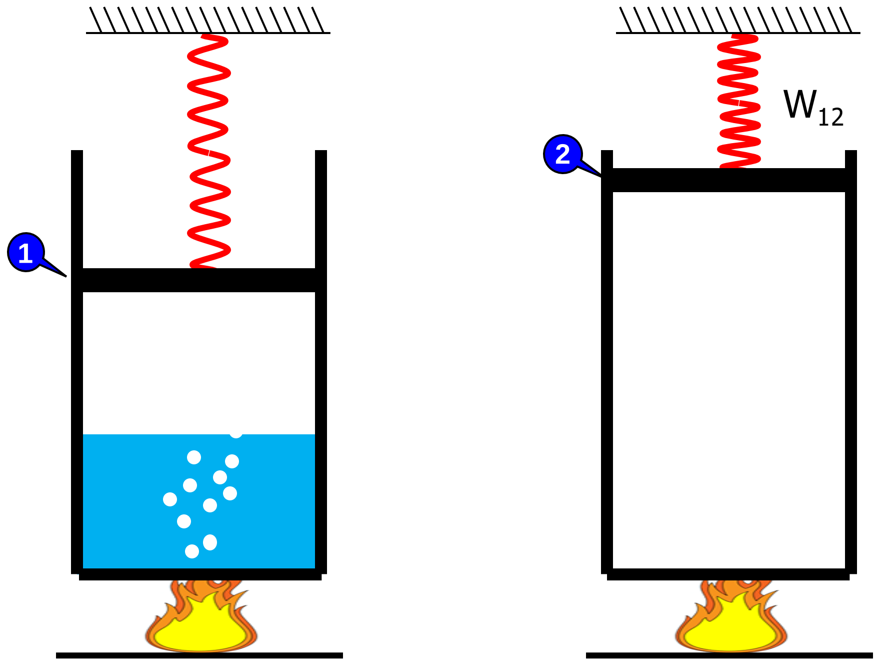
EQUAÇÕES DE BALANÇO DE ENERGIA PARA SISTEMAS FECHADOS

Paulo Seleghim Jr.
Universidade de São Paulo

Sistemas Termodinâmicos:

Fechado: não há fluxo de massa em suas fronteiras

Aberto: há fluxo de massa em suas fronteiras

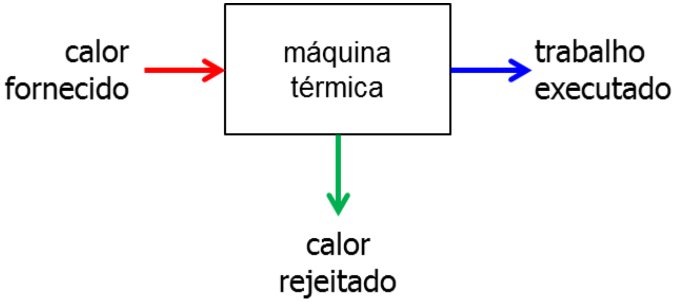


$$\Delta U = Q_{12} - W_{12}$$

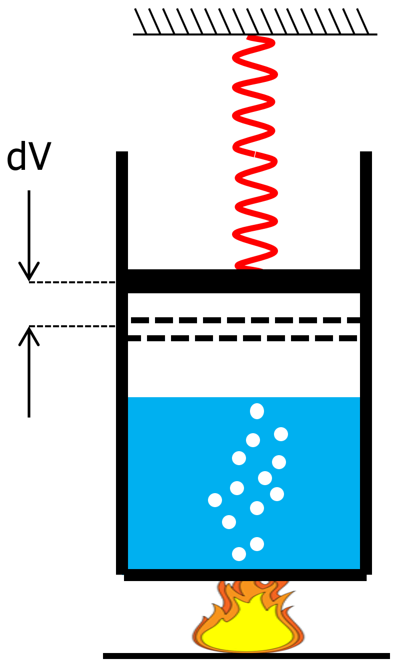
$$U_2 - U_1 = Q_{12} - W_{12}$$

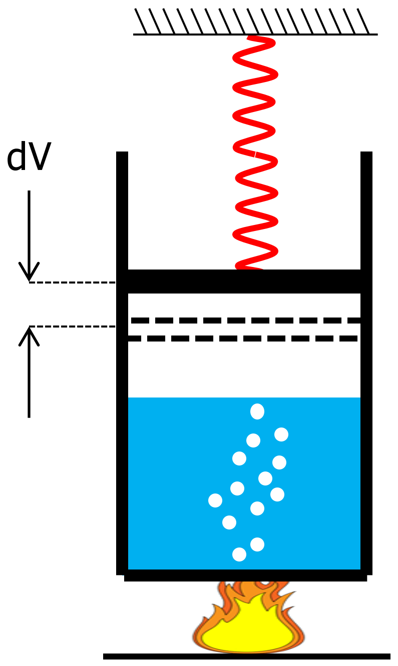
Q_{12} = calor fornecido para o sistema (>0)

W_{12} = trabalho executado pelo sistema (>0)



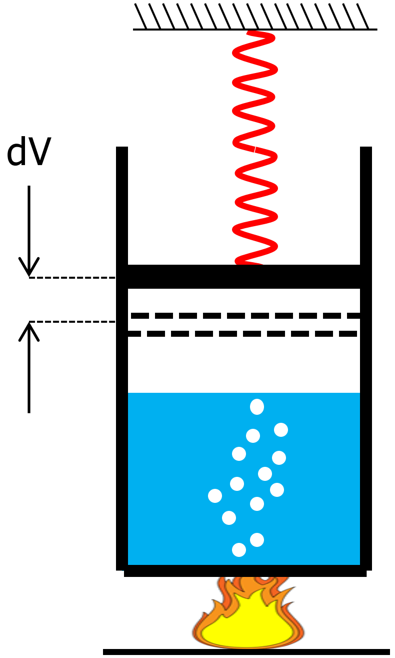
$$\delta W = F \cdot dx$$





$$\delta W = F \cdot dx$$

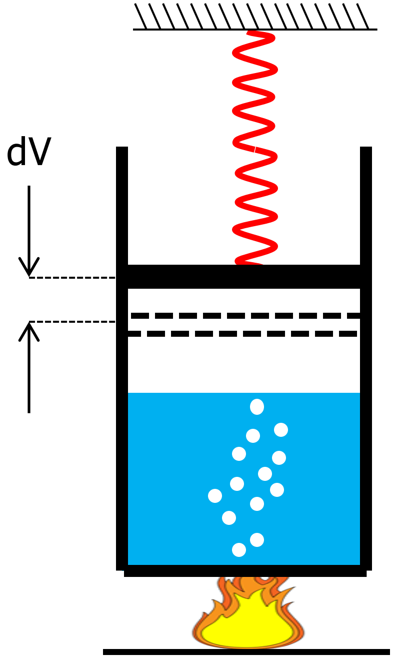
$$\delta W = (P \cdot A) \cdot dx$$



$$\delta W = F \cdot dx$$

$$\delta W = (P \cdot A) \cdot dx$$

$$\delta W = P \cdot (A \cdot dx)$$

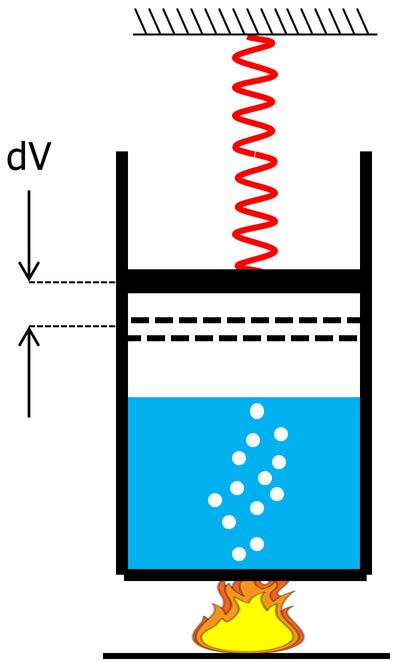


$$\delta W = F \cdot dx$$

$$\delta W = (P \cdot A) \cdot dx$$

$$\delta W = P \cdot (A \cdot dx)$$

$$\delta W = P \cdot dV$$



$$\delta W = F \cdot dx$$

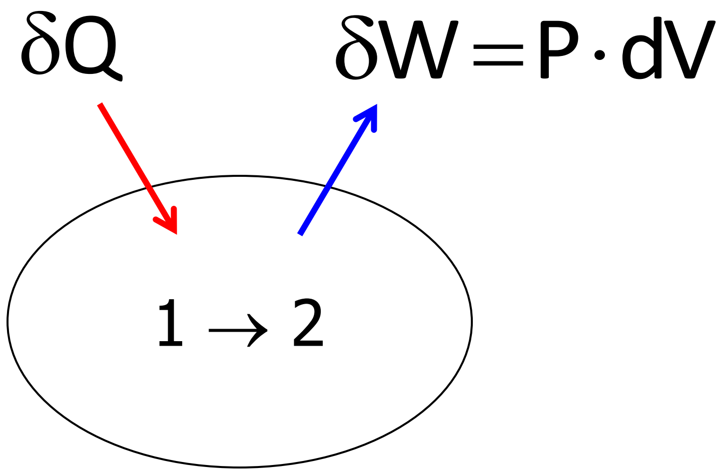
$$\delta W = (P \cdot A) \cdot dx$$

$$\delta W = P \cdot (A \cdot dx)$$

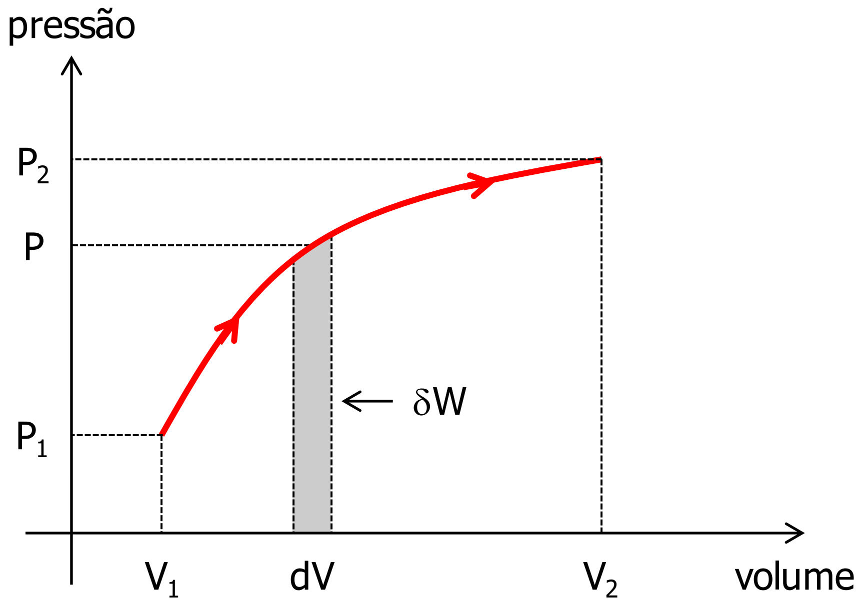
$$\delta W = P \cdot dV$$

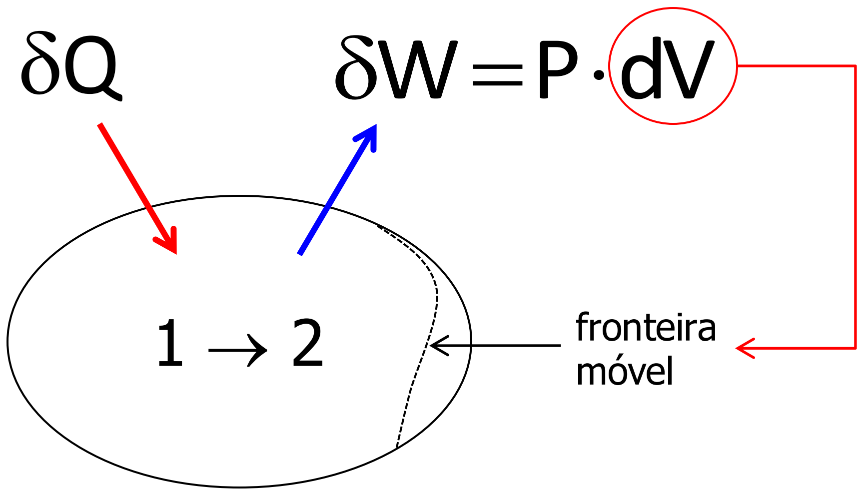
$$W_{12} = \int_1^2 \delta W = \int_1^2 P \cdot dV$$

