THE EFFECT OF SUPERCRITICAL POWER CYCLES AT HYDROGEN PRODUCTION PLANTS

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CONTENTS

1 The goal

- The main goal of this informaton is to prepare basis for opprimization of high temperature H2 production in connection with GFR, HTR and VHTR.

- It is also necessary to analyse the criteria for optimization

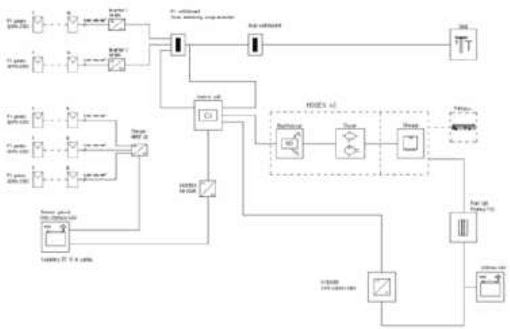
- The special effect of sCO2 cycles is analysed

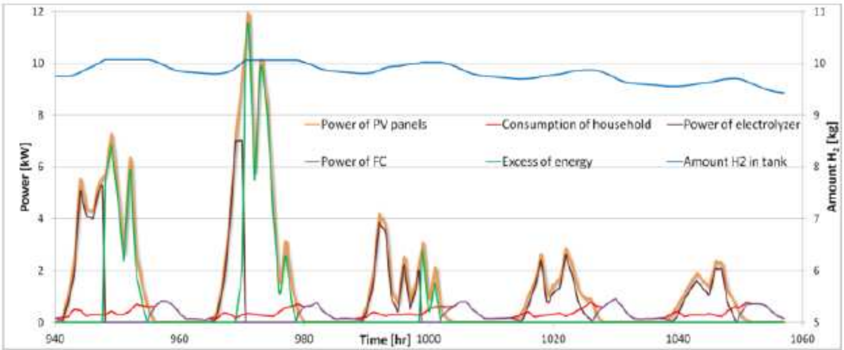
- The reqirememt outcoming from cycles optimization will going to HTE modification

2 High temperature electrolysis

Pilot Plant for Energy Storage in ÚJV Řež, Czech Republic

- **Main Parts**
  - Photovoltaic plant, electrolyzer (electricity → hydrogen), pressure tank 10 m³(N), fuel cellhydrogen→ electricity)





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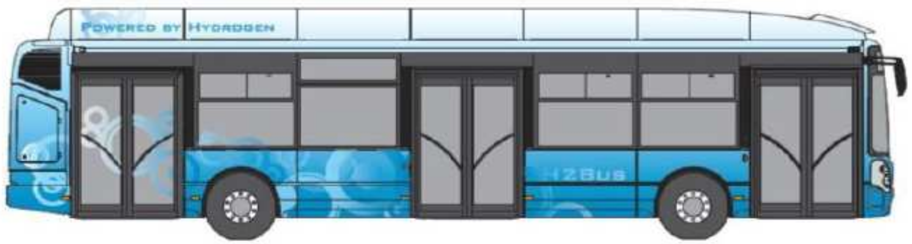
TriHyBus – Triple Hybride Hydrogen Bus

- **Operational parameters**
  - Weigh ~ 14 t
  - Maximal speed 65 km/hr
  - Consumption 7.5 – 8 kg H2/100 km
    - Full tank range 250 – 300 km



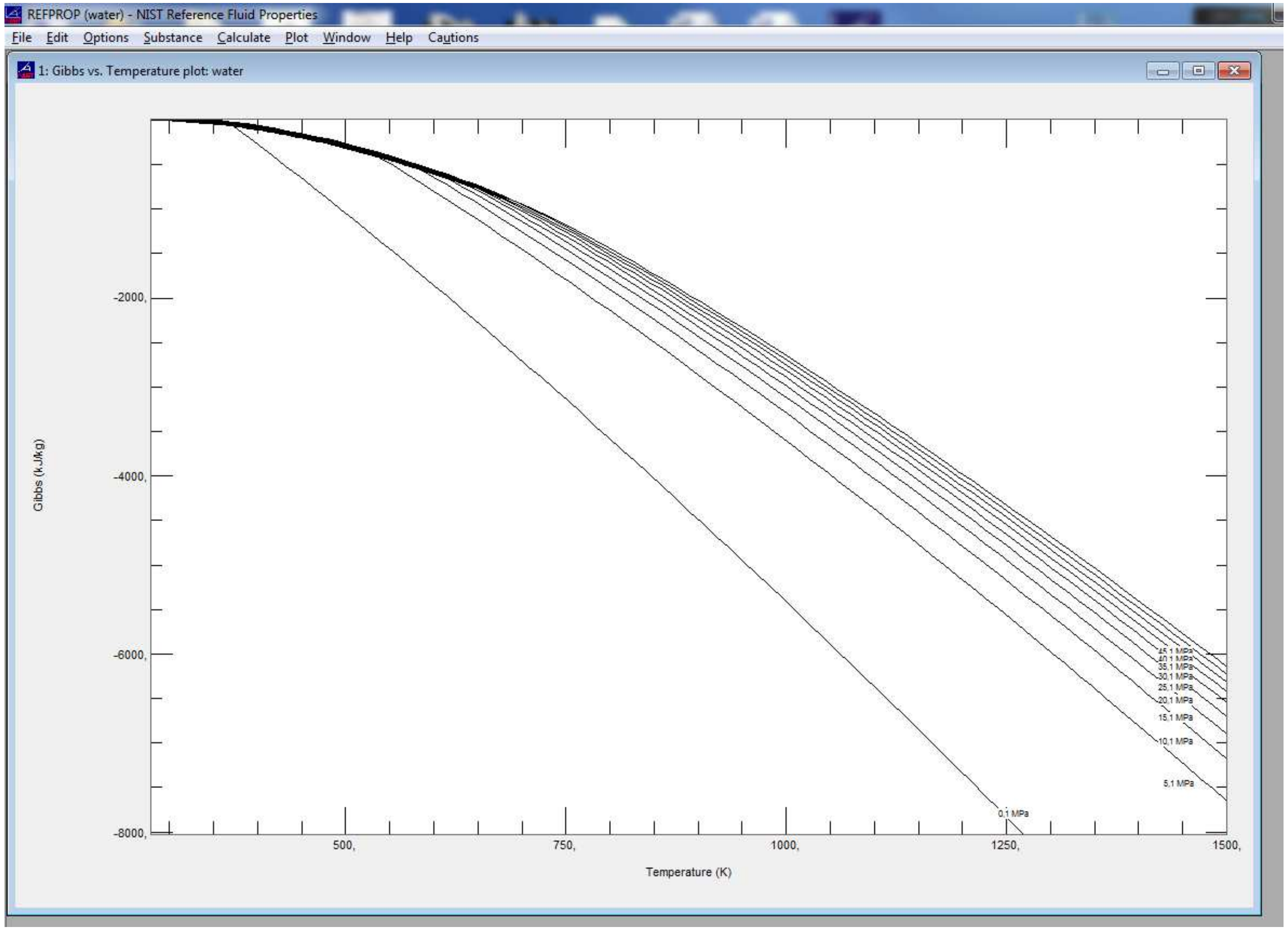
- **Hannover Fair 2010**
  - Hermes award nomination

