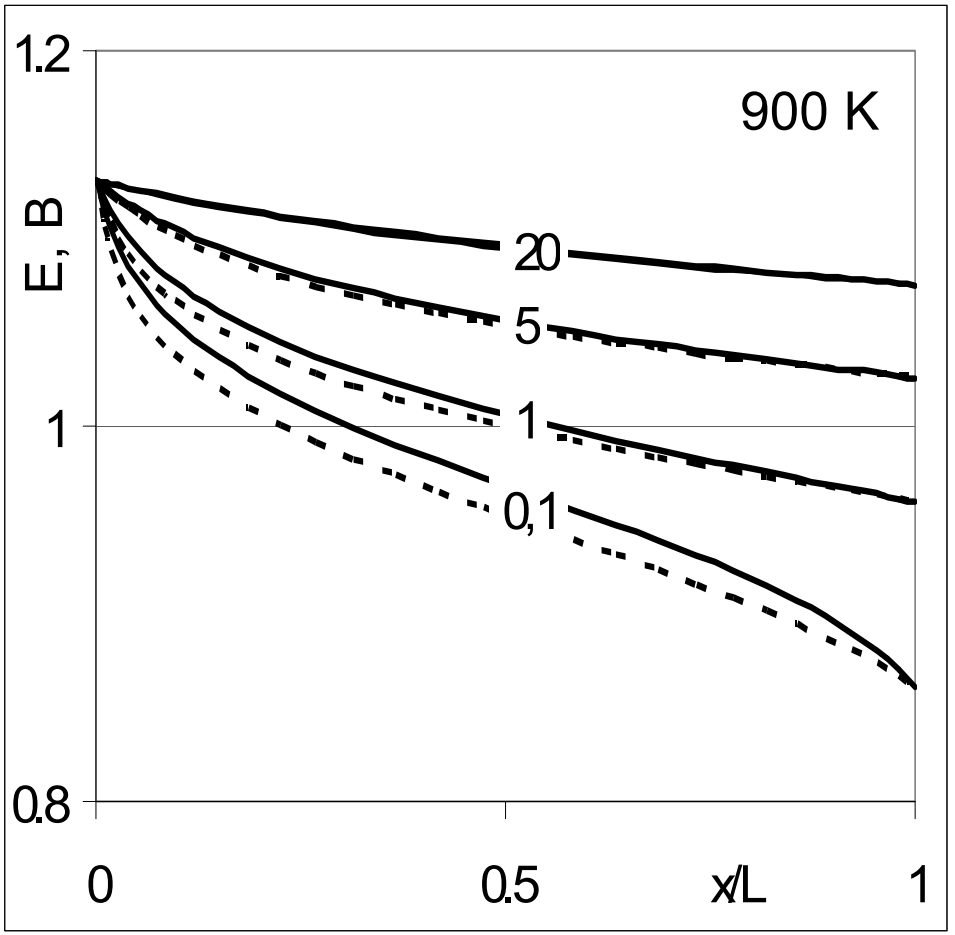
## Conventional SOFC system




## SOFC system with hydrogen recirculation

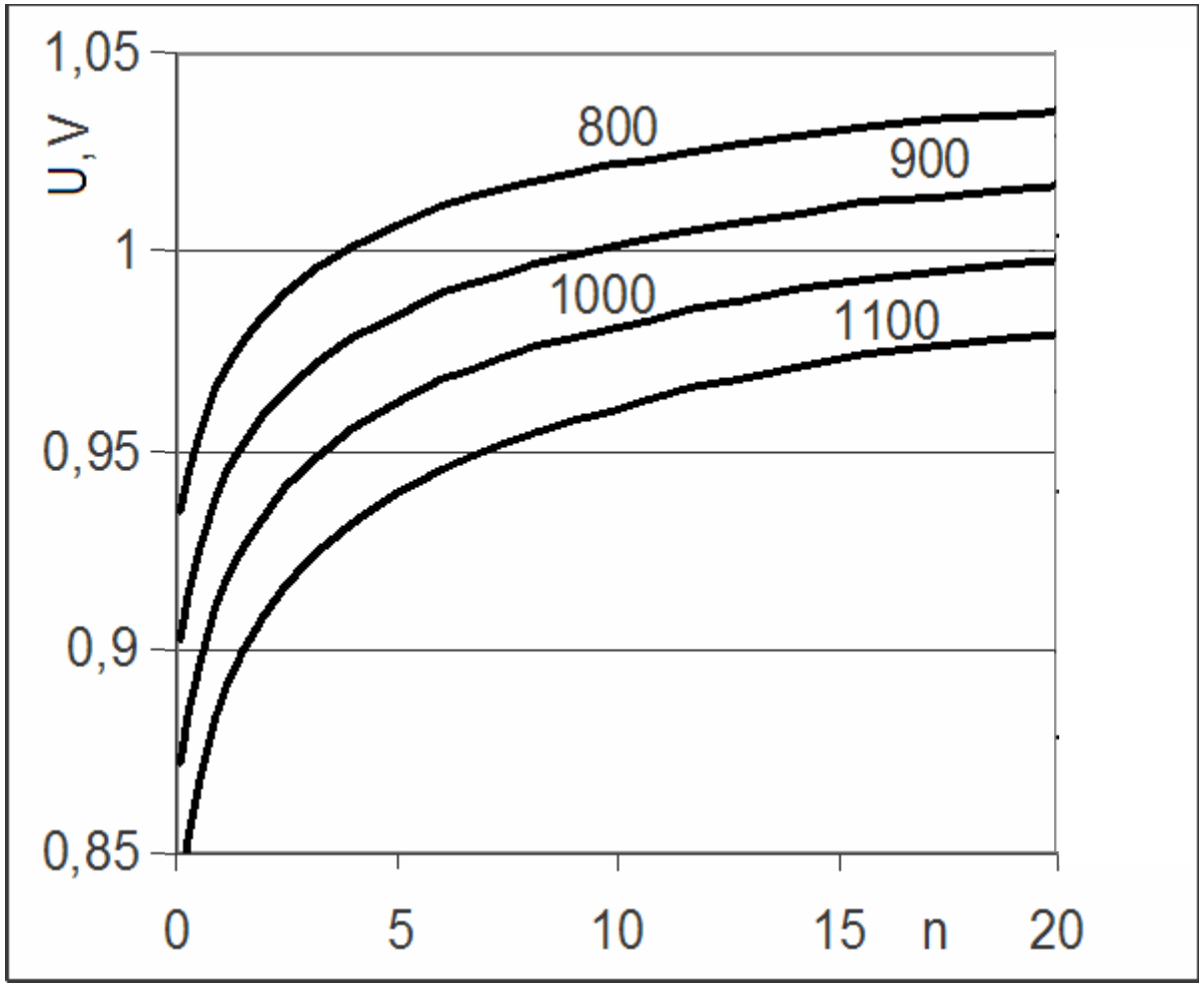
# Distribution of $p_{H2}$ EMF along the SOFC




Numbers on the curves are recirculation numbers (a ratio of hydrogen flow in the hydrogen loop to the hydrogen flow at the system inlet); solid lines correspond to a stack; dashed lines correspond to a single cell)