O cálculo do trabalho requer o conhecimento da relação funcional entre P e V

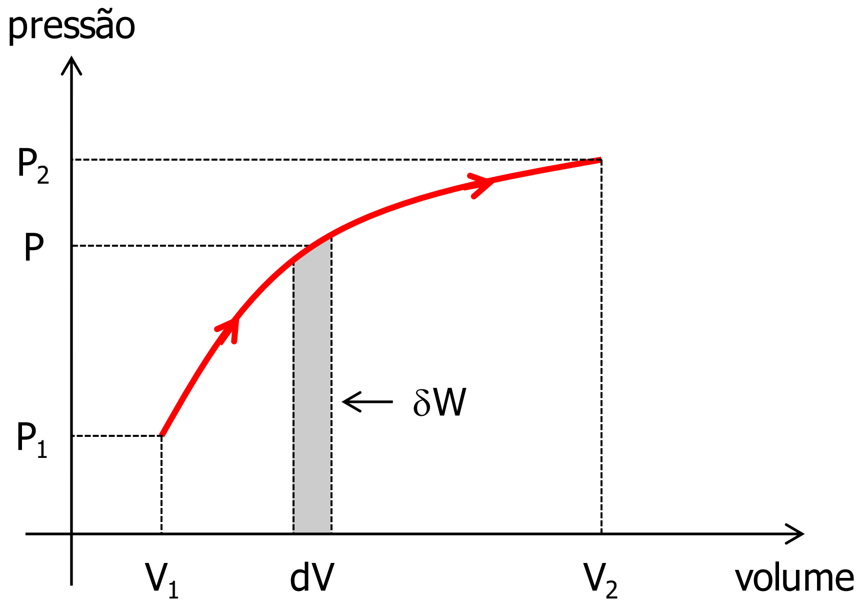


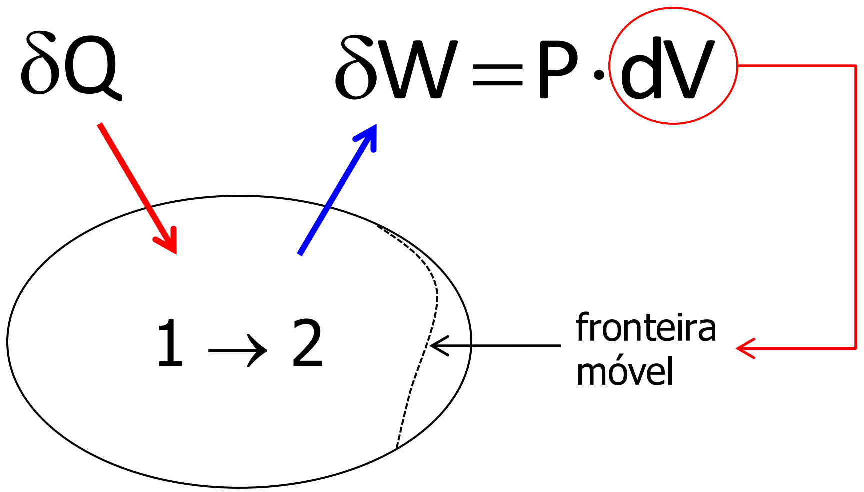
$$dU = \delta Q - \delta W$$





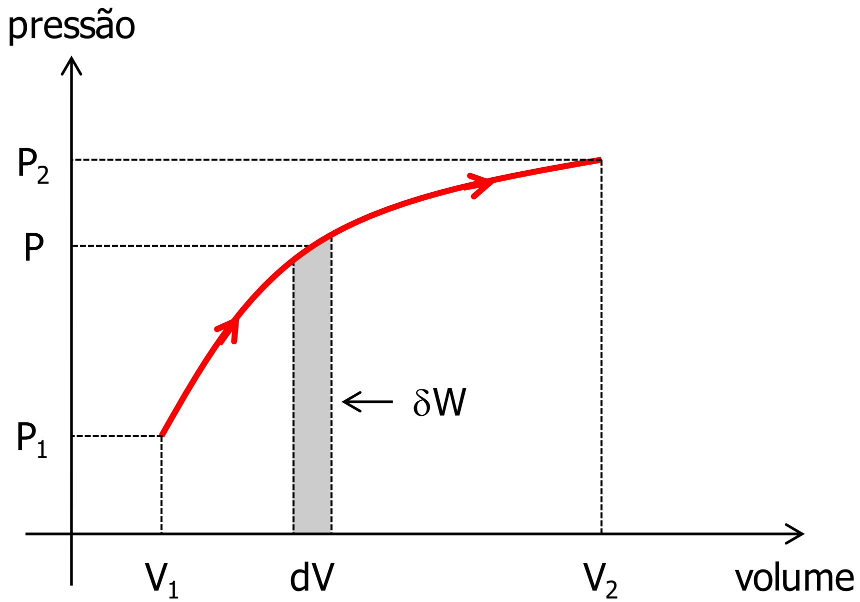
$$dU = \delta Q - \delta W$$

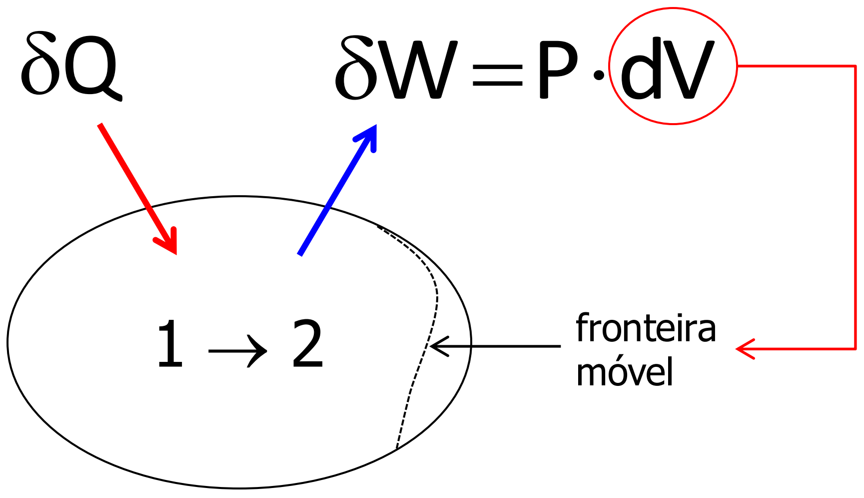




$$dU = \delta Q - \delta W$$

$$\int_1^2 dU = \int_1^2 \delta Q - \int_1^2 \delta W$$

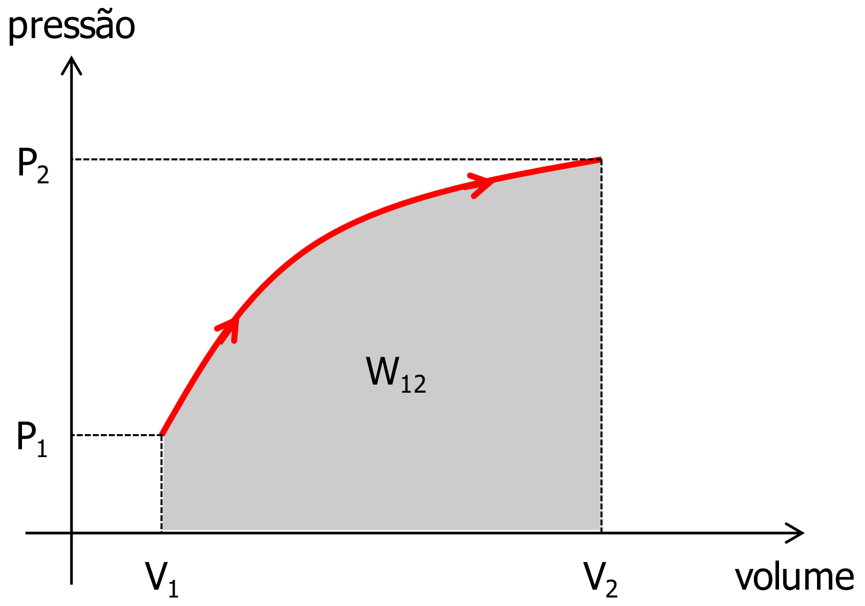




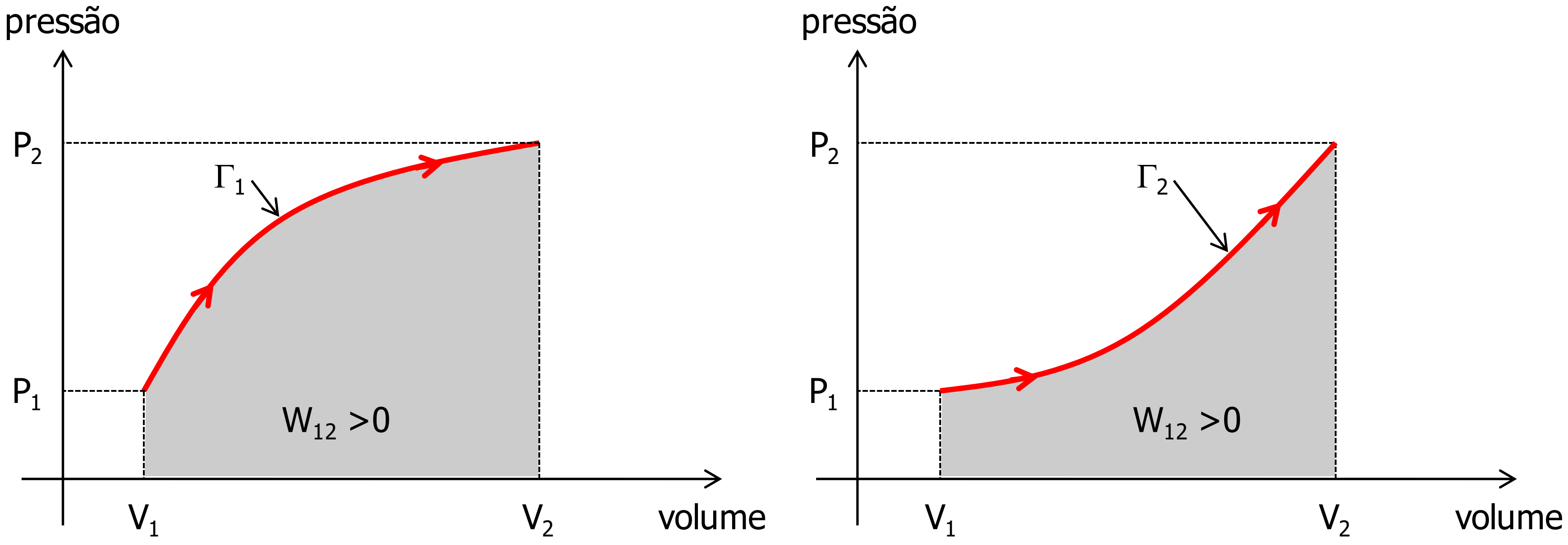
$$dU = \delta Q - \delta W$$

$$\int_1^2 dU = \int_1^2 \delta Q - \int_1^2 \delta W$$

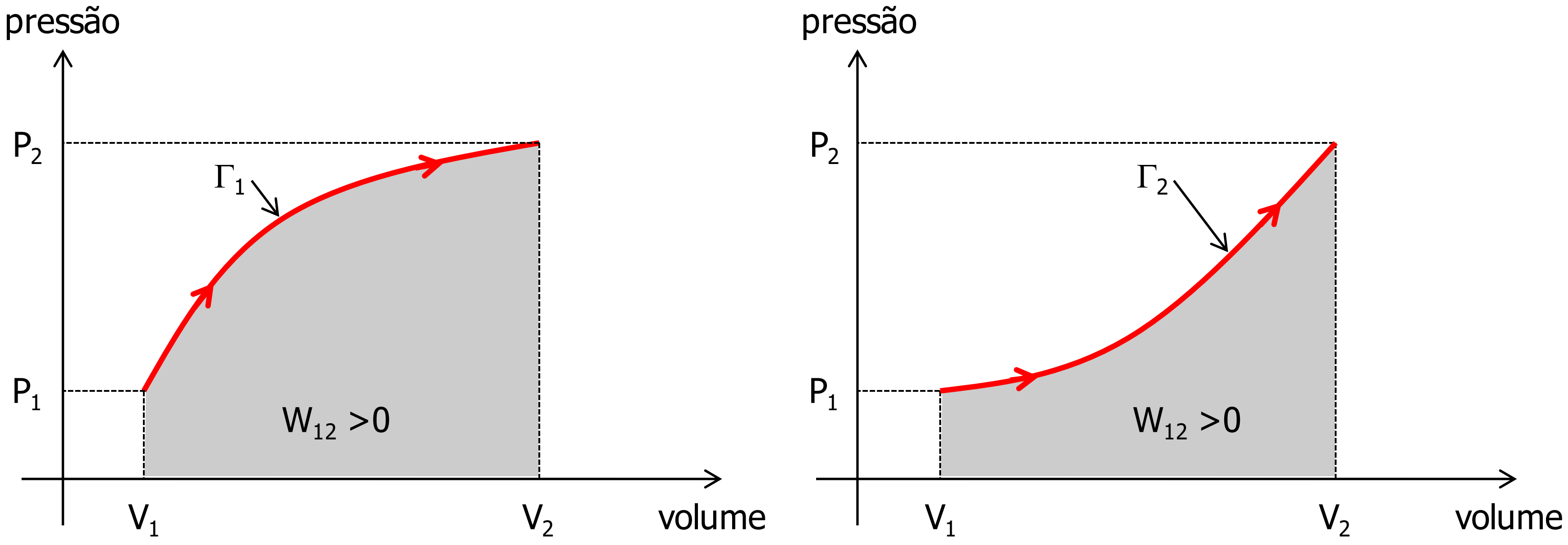
$$\Delta U = Q_{12} - W_{12}$$



Trabalho executado por diferentes transformações ligando os mesmos estados inicial e final...

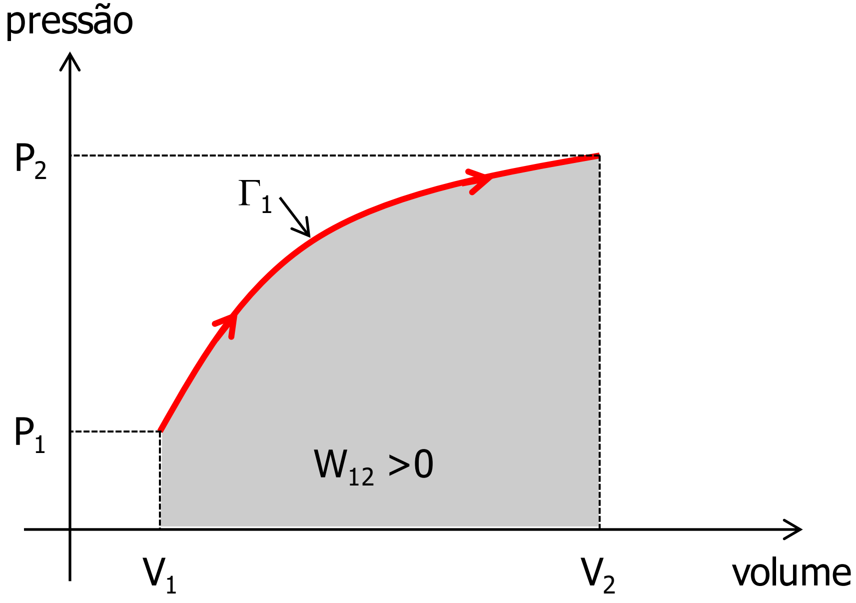


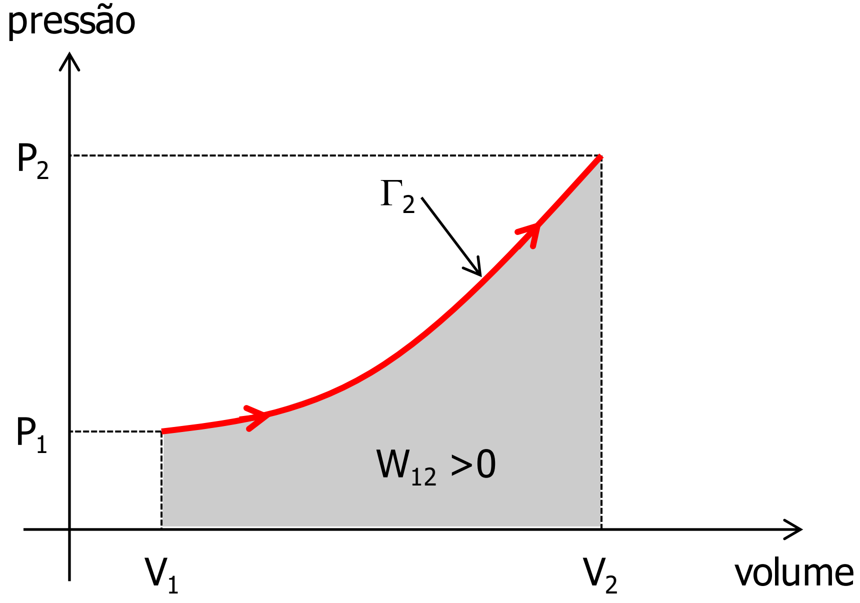
$$\int_{\Gamma_1} \delta W \neq \int_{\Gamma_2} \delta W$$