- **Brno International engineering Fair**
  - Gold medal

2 High temperature electrolysis

2 High temperature electrolysis

- **The reduction of electricity consumption is done by Gibs energy**



- **The main equations**

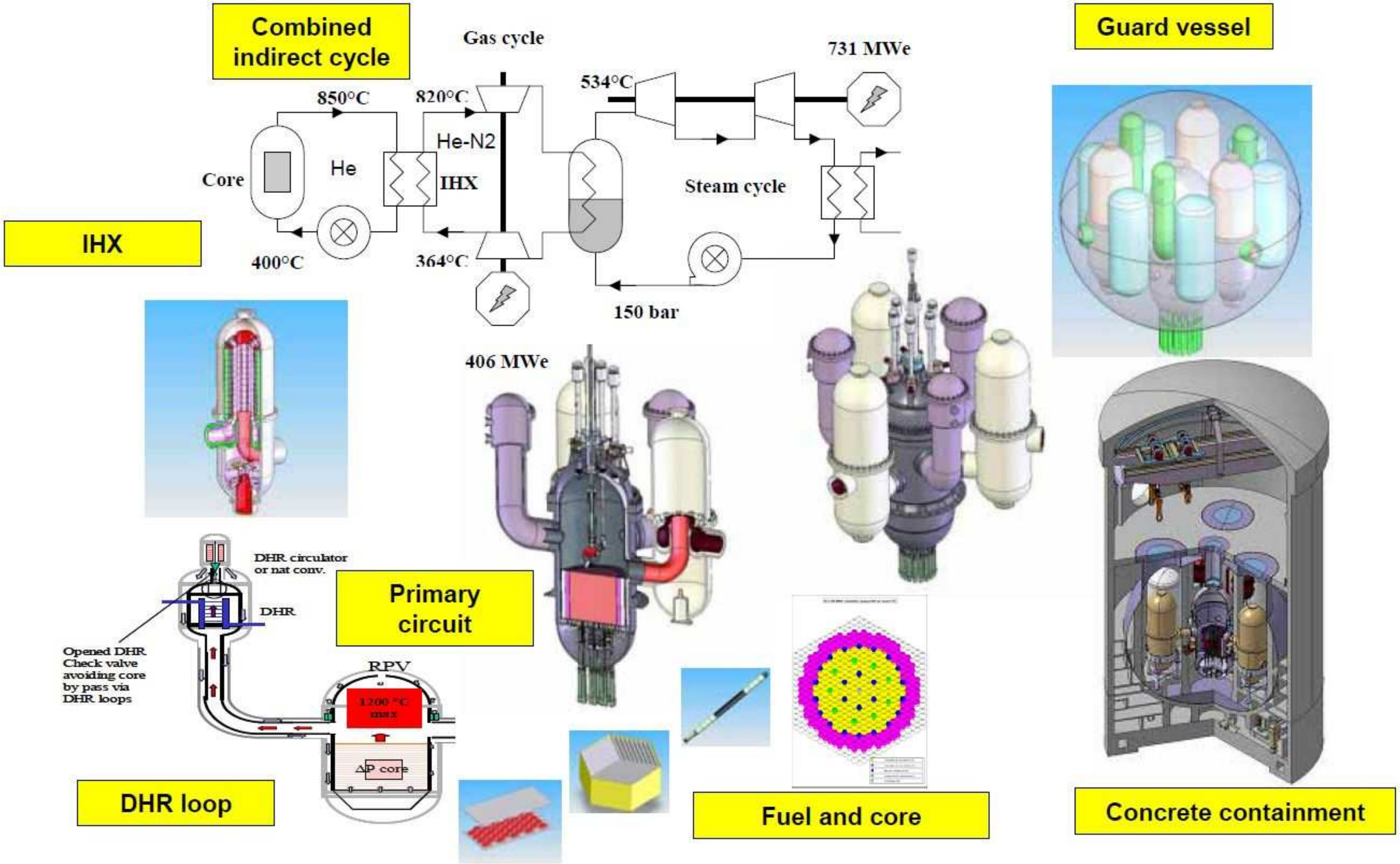
$$\Delta H_r(T) = \Delta H_{sl}(H_2)(T) + \frac{1}{2}\Delta H_{sl}(O_2)(T) - \Delta H_{sl}(H_2O)(T)$$

$$\Delta S_r(T) = S\ (H_2)(T) + \frac{1}{2}S\ (O_2)(T) - S\ (H_2O)(T)$$

$$\Delta G_r(T) = \Delta H_r(T) - T\Delta S_r(T)$$

3 Gas Fast Reactors

- The CEA's 2007 GFR Reference Concept – 2400 MWth Reactor



The CEA's 2007 GFR Reference Concept

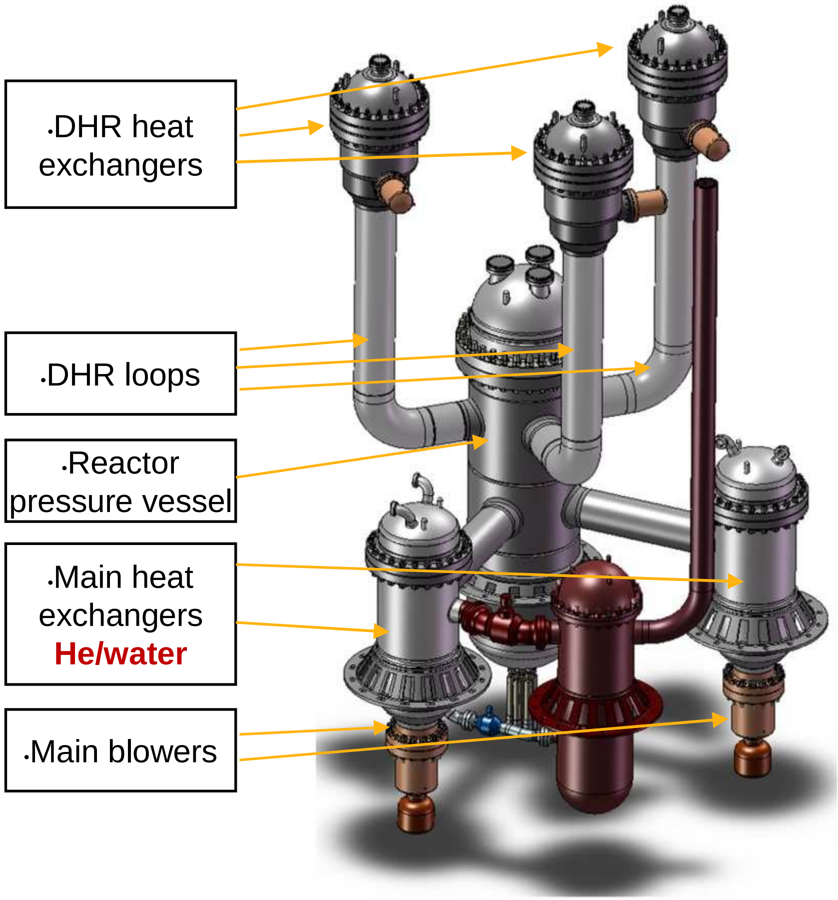
COMMENTS:

