



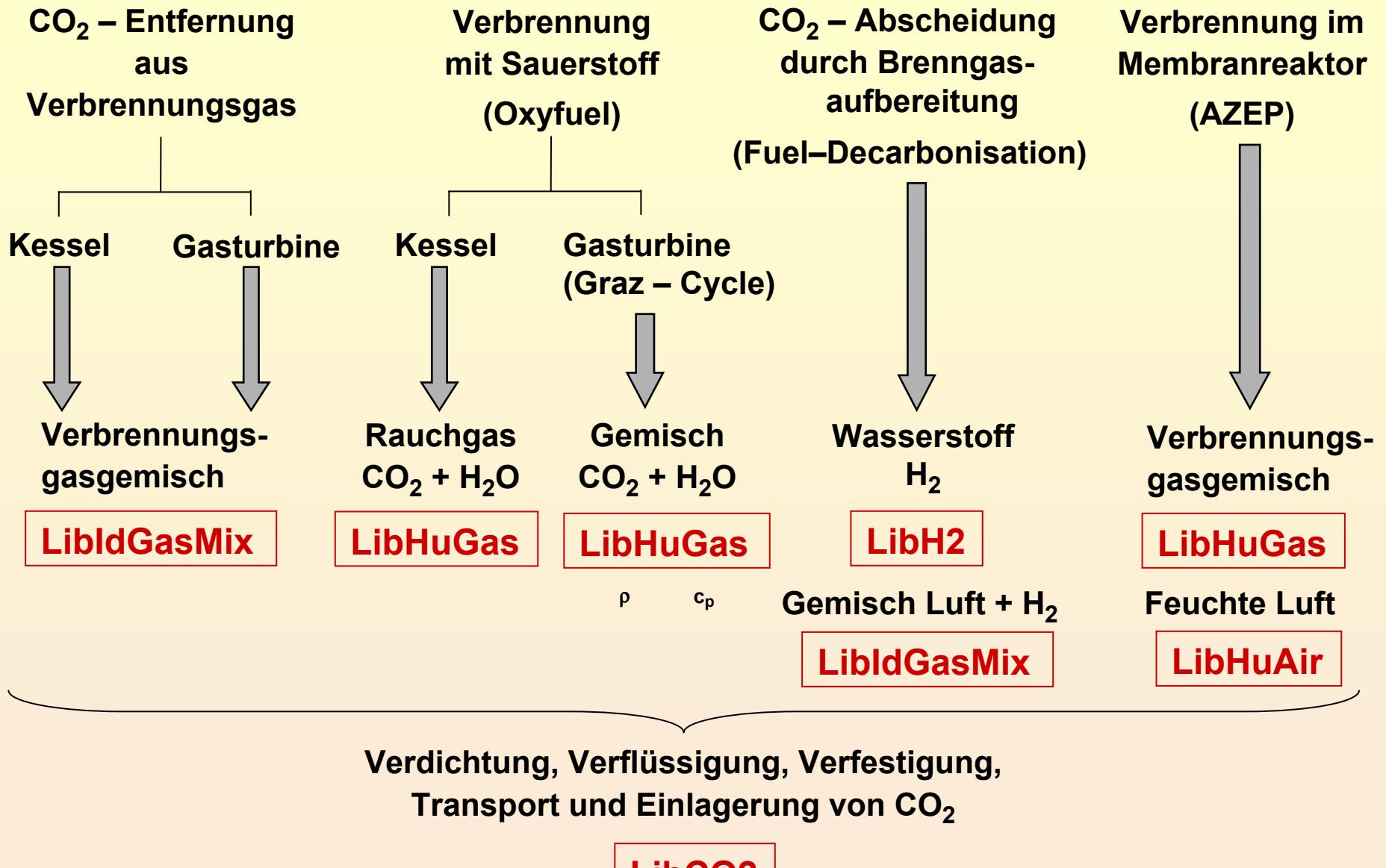
Hochschule Zittau/Görlitz (FH)
Fachgebiet Technische Thermodynamik
<http://thermodynamik.hs-zigr.de>