$$\int_{\Gamma_1} \delta W \neq \int_{\Gamma_2} \delta W$$

$$W\Big|_P = \int_{P=cte} P \cdot dV = P \cdot \Delta V$$

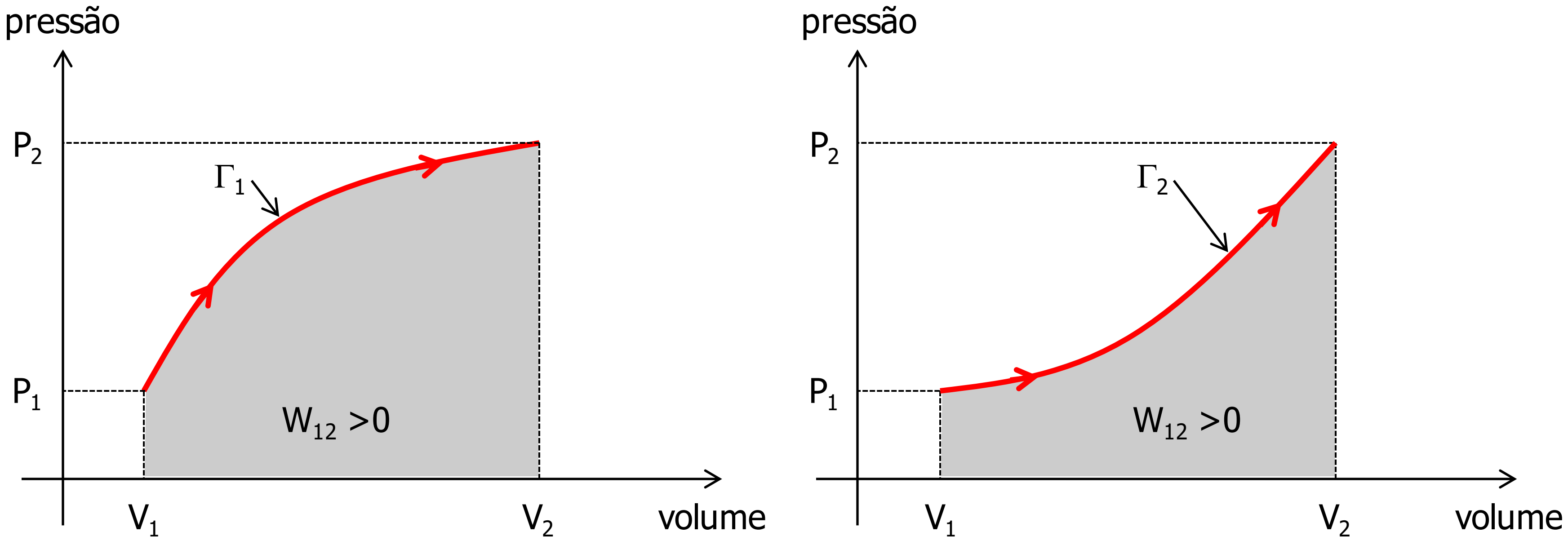




$$\int_{\Gamma_1} \delta W \neq \int_{\Gamma_2} \delta W$$

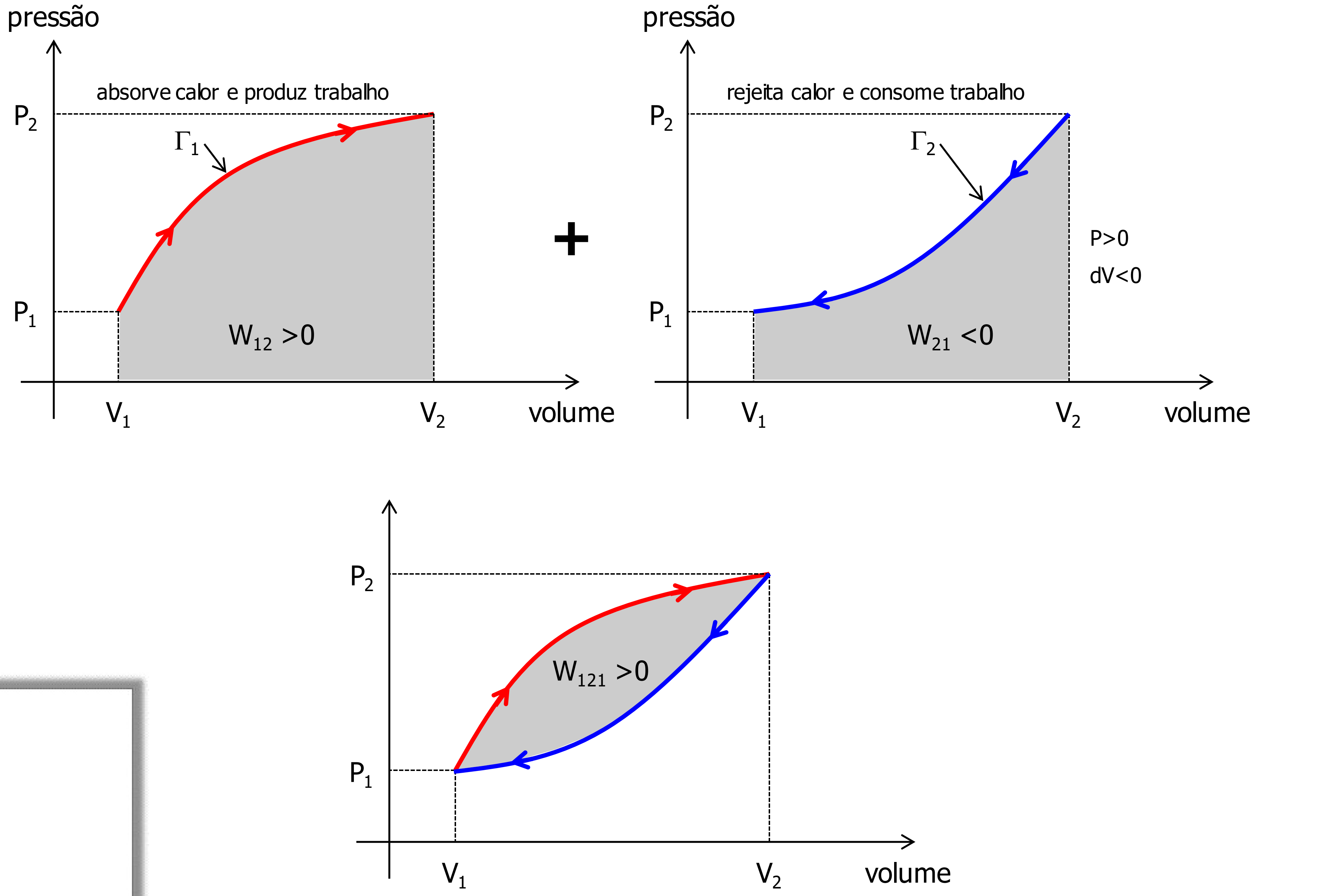
$$W\big|_P = \int_{P=cte} P \cdot dV = P \cdot \Delta V$$

$$W\big|_T = \int_{T=cte} P \cdot dV \overset{LGP}{=} nRT \cdot \ln(V_2 / V_1)$$



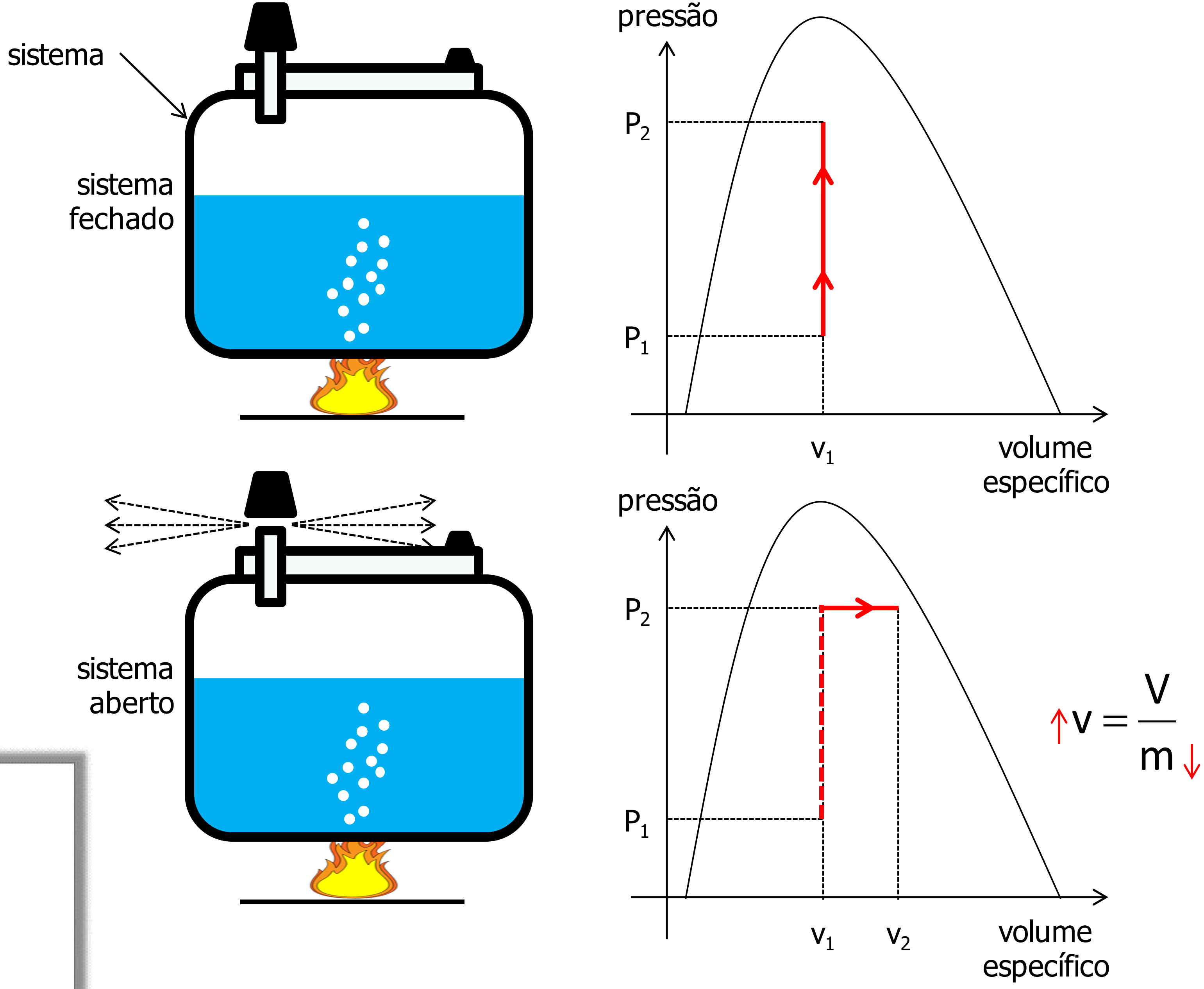
$$\int_{\Gamma_1} \delta W \neq \int_{\Gamma_2} \delta W$$

O que aconteceria se a transformação fosse cíclica ?

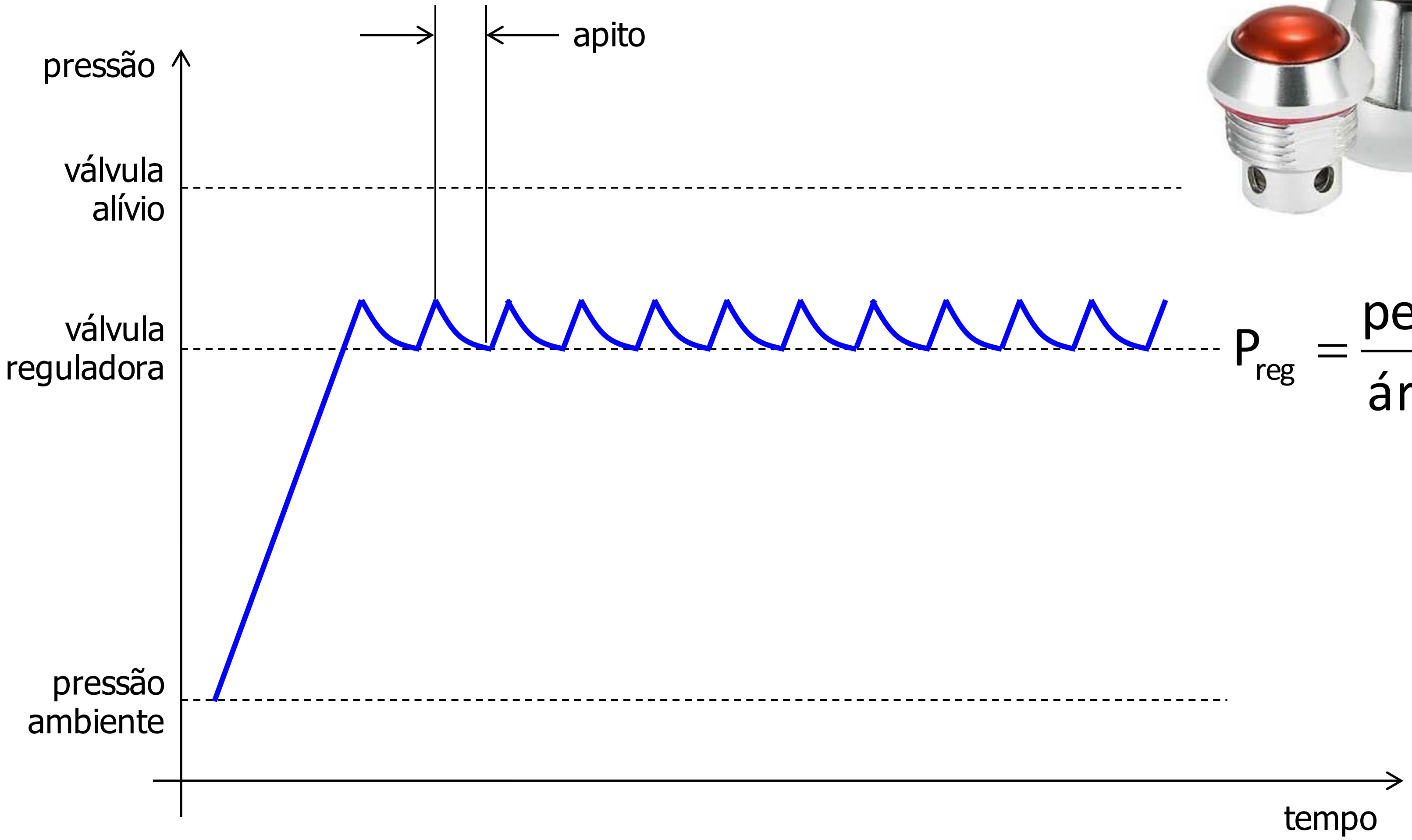

pressão
absorve calor e produz trabalho
P2
P1
Γ1
W12 >0
V1
V2
volume
+
pressão
rejeita calor e consome trabalho
P2
P1
Γ2
P>0
dV<0
W21 <0
V1
V2
volume
P2
P1
W121 >0
V1
V2
volume