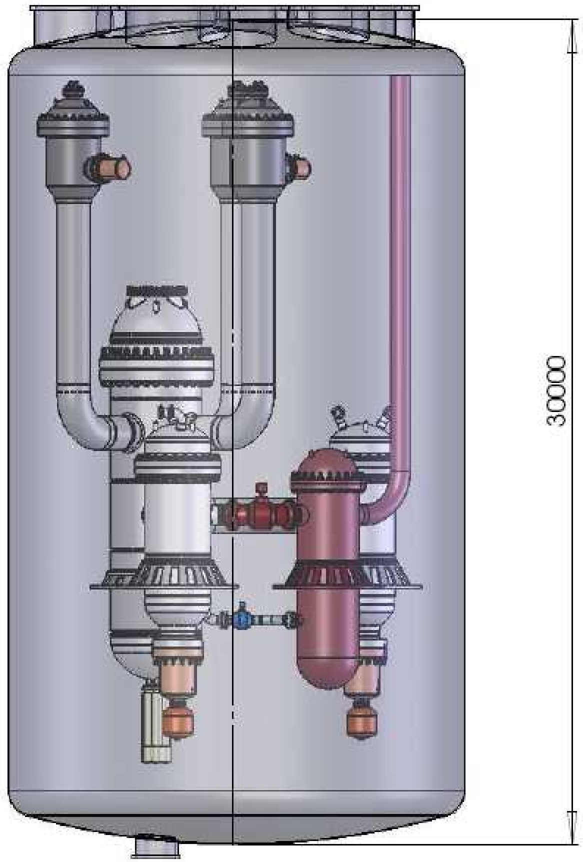
- **Main supposed advantages:**
  - no activated coolant
  - appropriate efficiency more than 40%
- - high temperature heat
-

Main supposed problems:
  - very high temperatures
  - material problems
- - fuel, fuel manipulation
- - safety
  - He is very bad coolant (in comparison with water, liquids metals)
- **GFR concept has no connection to the hydrogen production**

3 Allegro

The CEA's GFR experimental reactor – 75 MWth Reactor





4 Conversion cycles

- The main goal of this information is to prepare basis for optimization.
- In this first step of analysis was no possible to include all factors into optimization.
- Some of them was fixed from different reasons:
- - Input temperature (400℃) into He reactor – the rae ason is avoid too large temperatures differences
- - High pressure of He into coversion cycle (6,5 MPa) – it must by lower than pressure into primary circuit
- - Low pressure of sCO2 cycle – fixed at 7 Mpa due low compression enthalpy

4 Conversion cycles

- The optimal plant configuration of high temperature H2 production is **no added** energy and **no cooling** of conversion cycle

- From this is derived main criterion:

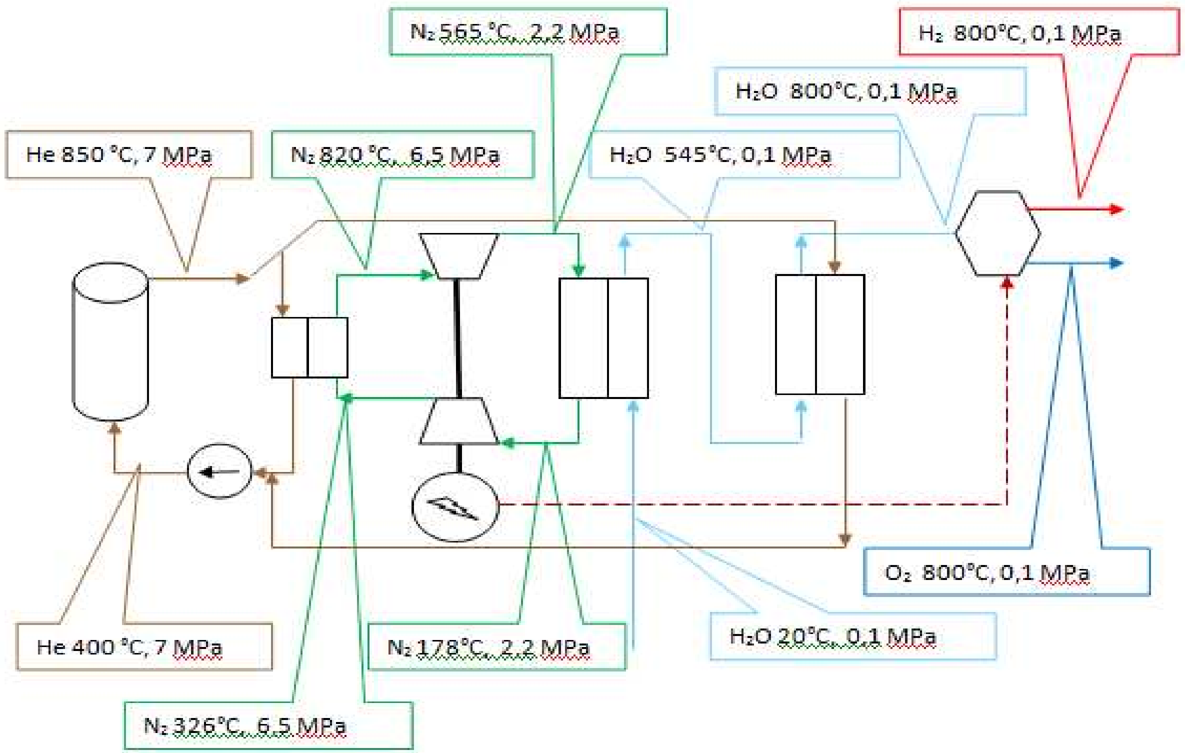
Electrolysis energy ratio = {electrical power of coversion} / { necessary power for HTE }

