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WORKSHOP ON DESIGNING SUSTAINABLE ENERGY SYSTEMS
18 October - 5 November 2004

MODELLING OF COMBINED HEAT AND POWER PLANTS

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These are preliminary lecture notes, intended only for distribution to participants.

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Modeling of Combined Heat and Power Plants

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Topics covered

Single fuel back pressure units,

Multiple fuel back pressure units,

Single fuel extraction units,

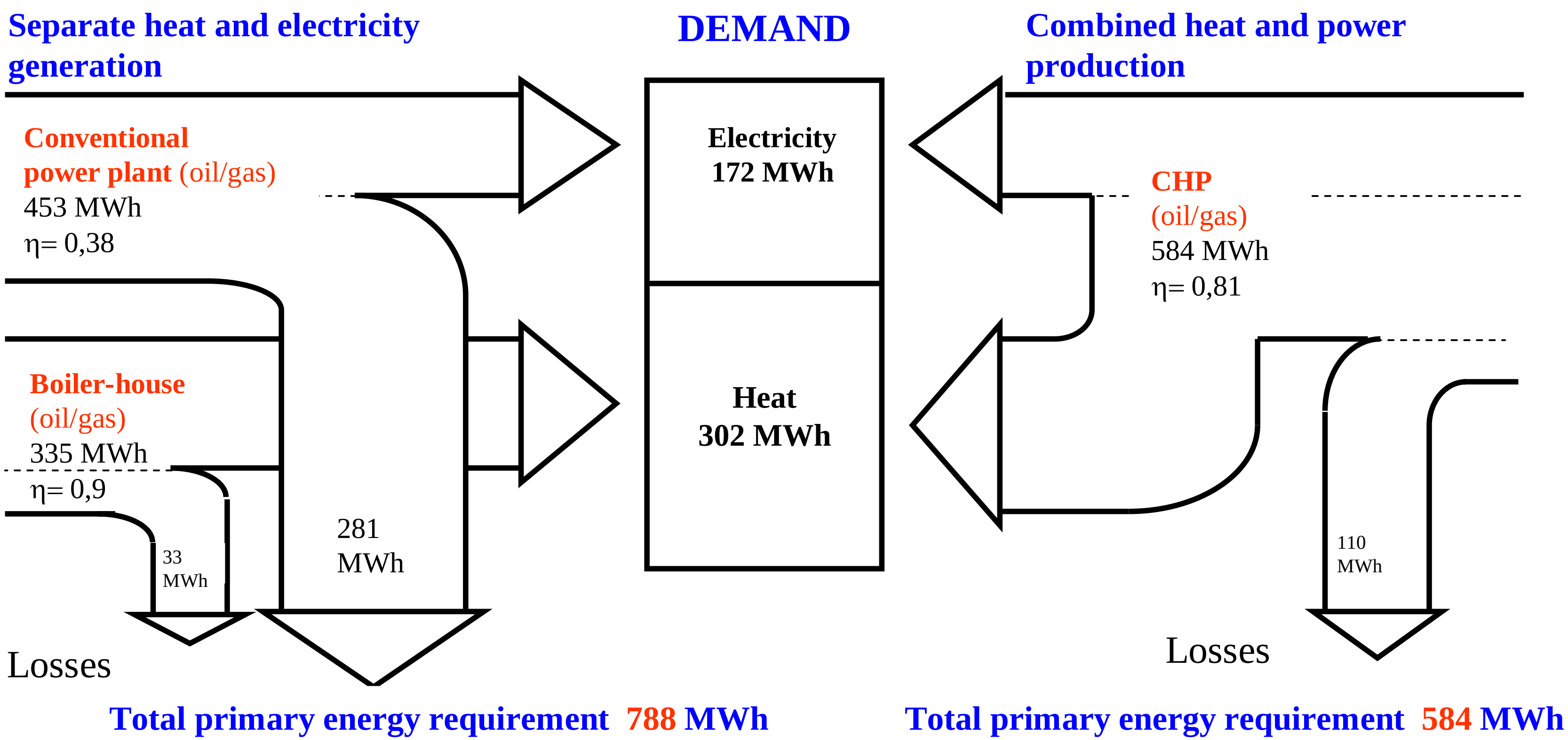
Multiple fuel extraction units,

Ability to cover heat and electricity demand,

System with CHP and heat accumulator,

Data example for case studies.

Combined and separate heat and electricity production



Saving of primary energy requirement 26%

Types of combined heat and power plants

Back pressure CHP – relation between heat and electricity output is fixed,

Extraction CHP – heat and electricity output is not in a fixed relation.