Aplicação:

funcionamento de uma panela de pressão

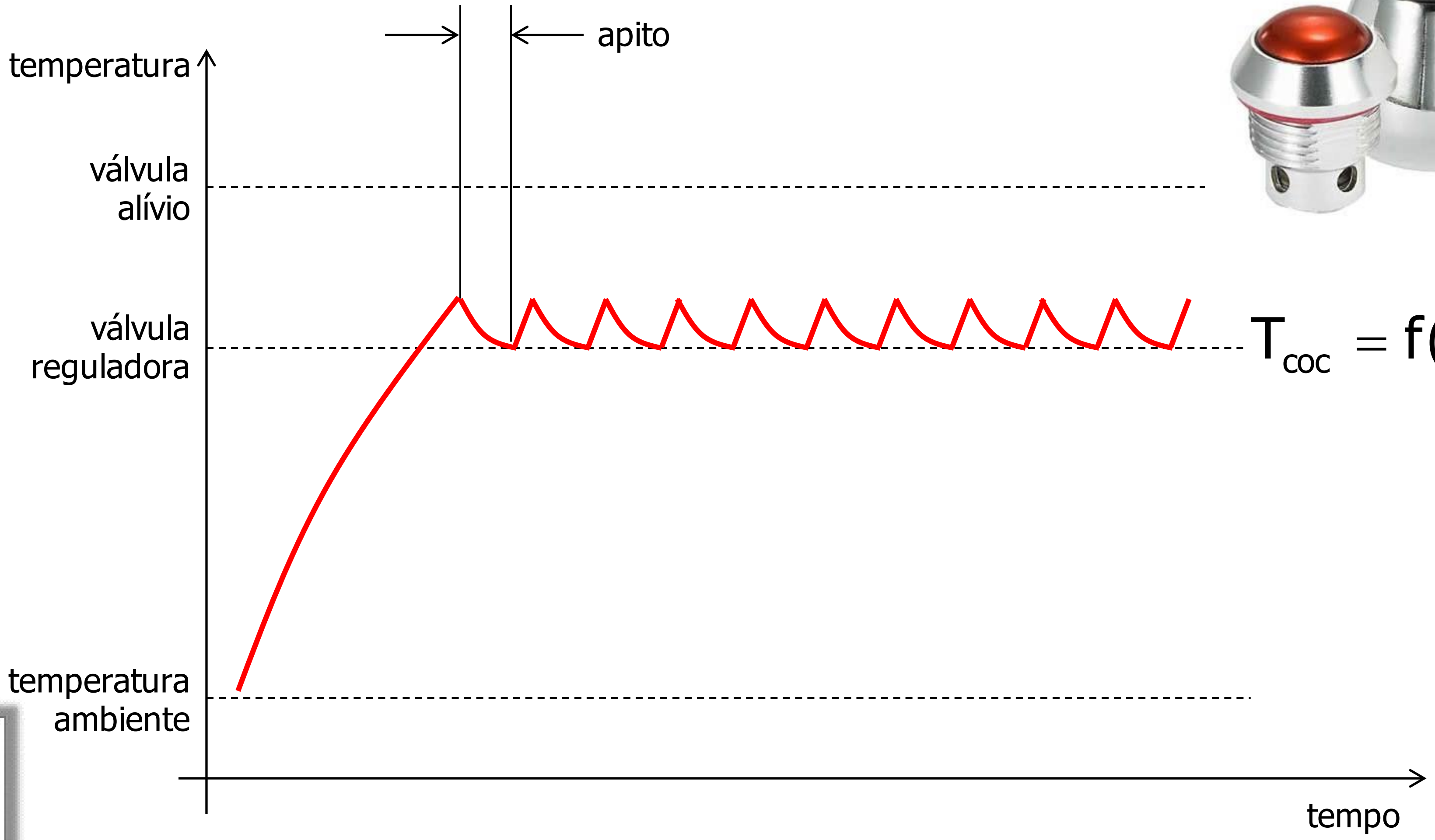

sistema
sistema fechado
sistema aberto
pressão
P_2
P_1
v_1
volume específico
pressão
P_2
P_1
v_1
v_2
volume específico
$\uparrow v = \frac{V}{m} \downarrow$

Histórico da pressão no tempo

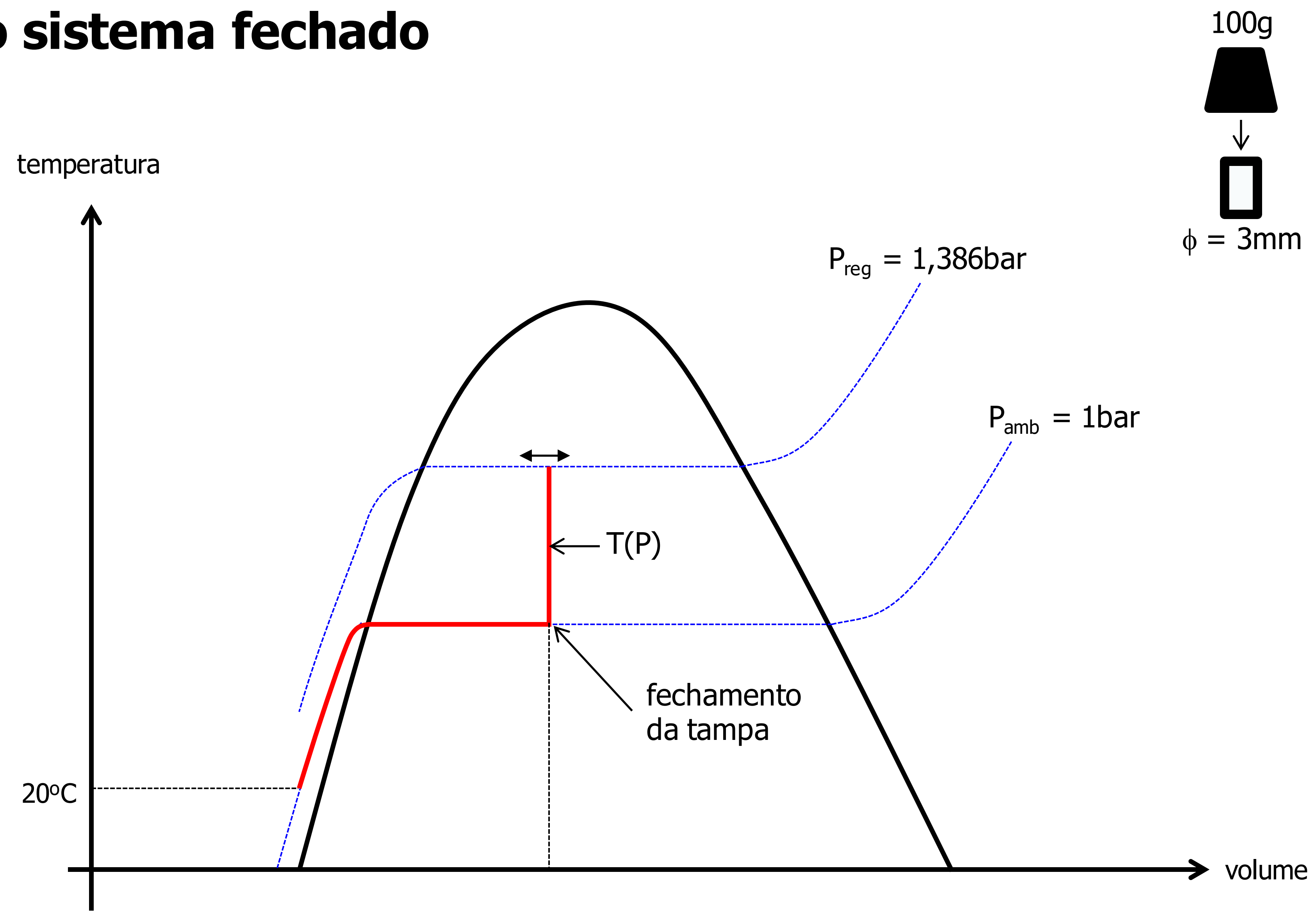


$$P_{reg} = \frac{peso}{área}$$

Histórico da temperatura no tempo



Análise do sistema fechado



$$P_{reg} = \frac{9{,}8\,m/s^2 \times 0{,}1\,kg}{\pi \times (3 \cdot 10^{-3}\,m)^2 / 4}$$

$$P_{reg} = 138{,}6 \cdot 10^3 \frac{kg}{m \cdot s^2}$$

$$P_{reg} = 138{,}6 \cdot 10^3 \frac{kg \cdot m}{s^2} \cdot \frac{1}{m^2}$$

$$P_{reg} = 138{,}6 \cdot 10^3 \frac{N}{m^2}$$

$$P_{reg}\, 138{,}6 \cdot 10^3\, Pa$$

$$P_{reg}\, 138{,}6 \cdot kPa$$

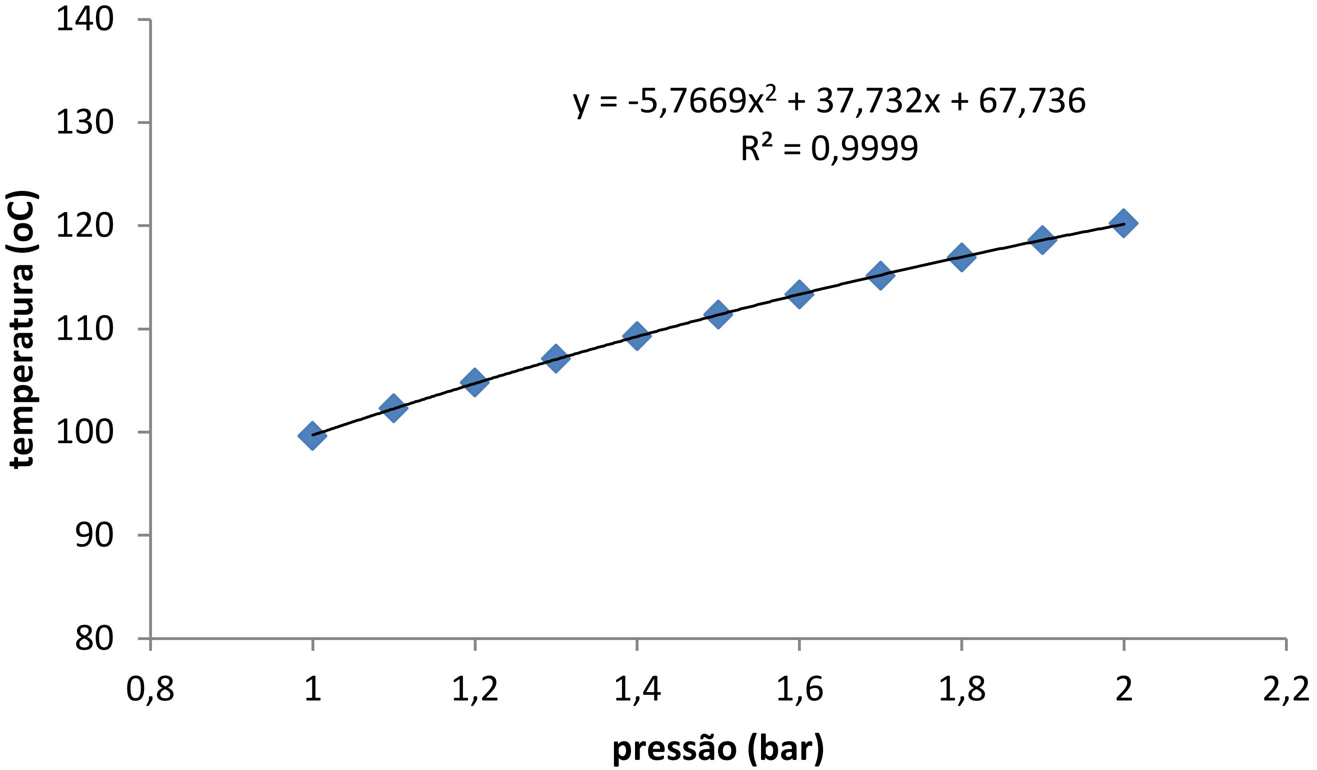
$$P_{reg} = 1{,}386\ bar$$

REFPROP (water) - NIST Reference Fluid Properties

File Edit Options Substance Calculate Plot Window Help Cautions

1: water: V/L sat. p=1, to 2, bar

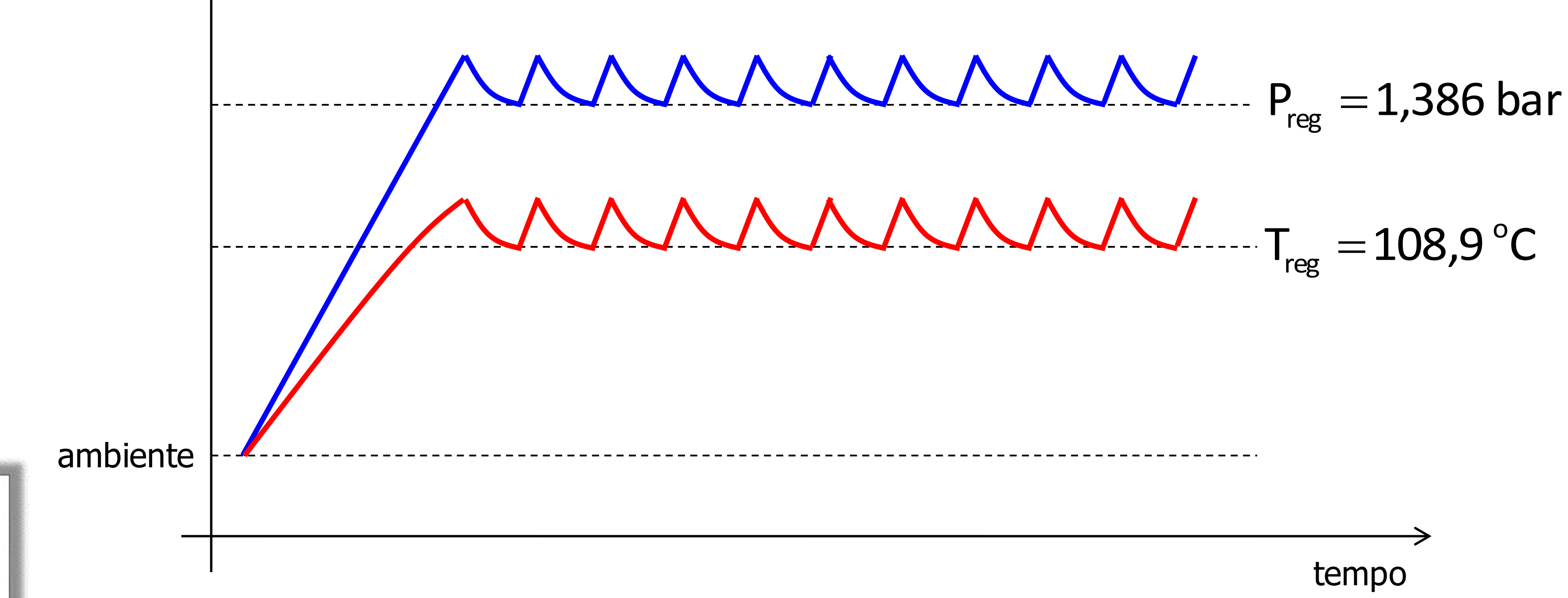
	Temperature (°C)	Pressure (bar)	Liquid Density (kg/m³)	Vapor Density (kg/m³)	Liquid Enthalpy (kJ/kg)	Vapor Enthalpy (kJ/kg)	Liquid Entropy (kJ/kg-K)	Vapor Entropy (kJ/kg-K)
1	99,606	1,0000	958,63	0,59034	417,50	2674,9	1,3028	7,3588
2	102,29	1,1000	956,69	0,64539	428,84	2679,2	1,3330	7,3269
3	104,78	1,2000	954,86	0,70010	439,36	2683,1	1,3609	7,2977
4	107,11	1,3000	953,13	0,75453	449,19	2686,6	1,3868	7,2709
5	109,29	1,4000	951,49	0,80869	458,42	2690,0	1,4110	7,2461
6	111,35	1,5000	949,92	0,86260	467,13	2693,1	1,4337	7,2230
7	113,30	1,6000	948,41	0,91629	475,38	2696,0	1,4551	7,2014
8	115,15	1,7000	946,97	0,96976	483,22	2698,8	1,4753	7,1812
9	116,91	1,8000	945,57	1,0230	490,70	2701,4	1,4945	7,1621
10	118,60	1,9000	944,23	1,0761	497,85	2703,9	1,5127	7,1440
11	120,21	2,0000	942,94	1,1291	504,70	2706,2	1,5302	7,1269