- The cooling energy from conversion cycle must be used minimally for water evaporation

- The He and O2 regeneration is not included in calculations

4 Conversion cycles - He

Schema I

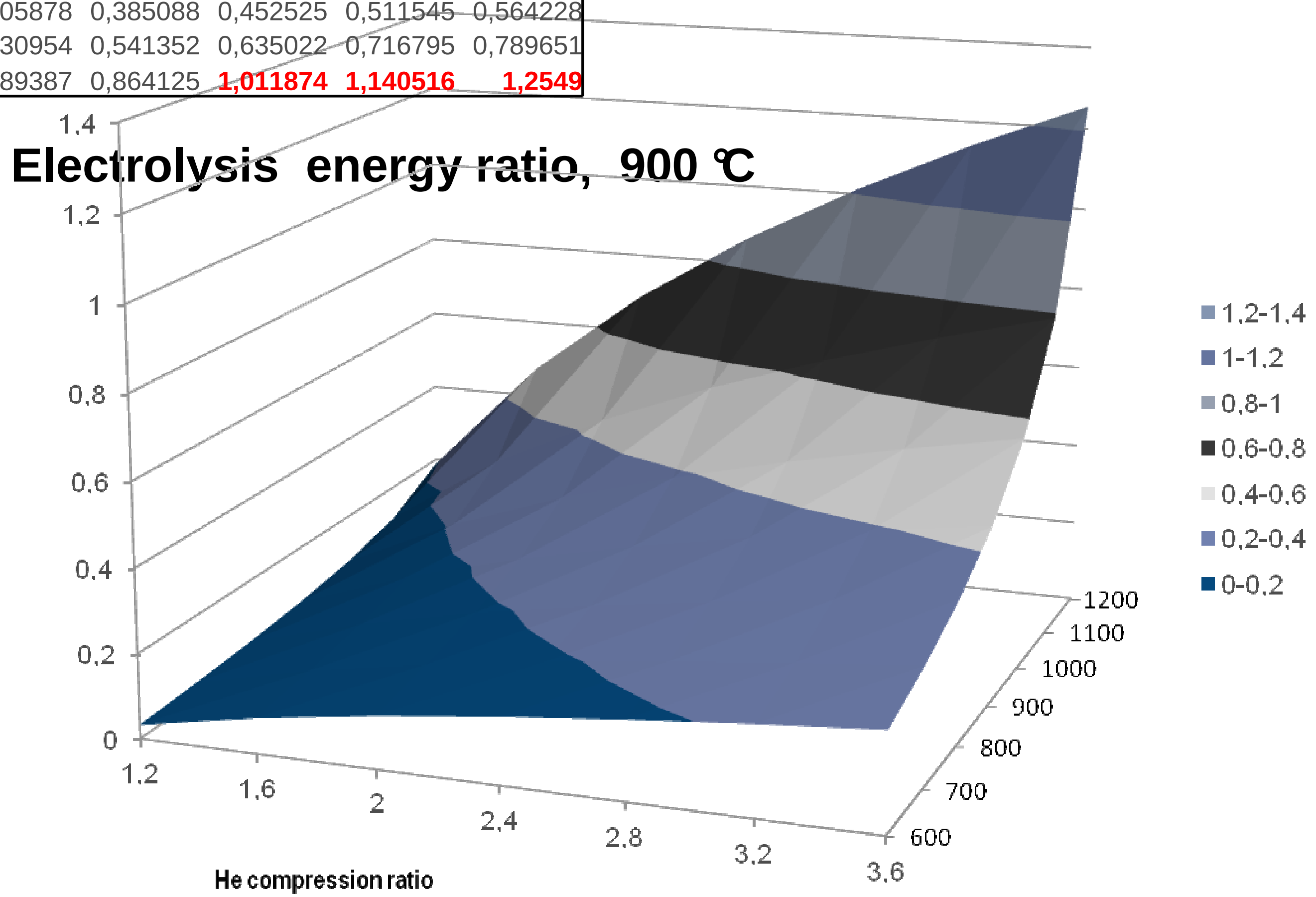


- Indirect Brayton cycle, without H2 and O2 regeneration
- Realistic and acceptable solution

4 Conversion cycles- He

3D graf

t high \ compression	1,2	1,6	2	2,4	2,8	3,2	3,6
600	0,03248	0,083838	0,124172	0,157668	0,186433	0,211659	0,234058
700	0,039424	0,101316	0,149635	0,189647	0,224001	0,254216	0,281232
800	0,048791	0,124852	0,183847	0,232502	0,274184	0,310816	0,343595
900	0,062082	0,158201	0,232257	0,293063	0,345	0,39056	0,431291
1000	0,082331	0,208961	0,305878	0,385088	0,452525	0,511545	0,564228
1100	0,116772	0,295246	0,430954	0,541352	0,635022	0,716795	0,789651
1200	0,187979	0,473587	0,689387	0,864125	**1,011874**	**1,140516**	**1,2549**