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Berechnung der thermodynamischen Zustandsgrößen und Transporteigenschaften von Arbeitsfluiden in fortschrittlichen Energieumwandlungsprozessen

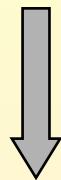
Universität Rostock, Lehrstuhl für Technische Thermodynamik, 02. Dezember 2005

Energieumwandlungsverfahren mit CO₂ - Rückhaltung



Energiespeicherung und Wasserstoffwirtschaft

Druckluftspeicher
(EU – Projekt AA-CAES)



Feuchte Luft
unter Druck

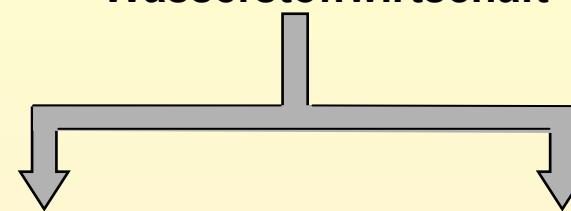
LibHuAir

ρ c_p

Berechnung als ideale
Mischung der realen Fluide

- trockene Luft nach Lemmon et al. (2000)
- Wasserdampf und Wasser nach IAPWS-IF97

Wasserstoffspeicher und
Wasserstoffwirtschaft



Wasserstoff
unter Druck

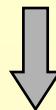
Flüssiger
Wasserstoff

LibH2

ρ c_p

Berechnung mit genauester
Zustandsgleichung von
Younglove (1982)

Kältetechnik und Wärmepumpen



Aktuelle Kältemittel

Kältemittel	Bibliothek	Berechnung
Ammoniak	LibNH3	Tillner-Roth et al. (1993)
R134a	LibR134a	Tillner-Roth und Baehr (1994)
Propan	LibPropan	Bücker et al. (2004)
Iso-Butan	LibButan_Iso	Bücker et al. (2004)
n-Butan	LibButan_n	Bücker et al. (2004)
Kohlendioxid	LibCO2	Span und Wagner (1996)

Energieumwandlungsprozesse mit Stoffgemischen

Dampfturbinenkraftwerk
mit Gemisch $\text{NH}_3 + \text{H}_2\text{O}$
(Kalina – Prozess)



Gemisch
 $\text{NH}_3 + \text{H}_2\text{O}$

Absorptions-
kältemaschinen



Gemische
 $\text{NH}_3 + \text{H}_2\text{O}$
 $\text{H}_2\text{O} + \text{LiBr}$

Absorptions-
wärmepumpen



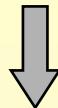
Gemische
 $\text{NH}_3 + \text{H}_2\text{O}$
 $\text{H}_2\text{O} + \text{LiBr}$

Bibliotheken

LibAmWa für $\text{NH}_3 + \text{H}_2\text{O}$ nach Tillner-Roth und Friend (1998)

LibWaLi für $\text{H}_2\text{O} + \text{LiBr}$ nach Kim und Infantre Ferreira (2004)

Entwicklung von Hochtemperaturreaktoren



Kühlmittel
Helium

Bibliothek
LibHe

Berechnung mit genauerer Zustandsgleichung
von McCarty (1990)

The following **thermodynamic** and **transport properties** can be calculated:

Thermodynamic Properties

- Saturation pressure p_s
- Saturation temperature T_s
- Density ρ
- Specific volume v
- Enthalpy h
- Internal energy u
- Entropy s
- Exergy e
- Isobaric heat capacity c_p
- Isochoric heat capacity c_v
- Isentropic exponent κ
- Speed of sound w
- Surface tension σ

Transport Properties

- Dynamic viscosity η
- Kinematic viscosity ν
- Thermal conductivity λ
- *Prandtl*-number Pr