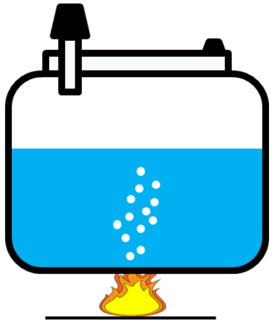


$$T_{reg} = -5{,}7669 \cdot (1{,}386)^2 + 37{,}732 \cdot (1{,}386) + 67{,}736$$

$$T_{reg} = 108{,}9\ ^{o}C$$

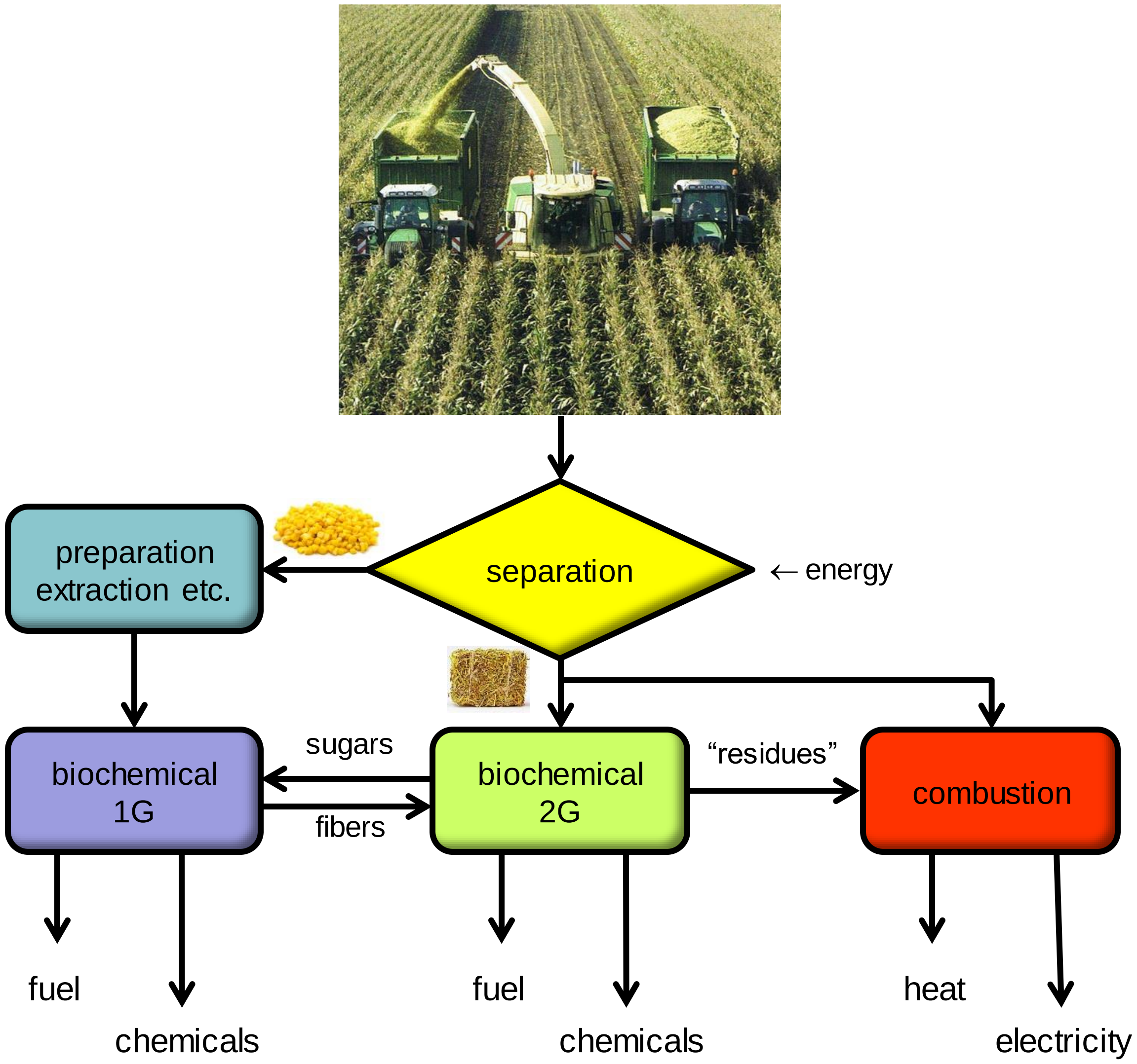
Histórico de funcionamento (cocção)





Aplicação:
reator de explosão de vapor para pré tratamento de biomassa

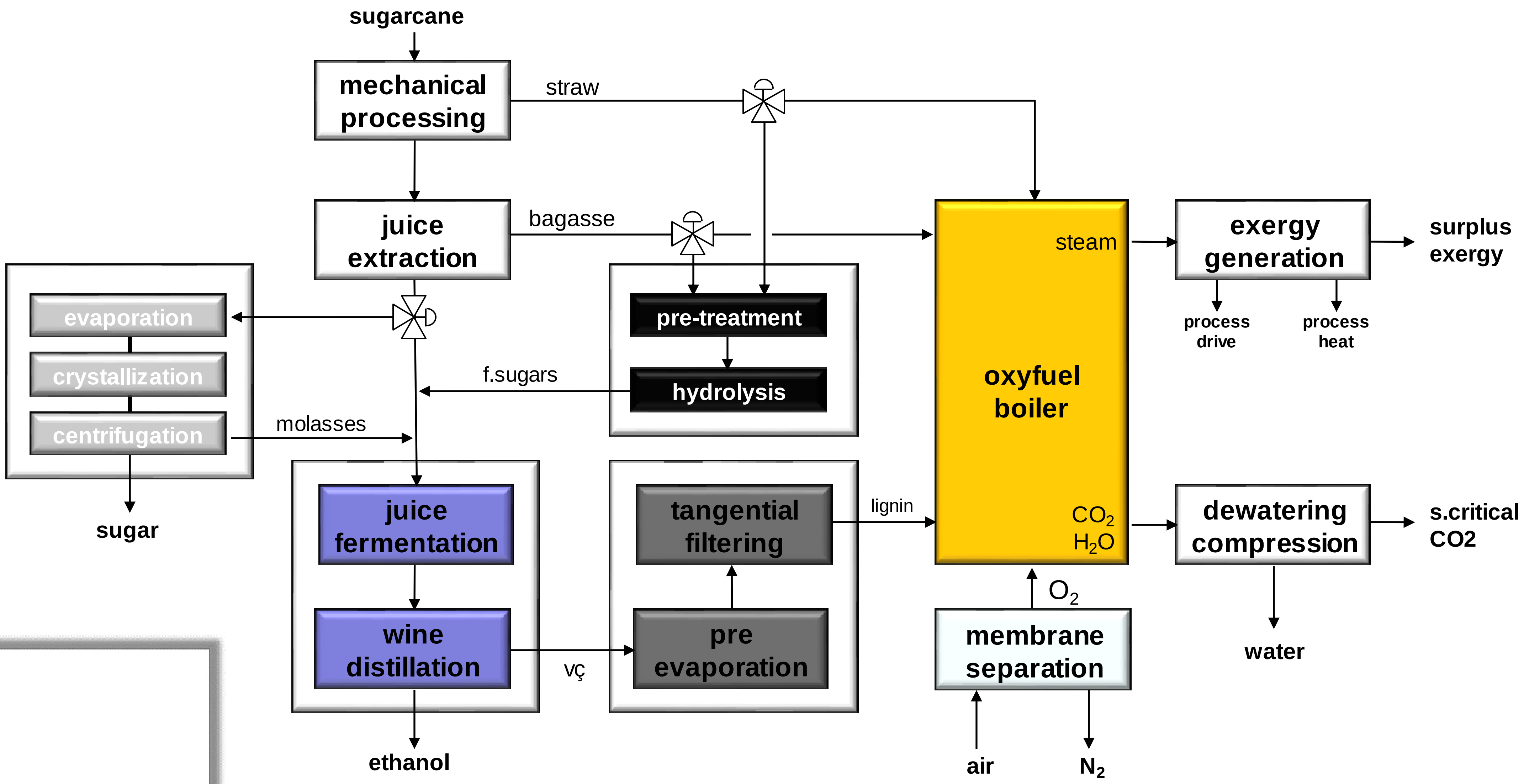
Produção de vetores energéticos a partir de insumos agrícolas...



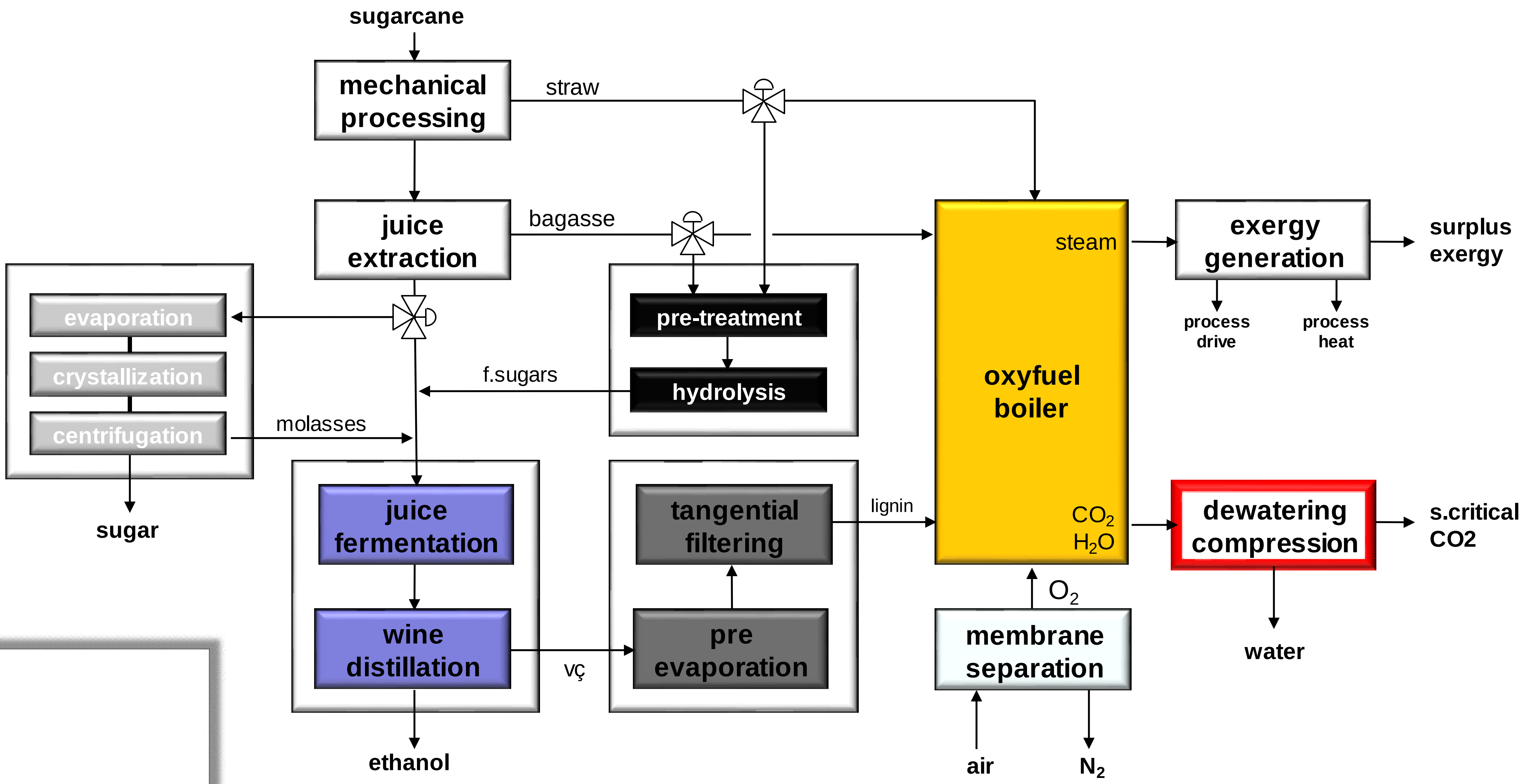
Bioflex 1 / Granbio

São Miguel dos Campos – AL

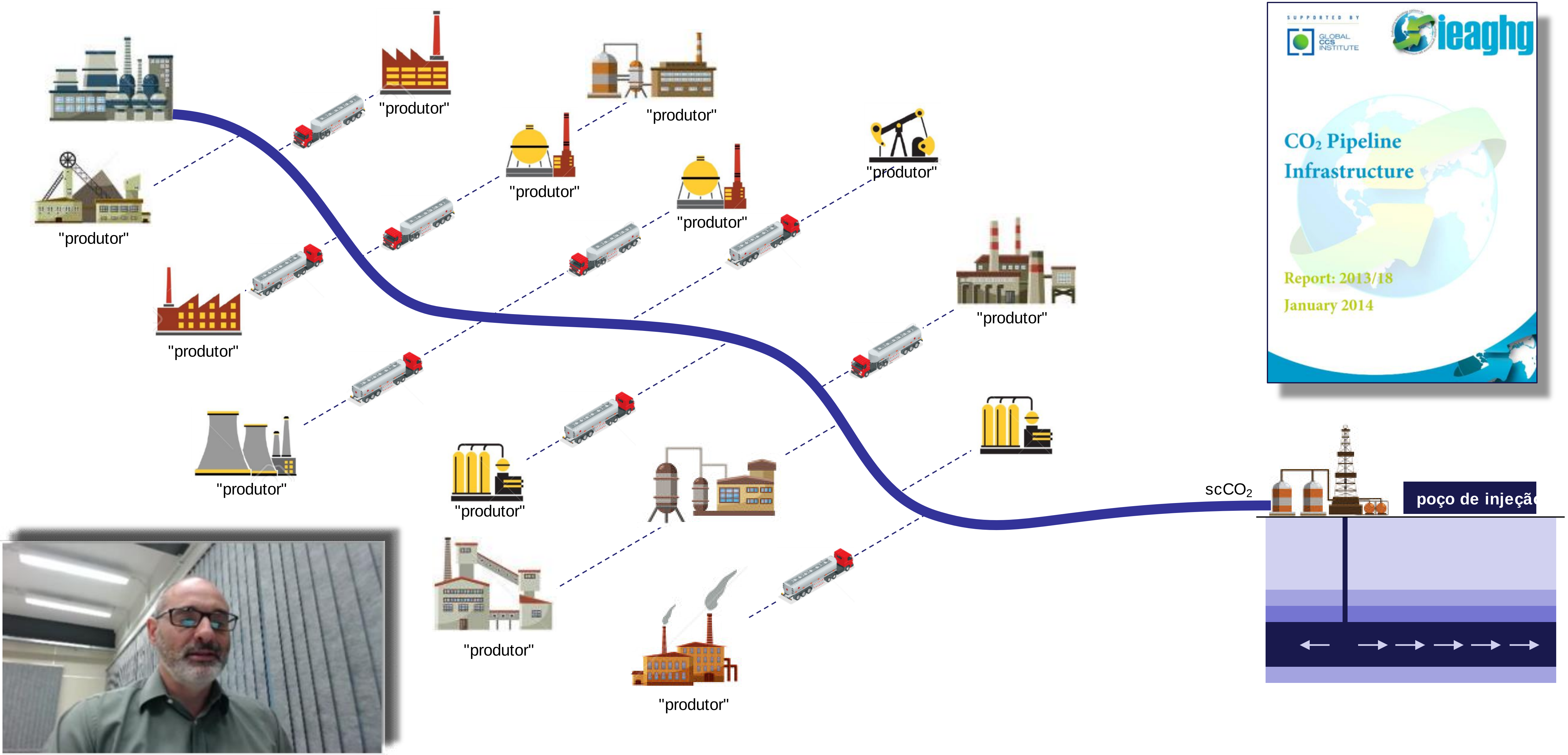
Usina Integrada 1G2G + Produção de $scCO_2$