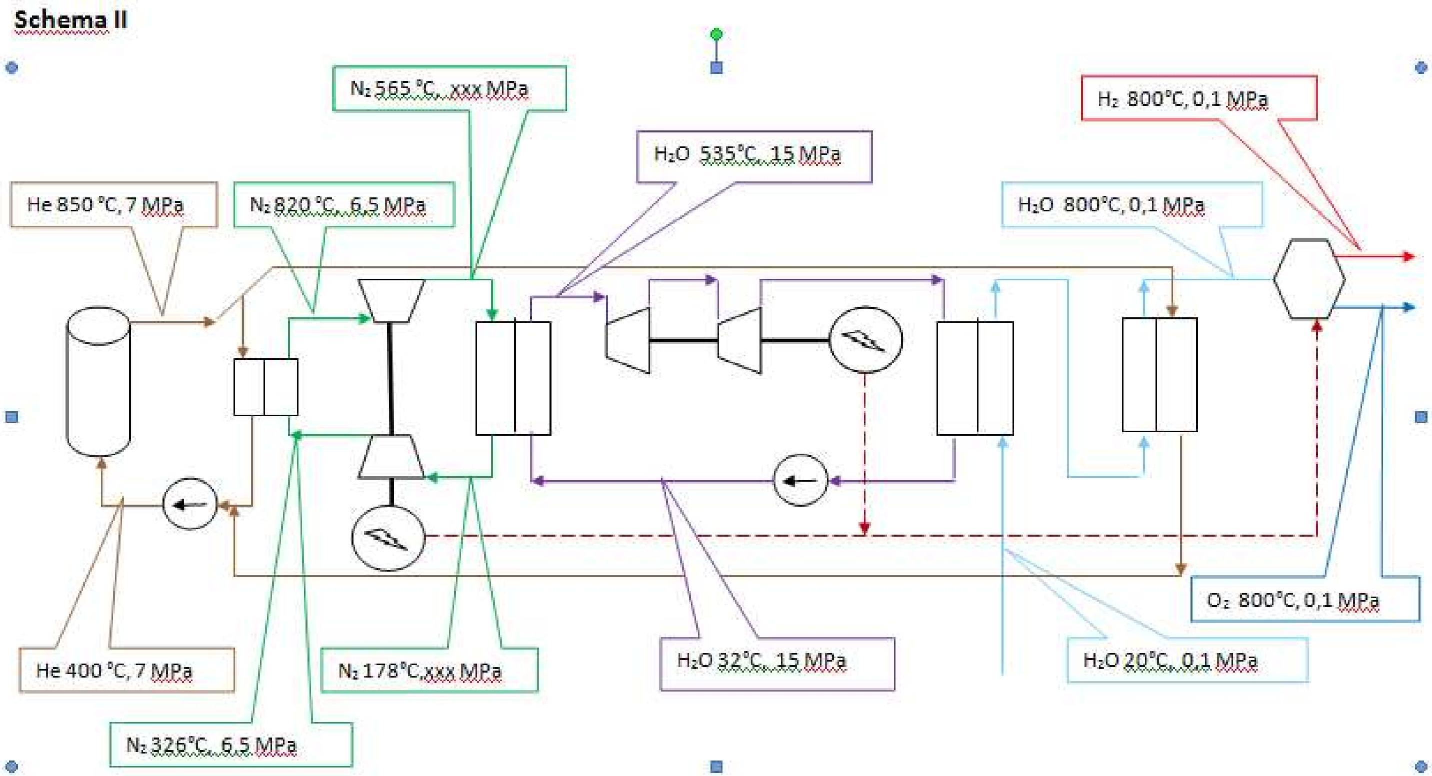


4 Conversion cycles- He

- **He cycle summary**

- **At the area 1200 ℃ is ideal output from the cycle, o nly hydrogen and oxygen, but 1150 ℃ heated**
- **The cycle has 0 cooling**
- **The He and O2 regeneration is not included in calculations, it can shift the temperatures down**
- **Realization of this reactor is now stopped, mainly safety reasons, , material problems**

4 Conversion cycles- He & steam



- Combined cycle, He and steam, without regeneration

4 Conversion cycles cycles- He & steam

- Combined cycle summary

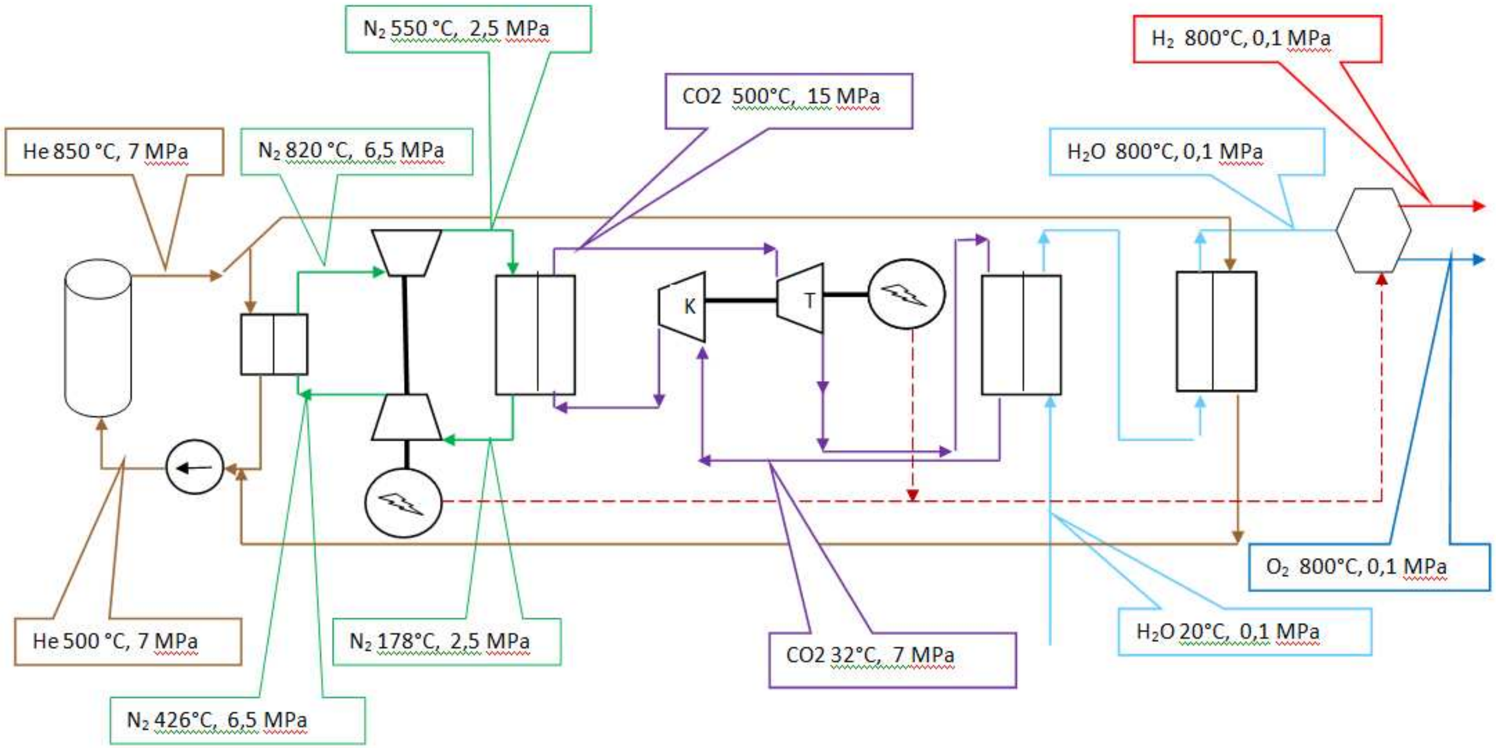
- The cooling heat of the cycles near 40 ℃, this hea t can not be used for water evaporation (according defined criteria)

- SOLUTIONS:
- The increasing lower temperature of the cycle above 100 ℃ has no sense, the efficiency loss is important
- Using the steam from the cycle is connected with pressurizing up to 1 bar, to high compression enthalpy