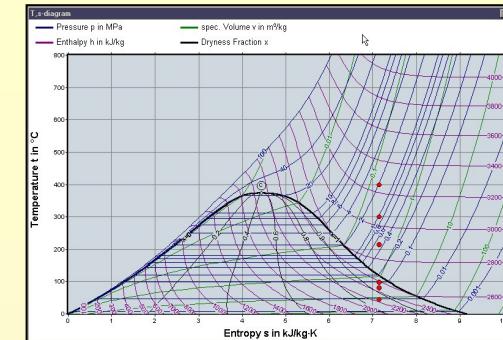
Backward Functions

- $T, v, s(p,h)$
- $p, v, h(T,s)$
- $T, v, h(p,s)$
- $p, T, v(h,s)$

Add-In FluidEXL^{Graphics} for Excel®

The screenshot illustrates the FluidEXL Graphics add-in integrated into Microsoft Excel. At the top, a function dialog box is open, showing the selected function as `h_ptcomp_HuGas`. The input parameters are defined in cells D2, D3, D4, and D5:D12. The output value is displayed as 1995,472089. Below this, the formula `=h_ptcomp_HuGas(D2;D3;D4;D5:D12)` is entered into cell D15, and the result 1995,4721 is shown in the adjacent cell.

Eingabewerte	
Druck	$p = 10$ bar
Temperatur	$t = 500$ °C
Typ	$\text{type} = 1$
Zusammensetzung	$\text{Ar} \quad \text{Xi} = 0 \quad \text{kg/kg}$ $\text{Ne} \quad \text{Xi} = 0 \quad \text{kg/kg}$ $\text{N}_2 \quad \text{Xi} = 0 \quad \text{kg/kg}$ $\text{O}_2 \quad \text{Xi} = 0 \quad \text{kg/kg}$ $\text{CO} \quad \text{Xi} = 0 \quad \text{kg/kg}$ $\text{CO}_2 \quad \text{Xi} = 0,50 \quad \text{kg/kg}$ $\text{H}_2\text{O} \quad \text{Xi} = 0,50 \quad \text{kg/kg}$ $\text{SO}_2 \quad \text{Xi} = 0 \quad \text{kg/kg}$
Ausgabewert	Spezifische Enthalpie $h(p,T,\text{comp}) = 1995,4721 \text{ kJ/kg}$



Thermodynamic Charts:

- T - s diagram
- h - s diagram
- $\log p$ - h diagram
- $\log p$ - $\log v$ diagram
- $\log p$ - T diagram
- p - T diagram
- T - h diagram
- T - $\log v$ diagram
- $\log p$ - s diagram
- h - $\log v$ diagram
- s - $\log v$ diagram
- h - x diagram for humid air

Library FluidMAT for Mathcad®

The screenshot shows the Mathcad software interface. In the top window, a function dialog is open with the title "Funktion einfügen". The left pane lists "Funktionskategorie" (Function categories) including "Kurvenanpassung", "LibAir_Stud", "LibFLUFT_FLC", "LibIDGAS", "LibI97" (which is highlighted with a red arrow), "Logarithmus und Exponential", "Regression und Glättung", "Sortieren", and "Spezial". The right pane lists "Funktionsname" (Function names) including "e_ptxu_97", "eta_ptx_97", "h_ps_97", "h_ptx_97" (selected), "kappa_ptx_97", "lambda_ptx_97", "nue_ptx_97", "p_hs_97", and "Pr_ntv_97". Below the categories, there is a description: "Spezifische Enthalpie h in kJ/kg aus Druck p in bar, Temperatur t in °C und Dampfanteil x in kg/kg". The bottom window shows the main workspace with the following input variables:

$$\begin{aligned} \text{bar} &:= 1 \cdot 10^5 \text{ Pa} \\ p &:= 10 \text{ bar} \\ t &:= 300^\circ\text{C} \\ x &:= -1 \frac{\text{kg}}{\text{kg}} \\ h &:= \boxed{\text{ }} \end{aligned}$$

Below these, the calculated result is shown:

$$h := h_{\text{ptx_97}} \left(\frac{p}{\text{bar}}, \frac{t}{^\circ\text{C}}, \frac{x}{\frac{\text{kg}}{\text{kg}}} \right) \frac{\text{kJ}}{\text{kg}}$$
$$h = 3051.70 \frac{\text{kJ}}{\text{kg}}$$