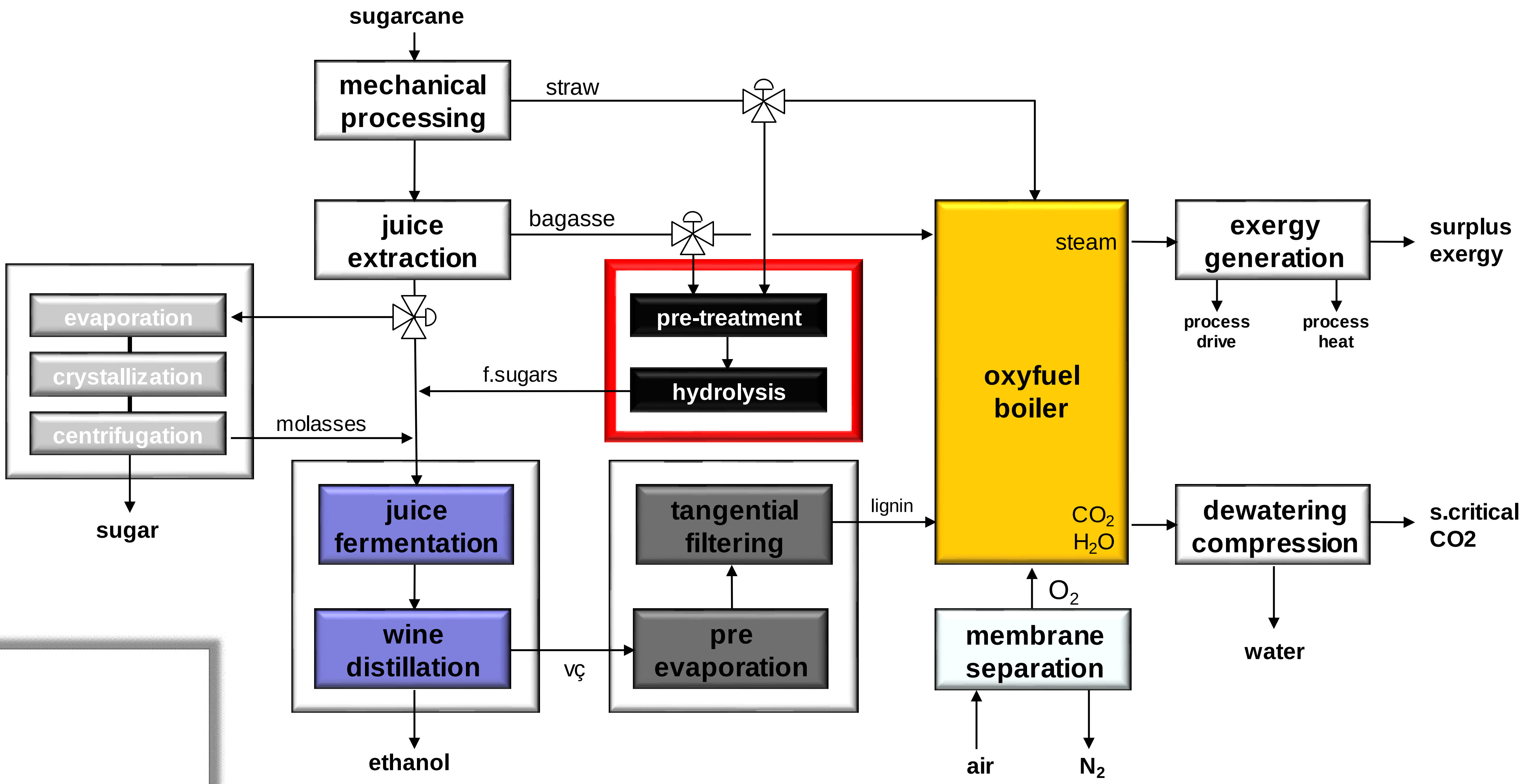
Usina Integrada 1G2G + Produção de $scCO_2$



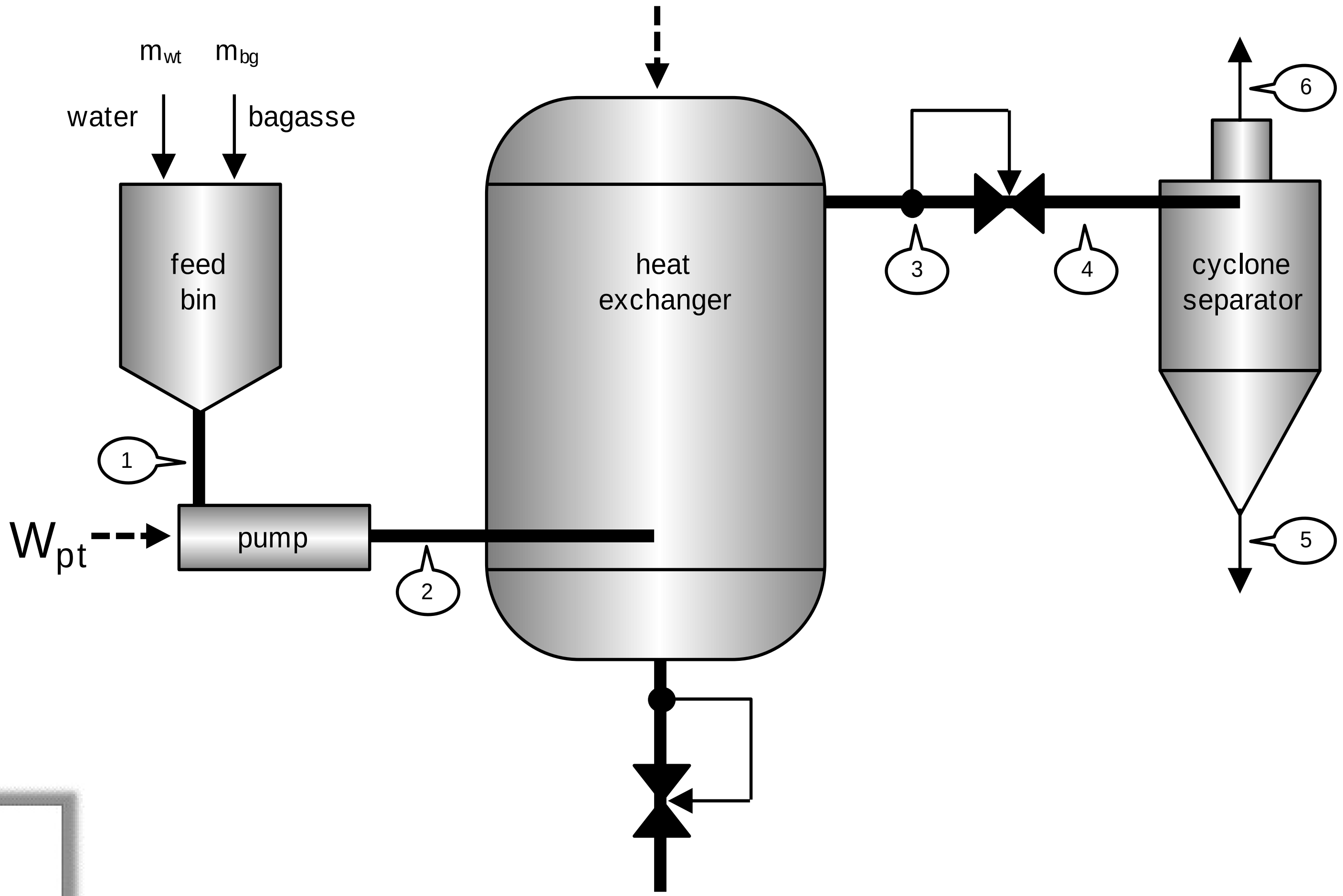
Captura, transporte e Armazenamento Geológico de Carbono



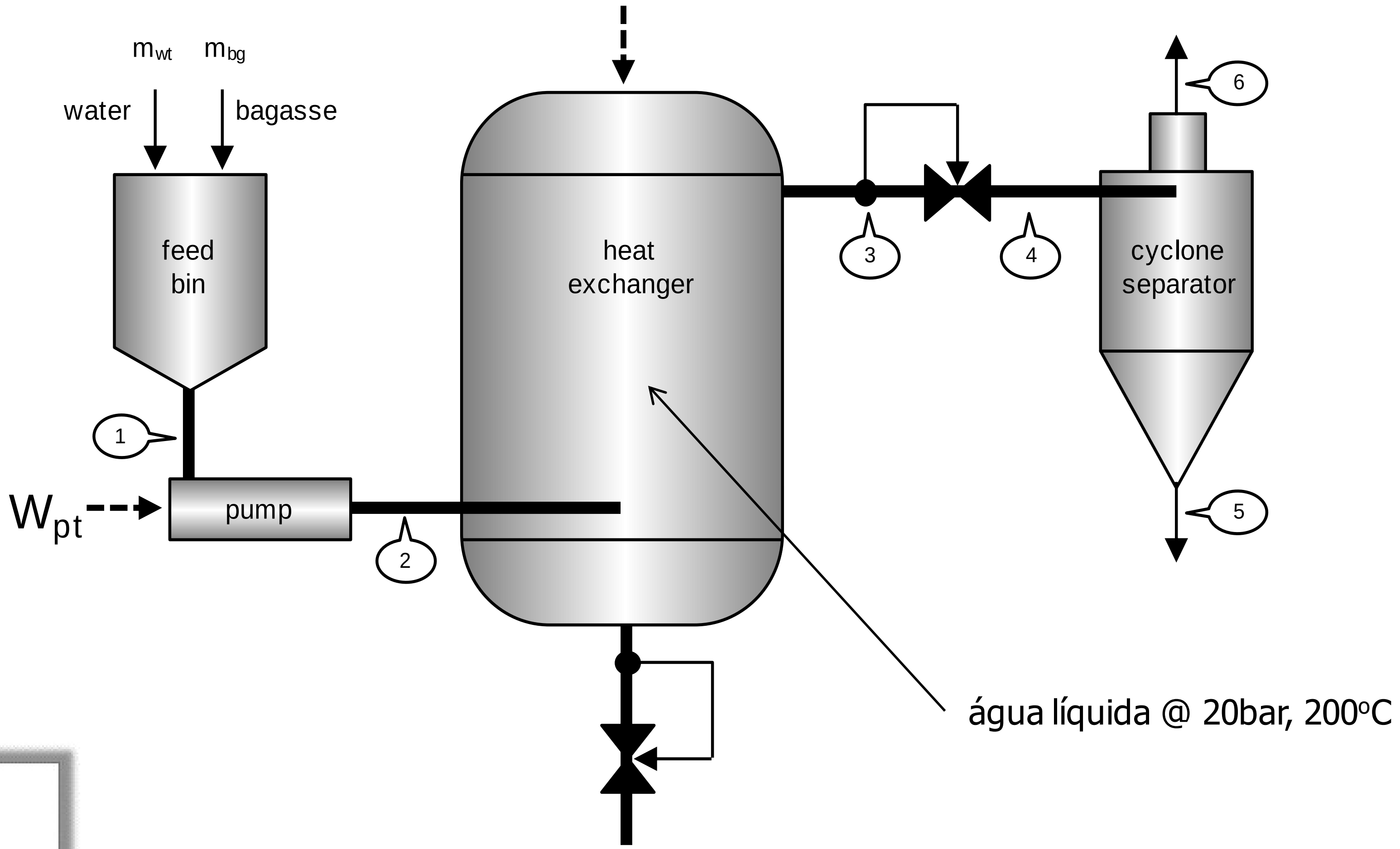
Usina Integrada 1G2G + Produção de $scCO_2$

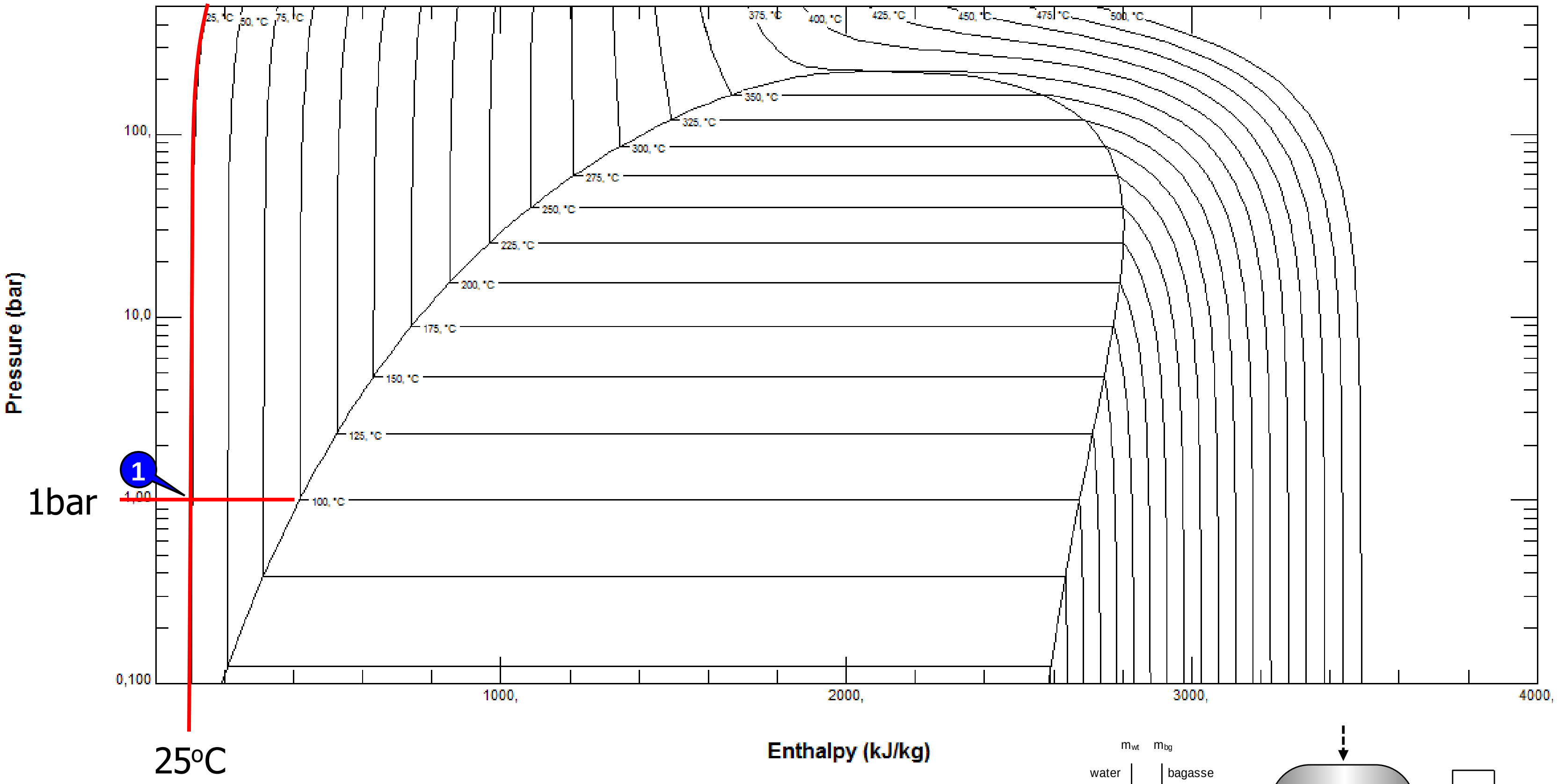


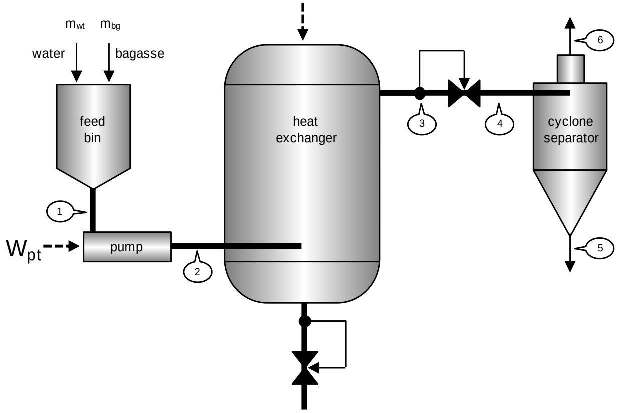
Reator industrial de pré tratamento hidrotérmico