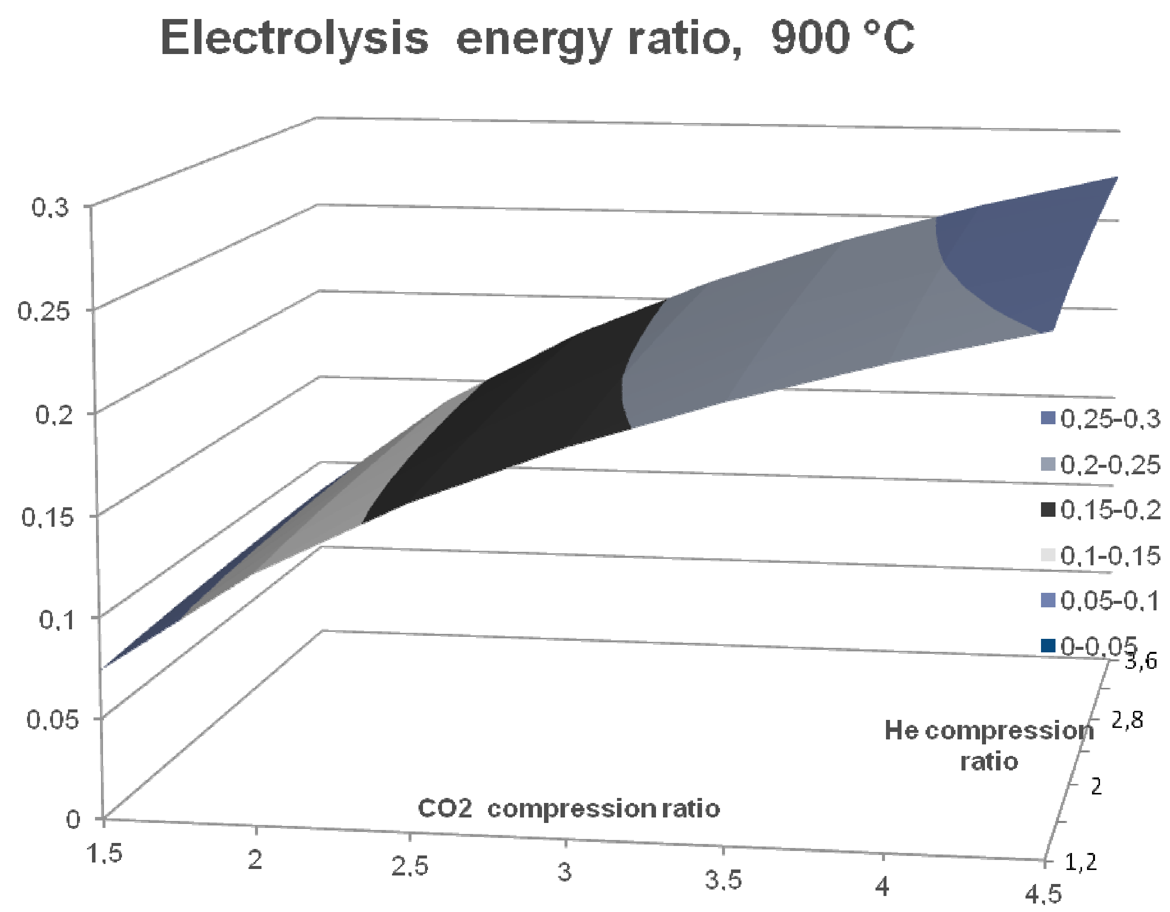
- CONCLUSION
- The cycle is not suitable for HTE