Software for Pocket Calculators

Software for calculating
thermodynamic and
transport properties for

- Water and steam
- Combustion Gases and
- Humid air

FluidTI



TI 83
TI 84
TI 89



TI 92



TI Voyage 200

FluidCasio

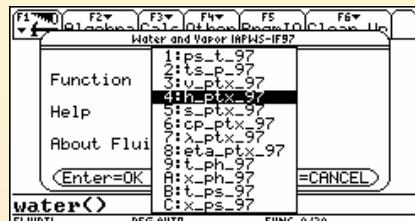


CFX-9850

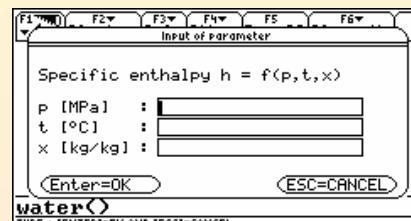


ALGEBRA
FX 2.0

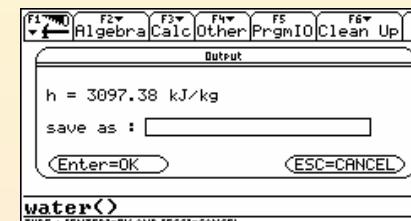
Example: Calculation of the Enthalpy of Steam Using FluidTI



Choice of the function $h = f(p,t,x)$



Input of the parameters p , t and x



Result for enthalpy

FluidHP



HP 48



HP 49

Property Libraries for Calculating Heat Cycles and Turbines

Water and Steam	Humid Combustion Gases	Humid Air																								
<p>Library LibIF97</p> <ul style="list-style-type: none"> - Industrial Formulation IAPWS-IF97 - Supplementary Standards 	<p>Library LibIdGas</p> <p>Ideal gas mixture (VDI-Guideline 4670)</p> <p>Library LibHuGas</p> <p>Ideal mixture of the real fluids: CO₂, H₂O, N₂, O₂ und Ar and of the ideal gases: SO₂, CO, Ne (scientific equations of Bücker et al.)</p>	<p>Library LibIdAir</p> <p>Ideal gas mixture</p> <p>Library LibHuAir</p> <p>Ideal mixture of the real fluids</p>																								
<p>Carbon Dioxide Library LibCO2</p> <p>Formulation of Span and Wagner</p> <p>Hydrogen Library LibH2</p> <p>Formulation of Younglove</p> <p>Helium Library LibHe</p> <p>Formulation of McCarty</p>	<p>Ideal Gas Mixture</p> <p>Library LibIdGasMix</p> <p>Ideal mixture of the ideal fluids:</p> <table> <tbody> <tr> <td>Ar</td> <td>Air</td> <td>OH</td> <td>Ethylene</td> </tr> <tr> <td>Ne</td> <td>NO</td> <td>He</td> <td>Propylene</td> </tr> <tr> <td>N₂</td> <td>H₂O</td> <td>F₂</td> <td>Propane</td> </tr> <tr> <td>O₂</td> <td>SO₂</td> <td>NH₃</td> <td>n-Butane</td> </tr> <tr> <td>CO</td> <td>H₂</td> <td>Methane</td> <td>Iso-Butane</td> </tr> <tr> <td>CO₂</td> <td>H₂S</td> <td>Ethane</td> <td>Benzene</td> </tr> </tbody> </table> <p>Mixtures in Absorption Processes</p> <p>Ammonia & Water Library LibAmWa</p> <p>Water & Lithiumbromide Library LibWaLi</p>	Ar	Air	OH	Ethylene	Ne	NO	He	Propylene	N ₂	H ₂ O	F ₂	Propane	O ₂	SO ₂	NH ₃	n-Butane	CO	H ₂	Methane	Iso-Butane	CO ₂	H ₂ S	Ethane	Benzene	<p>Refrigerants</p> <p>Ammonia Library LibNH3</p> <p>R134a Library LibR134a</p> <p>Propane Library LibPropan</p> <p>Iso-Butane Library LibButan_Iso</p> <p>n-Butane Library LibButan_n</p>
Ar	Air	OH	Ethylene																							
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