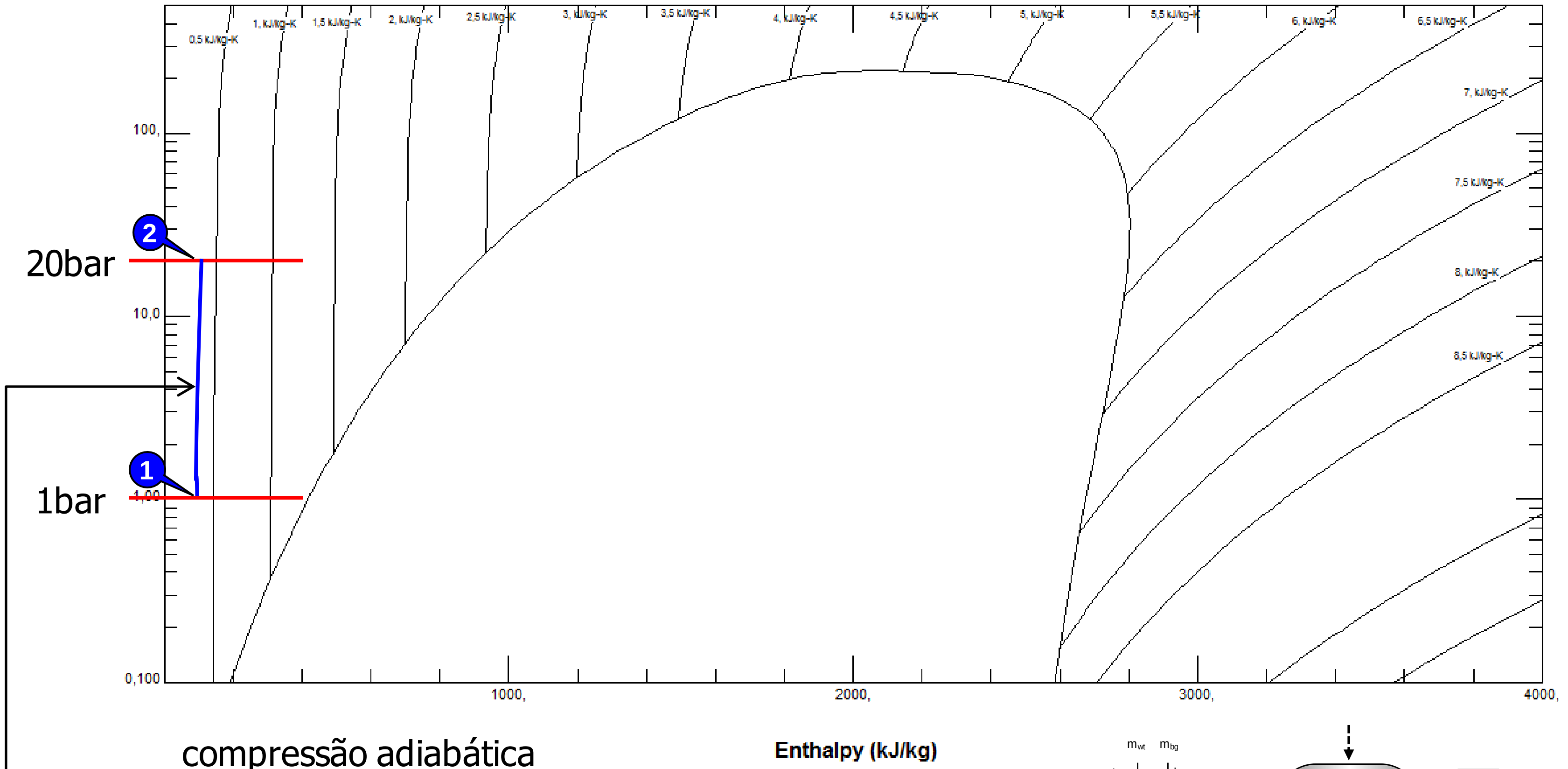


Reator industrial de pré tratamento hidrotérmico

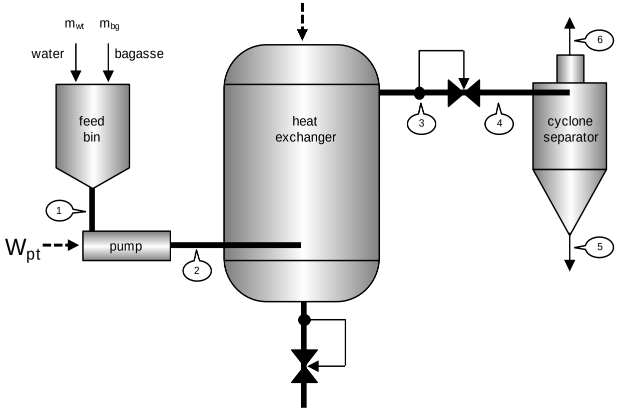


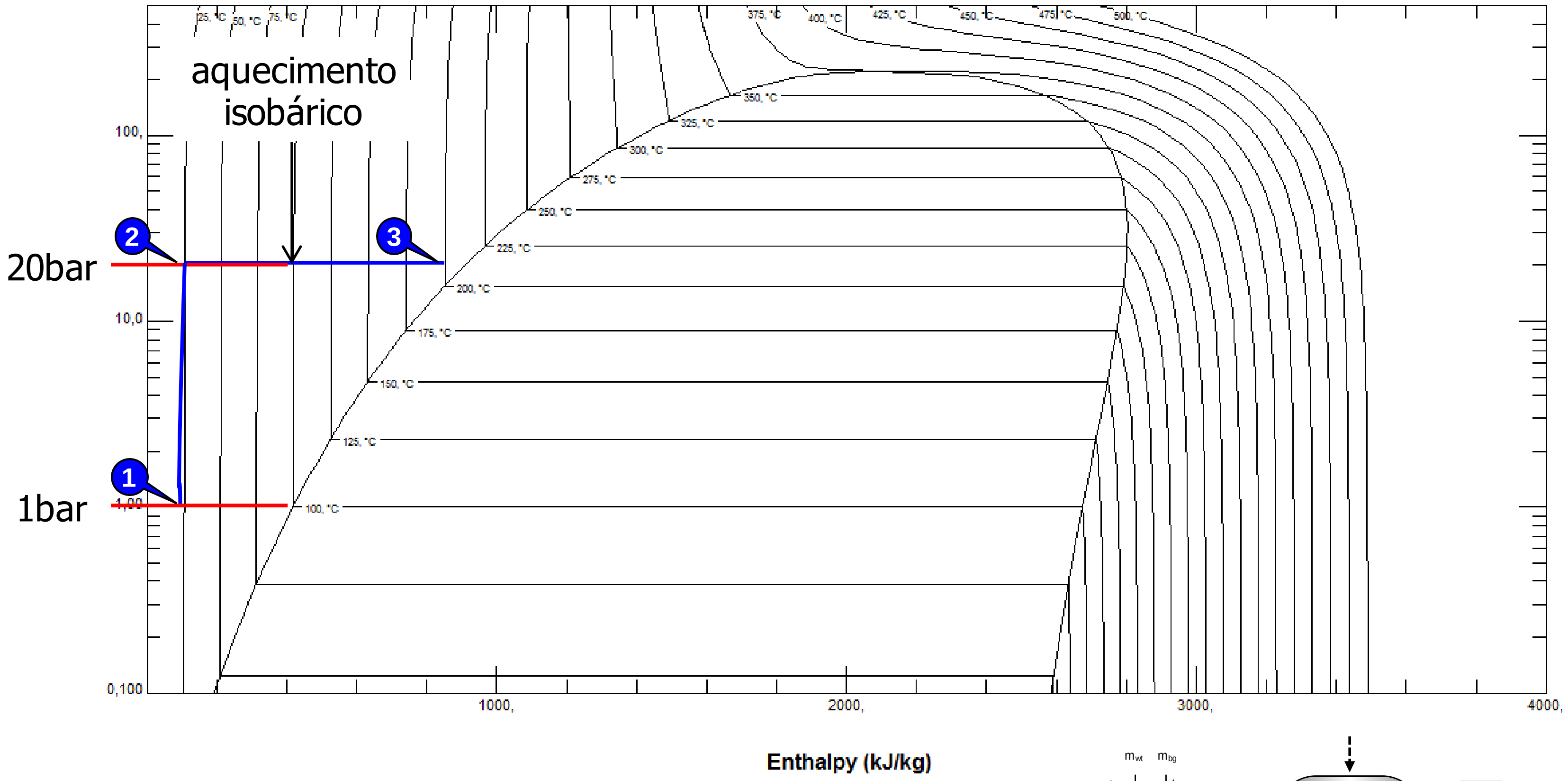

Pressure (bar)
Enthalpy (kJ/kg)
100,
10,0
1,00
0,100
1000,
2000,
3000,
4000,
25, °C
50, °C
75, °C
100, °C
125, °C
150, °C
175, °C
200, °C
225, °C
250, °C
275, °C
300, °C
325, °C
350, °C
375, °C
400, °C
425, °C
450, °C
475 °C
500, °C
1
1bar
25°C

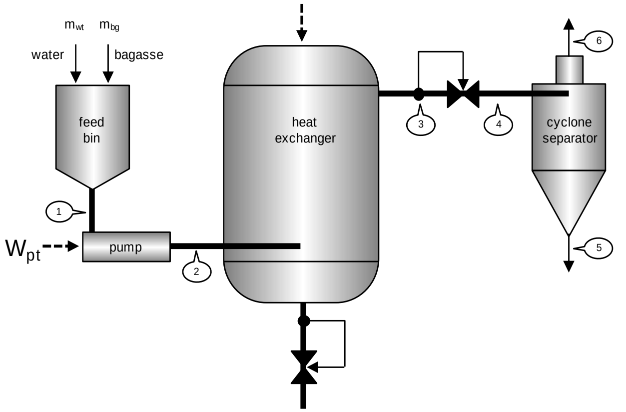

water
bagasse
feed bin
heat exchanger
cyclone separator
pump
W_{pt}
m_{wt}
m_{bg}
1
2
3
4
5
6

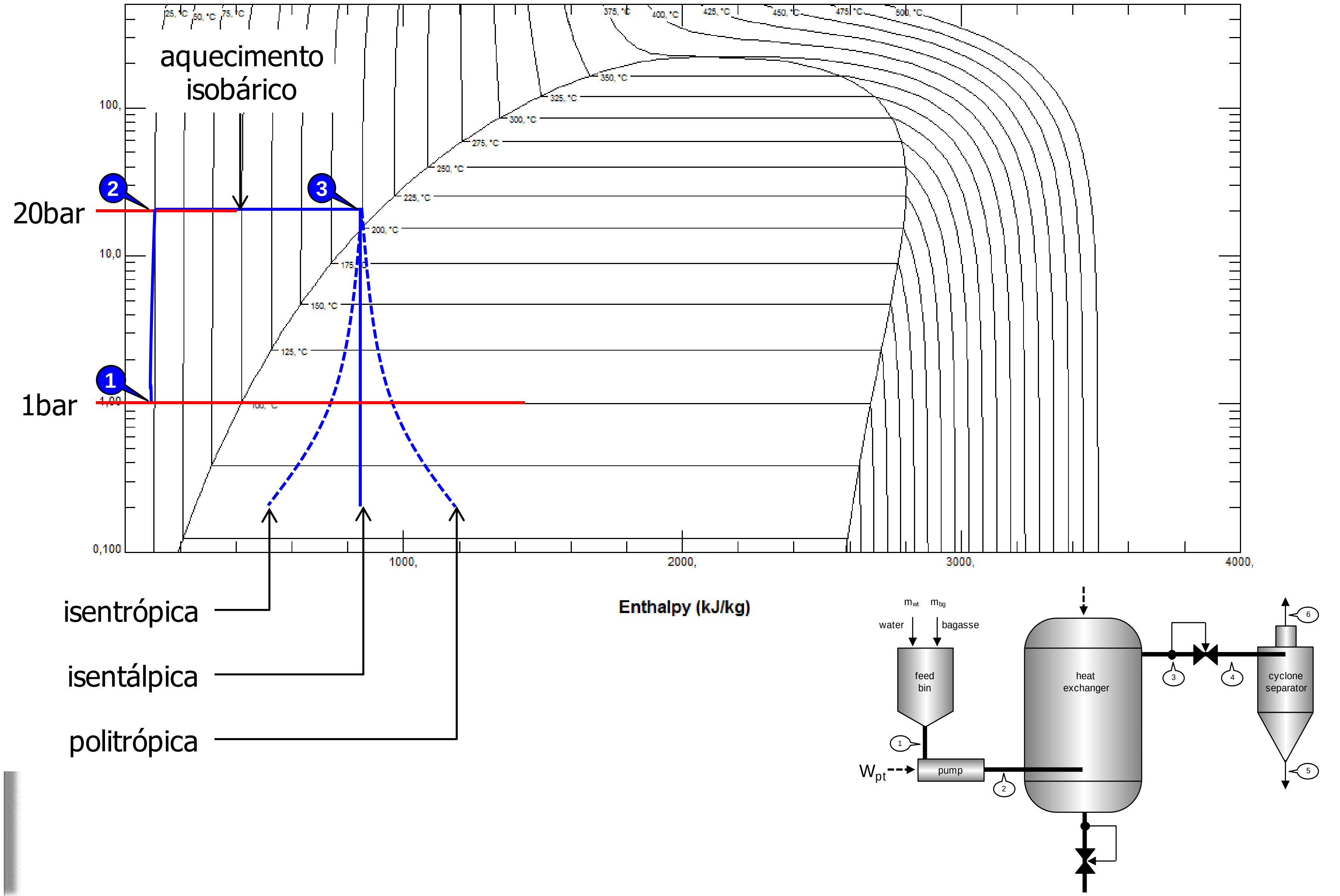


compressão adiabática
e sem atritos internos
(isentrópica)




aquecimento
isobárico
20bar
1bar
1
2
3
100,
10,0
1,00
0,100
1000,
2000,
3000,
4000,
25, °C
50, °C
75, °C
100, °C
125, °C
150, °C
175, °C
200, °C
225, °C
250, °C
275, °C
300, °C
325, °C
350, °C
375, °C
400, °C
425, °C
450, °C
475, °C
500, °C
Enthalpy (kJ/kg)


m_{wt}
m_{bg}
water
bagasse
feed
bin
heat
exchanger
cyclone
separator
pump
W_{pt}
1
2
3
4
5
6


aquecimento isobárico
20bar
1bar
1
2
3
100,
10,0
1,00
0,100
1000,
2000,
3000,
4000,
Enthalpy (kJ/kg)
25, °C
50, °C
75, °C
100, °C
125, °C
150, °C
175, °C
200, °C
225, °C
250, °C
275, °C
300, °C
325, °C
350, °C
375, °C
400, °C
425, °C
450, °C
475, °C
500, °C
isentrópica
isentálpica
politrópica
water
bagasse
feed bin
pump
W_{pt}
heat exchanger
cyclone separator

REFPROP...