4 Conversion cycles – He & sCO2

Schema III

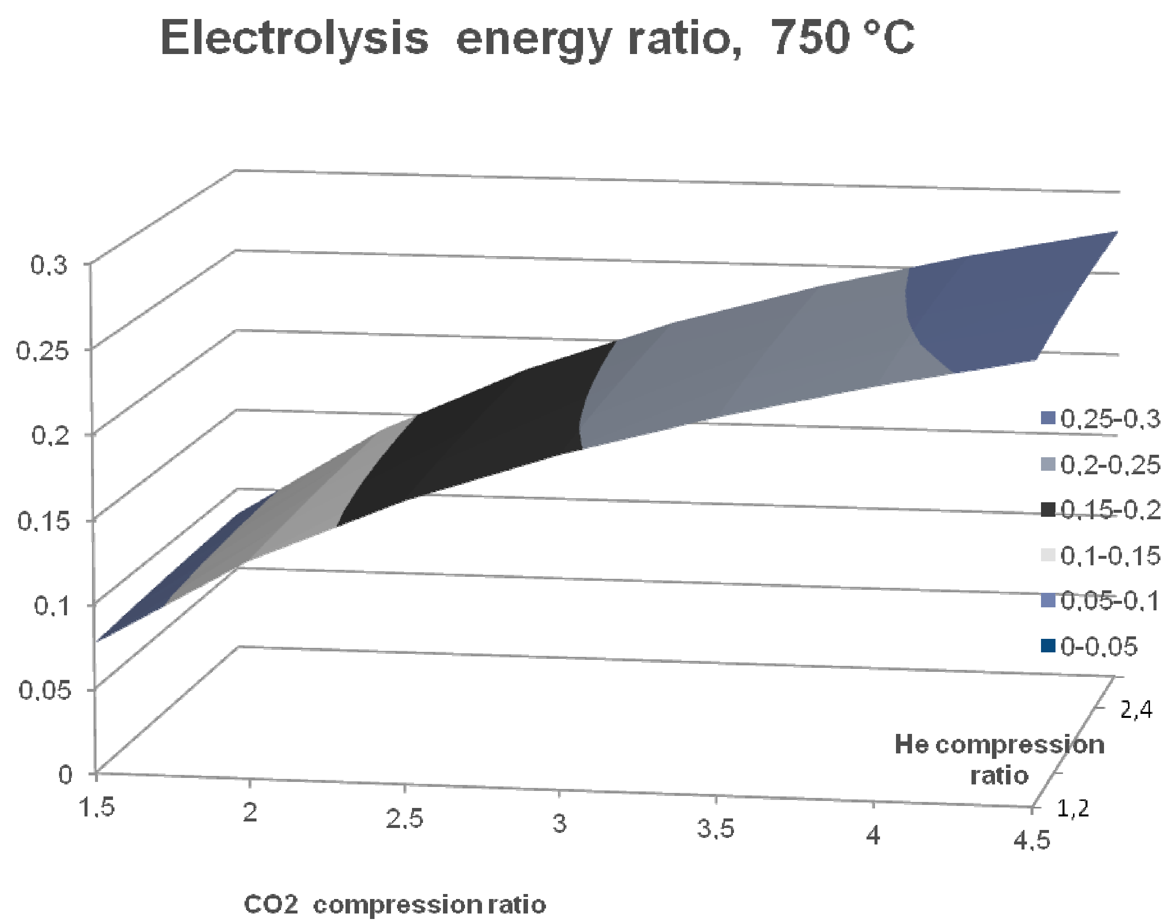


4 Conversion cycles – He & sCO2



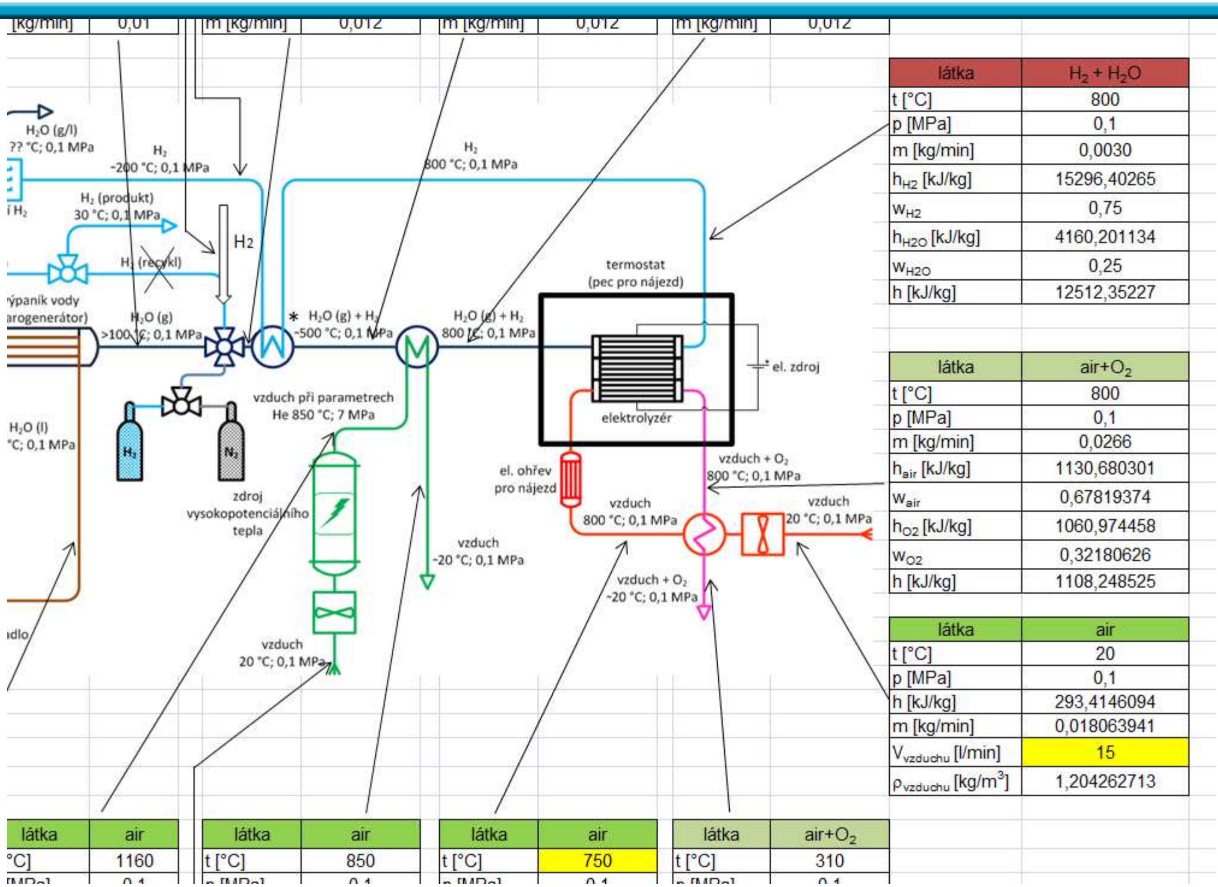
- Combined cycle with sCO2, without regeneration

4 Conversion cycles – He & sCO2



- Combined cycle with sCO2, without regeneration

4 Conversion cycles - H2 and O2 regeneration

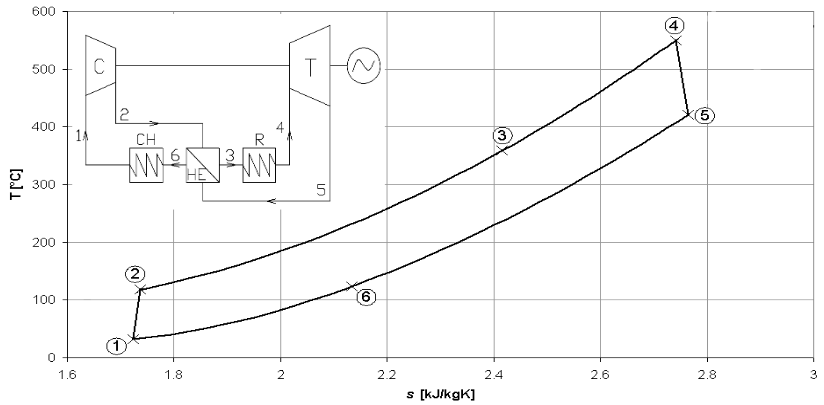


H2 and O2 regeneration

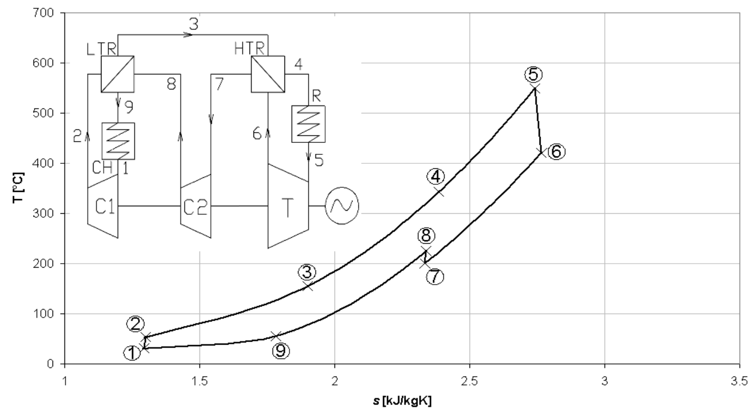
- At real HTE is not output pure:
- - hydrogen has high content of water
- - oxygen is mixed with air
- The main criterion is cycle optimization, and for optimization is not necessary take into account all, but the same condition