# Dependence of the average EMF, cell voltage and efficiency on the recirculation number for various temperatures (LHV)

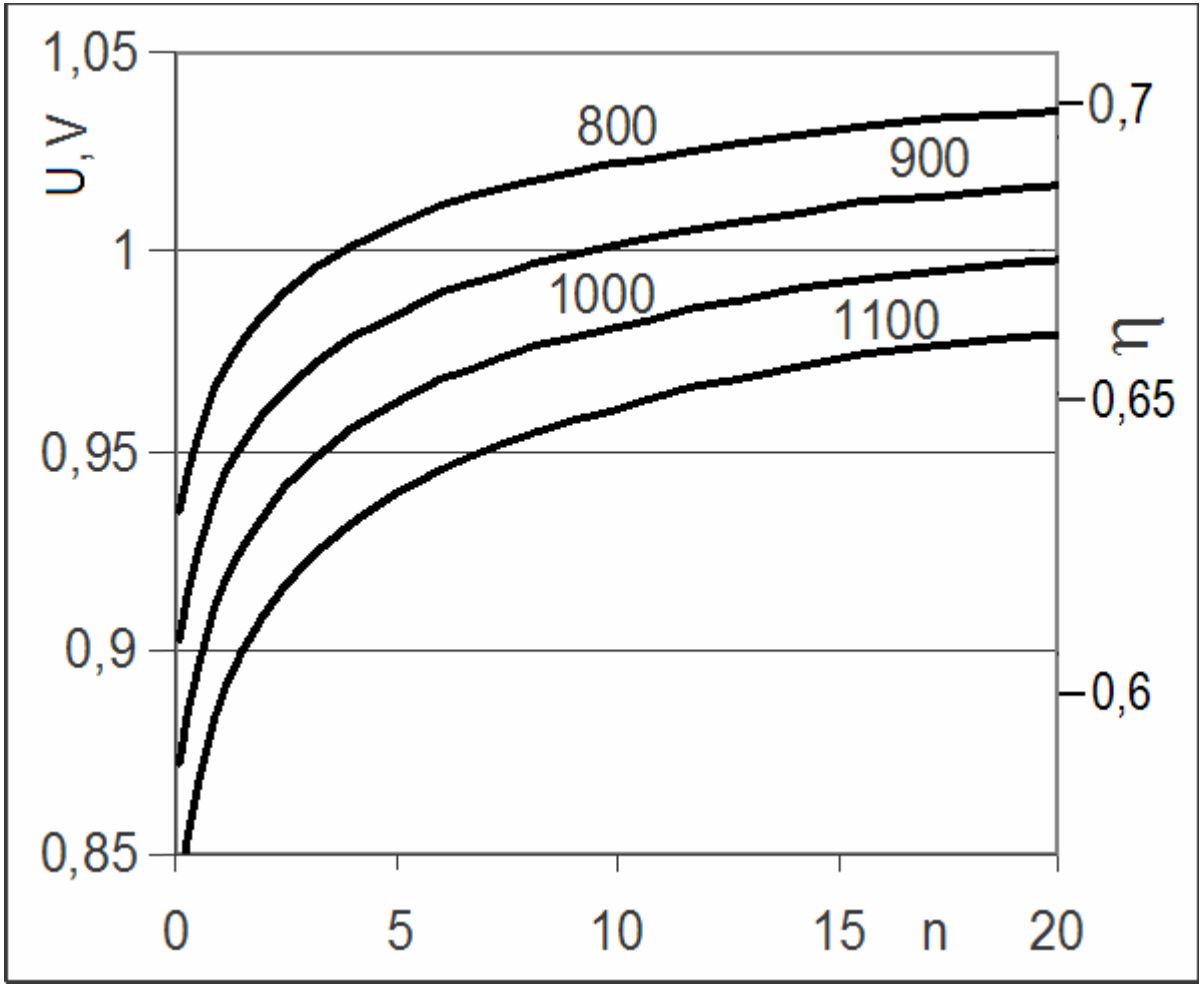



$\eta_{max}$ и $\eta$ are calculated for LHV

$\eta$ is calculated for $(E_{av} - U) = 0,1$ V

In the modern SOFCs, the internal losses of 0,1 V correspond to the current density 0,5 – 0,8 A/cm$^2$.

# Dependence of the average EMF, cell voltage and efficiency on the recirculation number for various temperatures (HHV)




$\eta_{max}$ и η are calculated for HHV

η is calculated for $(E_{av} - U) = 0,1$ V

# Conclusion

**SOFC has high efficiency when operating with natural gas: > 60% at $P_r$ = 0.7 and 750$^0$C, that is visibly higher than that of other known types of electrical generators of low power. It is problematic to lessen its operating temperature because of difficulties with low temperature operation of the fuel processor**

**Efficiency of hydrogen-air SOFC having a loop for hydrogen recirculation can exceed 65% at a specific power of 0.5 W/cm$^2$. There are no limitations for the operating temperature reduction for this type of SOFC.**