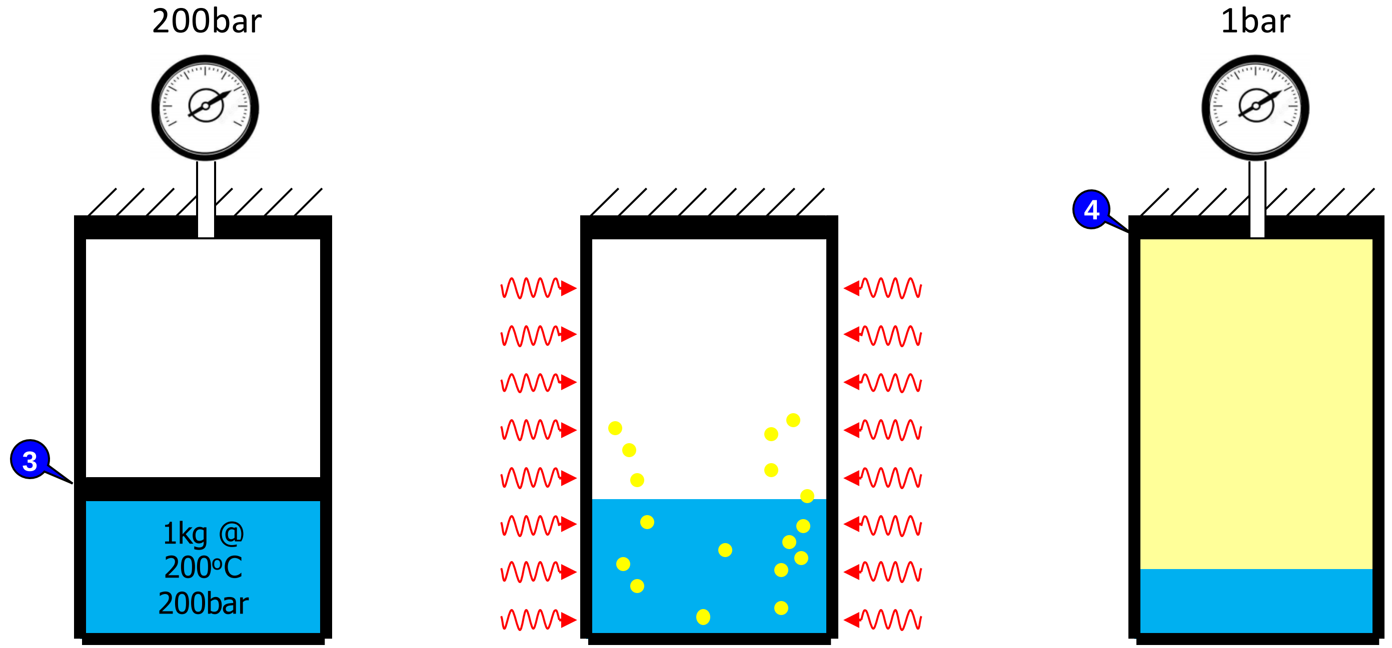
REFPROP (water) - NIST Reference Fluid Properties

File Edit Options Substance Calculate Plot Window Help Cautions

2: water: Specified state points

	Temperature (°C)	Pressure (bar)	Density (kg/m³)	Volume (m³/kg)	Int. Energy (kJ/kg)	Enthalpy (kJ/kg)	Entropy (kJ/kg-K)	Quality (kg/kg)	Exergy (kJ/kg)
1	25,000	1,0000	997,05	0,0010030	104,82	104,92	0,36720	Subcooled	158,70
2	25,035	20,000	997,89	0,0010021	104,82	106,82	0,36720	Subcooled	160,60
3	200,00	20,000	865,00	0,0011561	850,14	852,45	2,3298	Subcooled	321,07
4	99,606	1,0000	3,0561	0,32721	819,73	852,45	2,4696	0,19267	279,40
5	99,606	1,0000	3,0561	0,32722	819,73	852,45	2,4696	0,19267	279,40
6									

Expansão não resistida (200bar→1bar, $V_4 \overset{hip}{=} 300\times V_3$)



ρ=865,00 kg/m3
u=850,14 kJ/kg
h=852,45 kJ/kg/K

⇩

$$V=\frac{m}{\rho}=\frac{1kg}{865{,}00kg/m^3}$$

⇩

$$V=0{,}00115m^3$$

×300

$$0{,}346821m^3=\frac{1kg}{\rho}$$

⇩

$$\rho=2{,}88kg/m^3$$

⇩

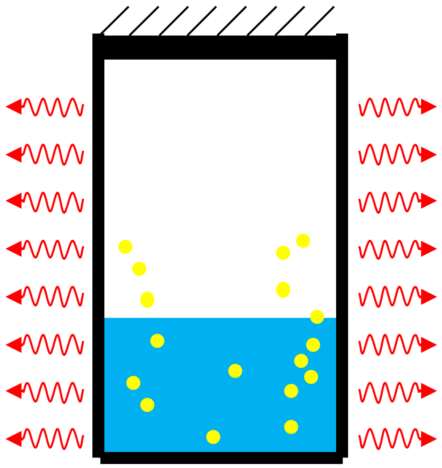
u=844,41 kJ/kg
h=879,13 kJ/kg/K
x=0,20449 kg/kg

Expansão não resistida (200bar→1bar, $V_4 \overset{\text{hip}}{=} 300\times V_3$)

$$\Delta U = Q_{34} - W_{34}$$

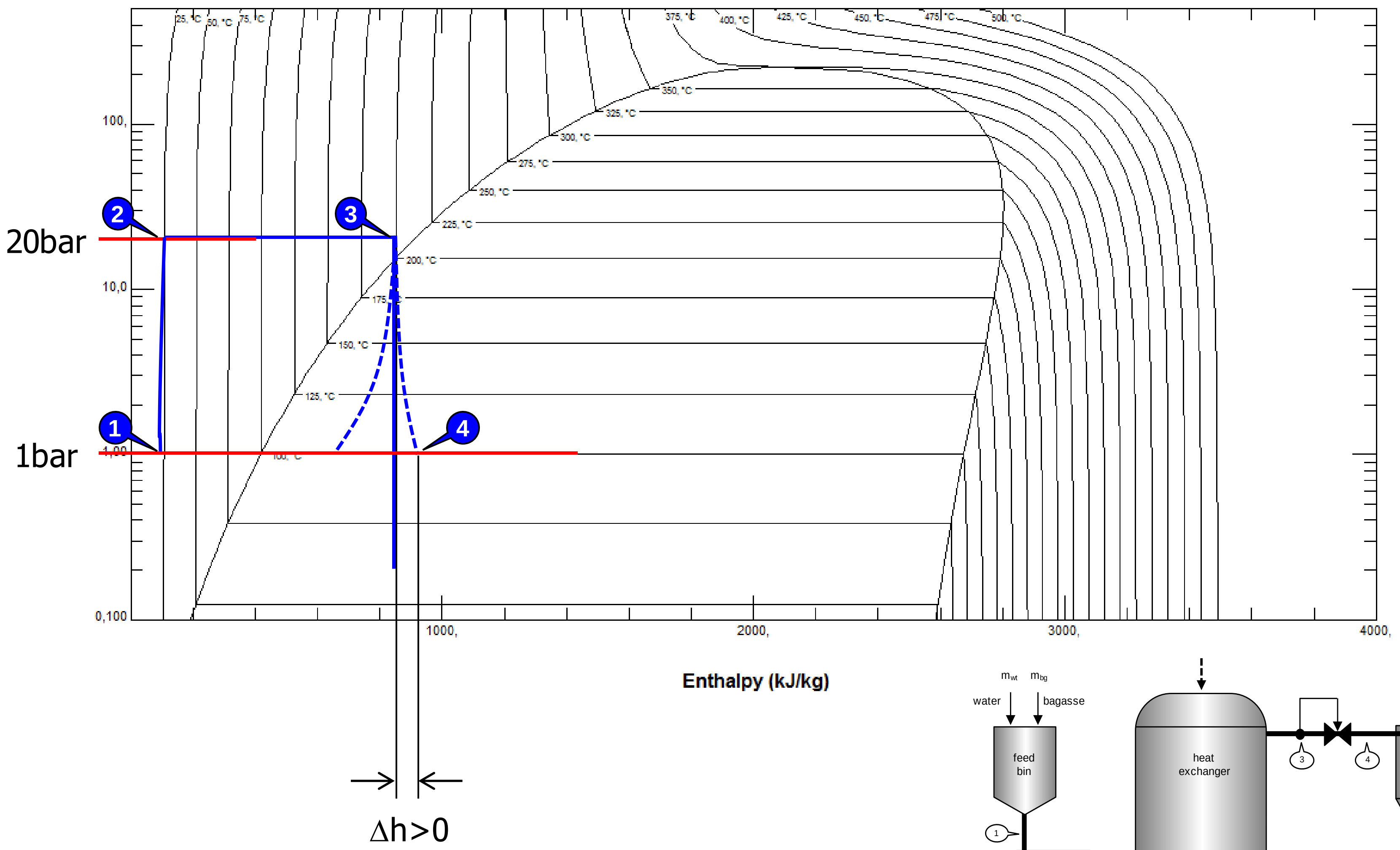
$$U_4 - U_3 = Q_{34}$$

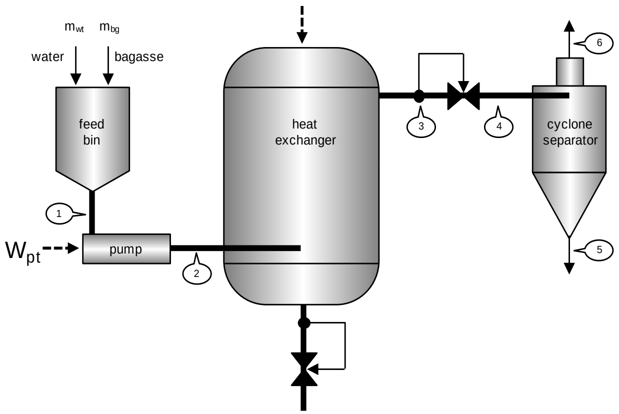
$$Q_{34} = (844{,}41 - 852{,}45)\,kJ/kg = -8{,}04\,kJ/kg$$



$$h_4 - h_3 = (879{,}13 - 852{,}45)\,kJ/kg$$

$$h_4 - h_3 = 26{,}68\,kJ/kg$$



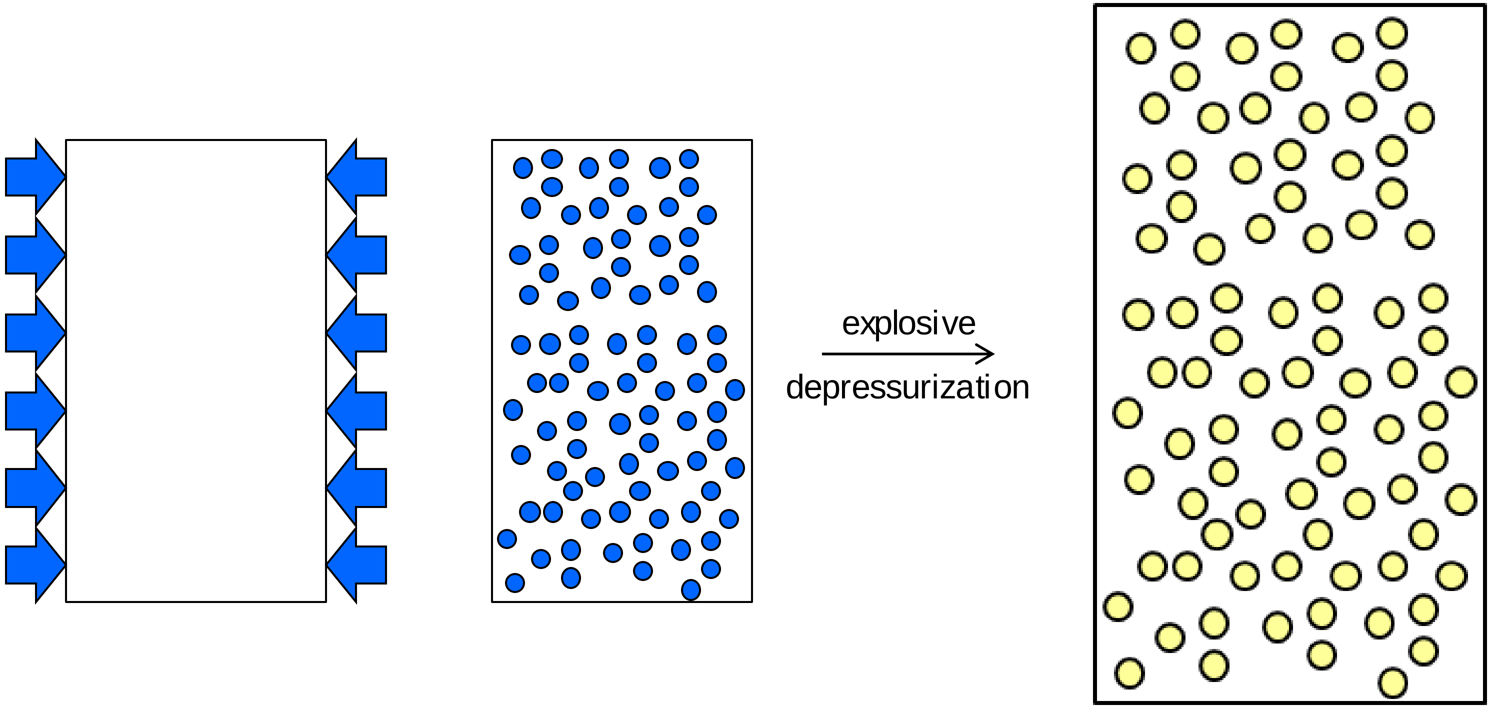


veremos que o processo isentálpico se aproxima mais da realidade

Pré tratamento hidrotérmico de bagaço de cana

Pré tratamento hidrotérmico

- ✓ Absorção de água líquida a alta temperatura e alta pressão (líquido comprimido)
- ✓ Despressurização explosiva induzindo vaporização in loco → "espumificação" do material



Espumificação do amido da pipoca

Avisos = www.facebook.com/sem0233

Streaming = www.youtube.com/c/pseleghim/live