4 Conversion cycles– He & sCO2

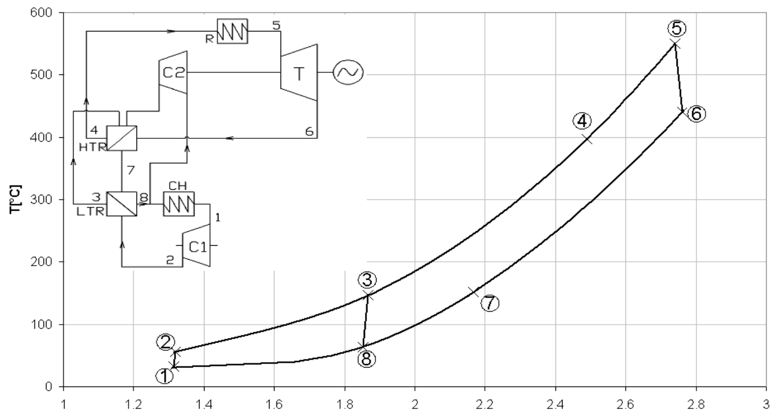
- Simple Brayton (A)



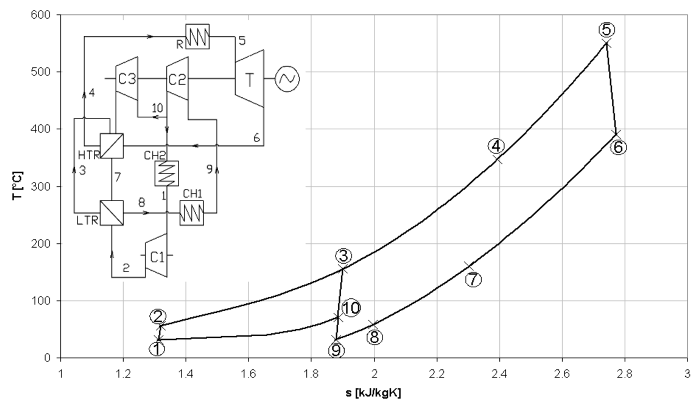
- Pre-compression (B)



- Re-compression (C)



- Partial Cooling Cycle (E)



4 Conversion cycles – He & sCO2

- CONCLUSIONS
- The He and sCO2 cycles calculations show promissing results at the power plant connected with HTE
- The hydrogen and oxygen regeneration can improve the electrolysis energy ratio
- Different cycles architecure can also imrove the ratio, but first results are negative. The detailed analysis is necessary.

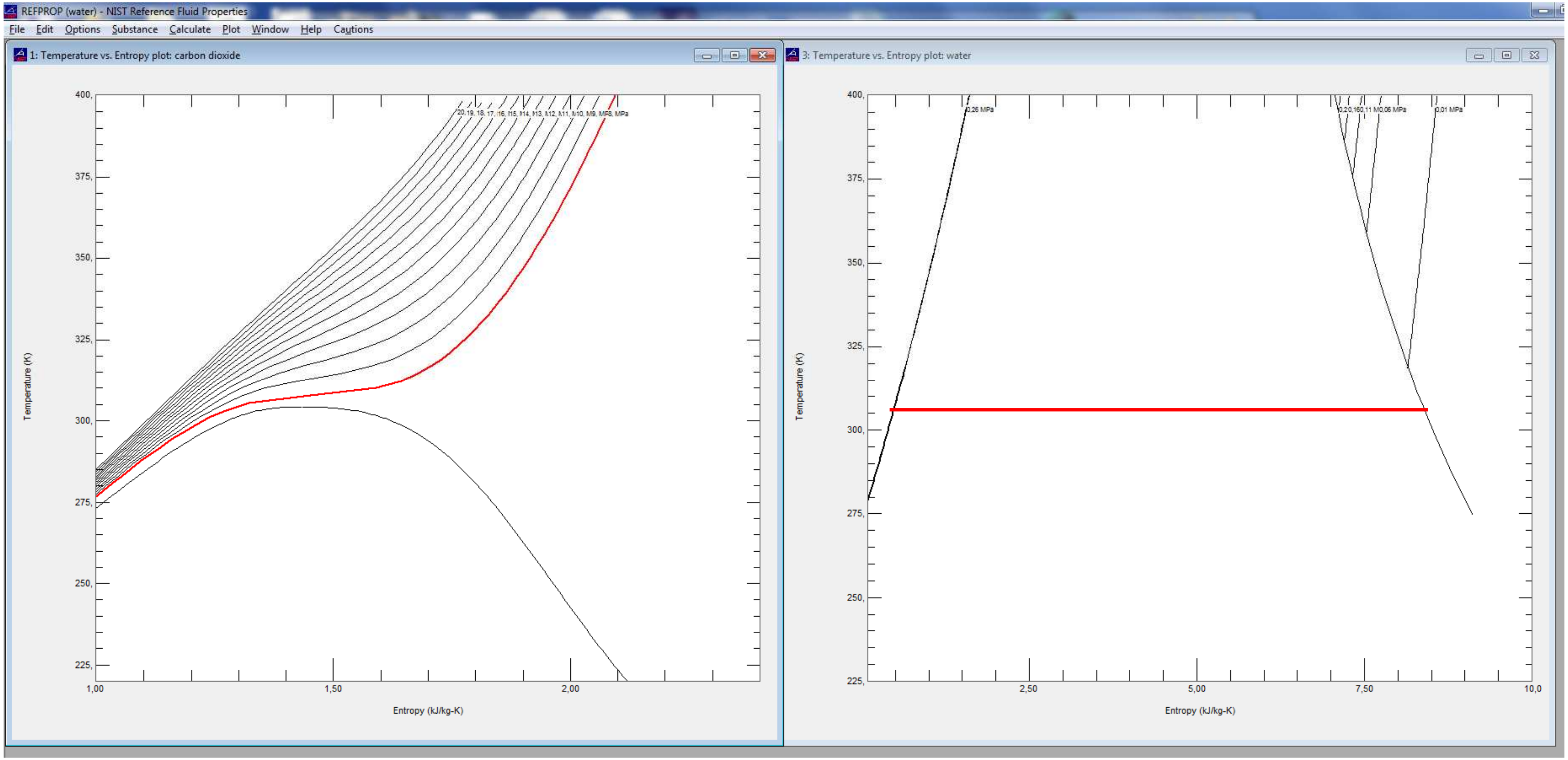
5 Next steps

- The final list of conversion cycles
- The SW connected with NIST
- Results evaluation
- Cycles optimization (for example minimum of HX etc.)
- Define new reqirements to HTE

CO2 cycles future

- Now is not probable that any important investor start with sCO2 cycle realization only for several % calculated growth of efficency
- The steam cycle is more than one hundert years operated and tested, at CO2 is this experience missing
- The effect of lower dimensions of sCO2 cycle goes to lower costs, but this is also not so important
- This important difference between steam cycle and CO2 cycle is cooling heat (see the pict.)

CO2 cycles future



Thank you for attention