Back pressure units

Technical parameters of CHP's

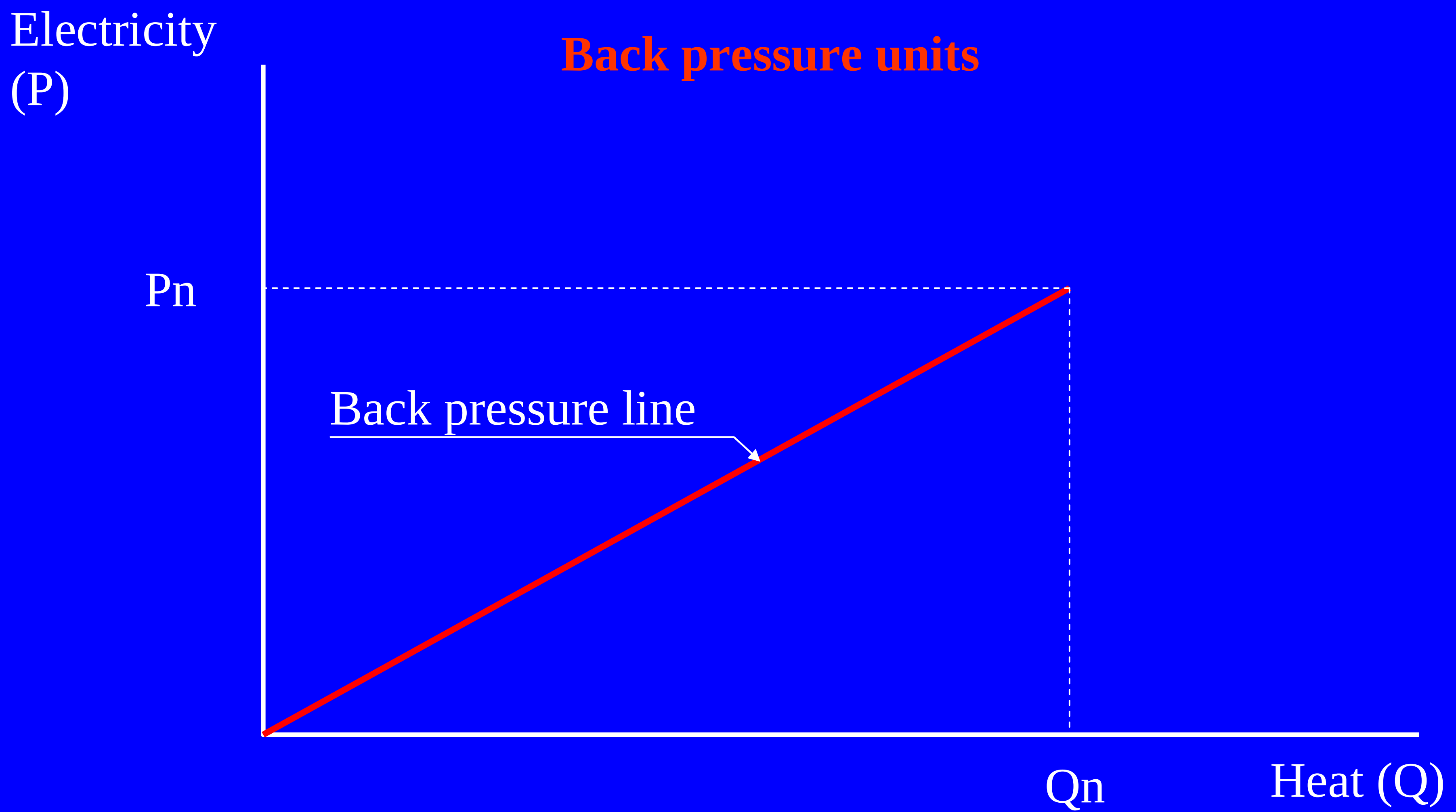
Back pressure units

Nominal electrical capacity (Pn),

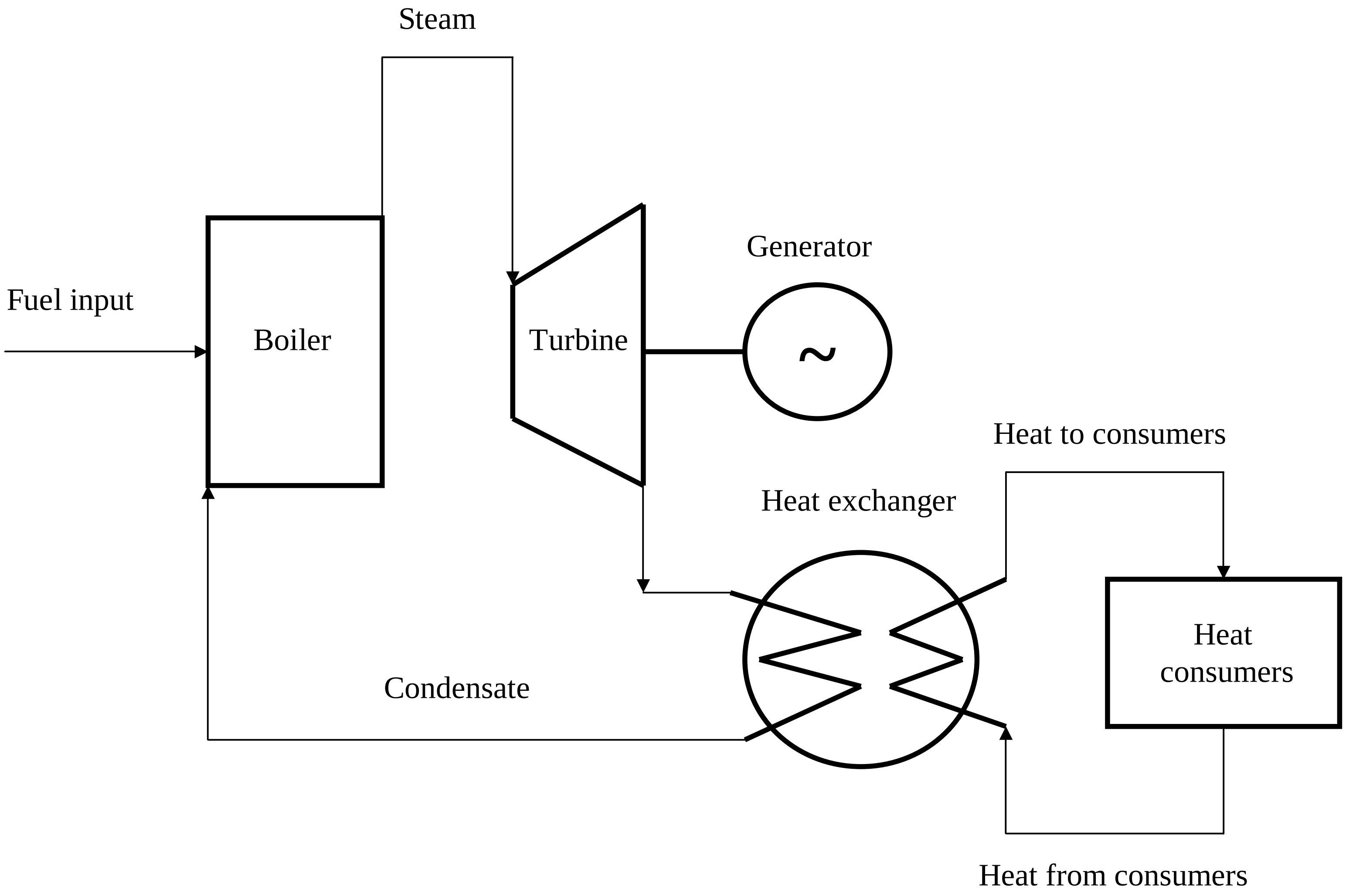
Nominal thermal capacity (Qn),

Total fuel efficiency η_{Σ}

Relation between heat and electricity output

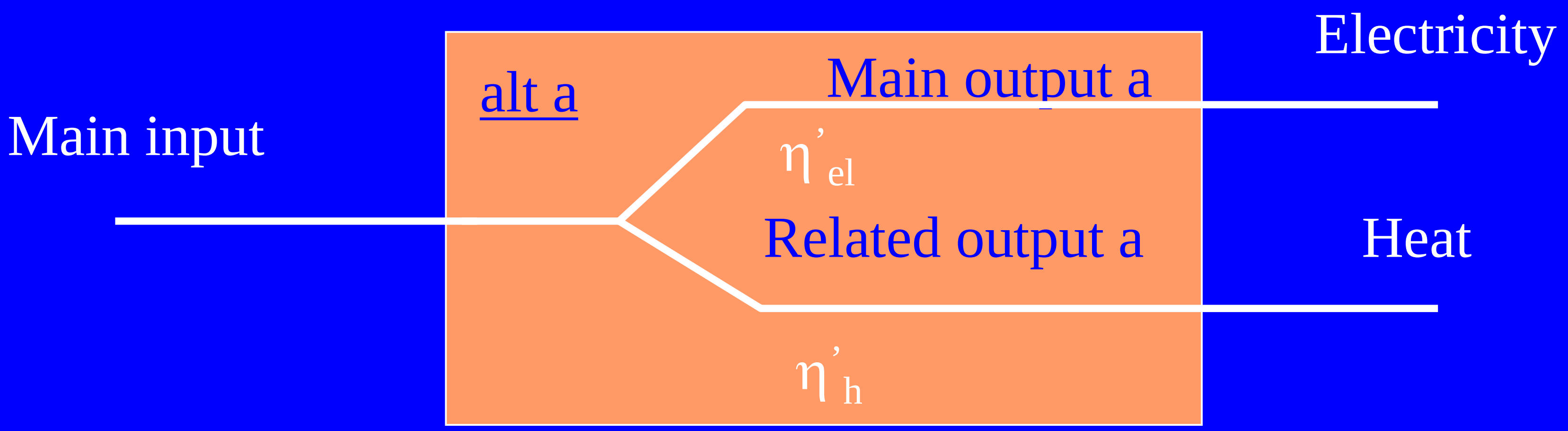


Back pressure units



Representation of CHP in MESSAGE

Back pressure unit



$$\eta'_{el} = \frac{Pn}{(Pn + Qn)/\eta_{\Sigma}} \quad ; \quad \eta'_{h} = \frac{Qn}{(Pn + Qn)/\eta_{\Sigma}} \quad ; \quad \mathbf{P' = Pn} \;;$$

Representation of CHP in MESSAGE

Back pressure unit

$Pn = 23.3$ MW; $Qn = 102.3$ MW; $\eta_{\Sigma} = 0.825$;

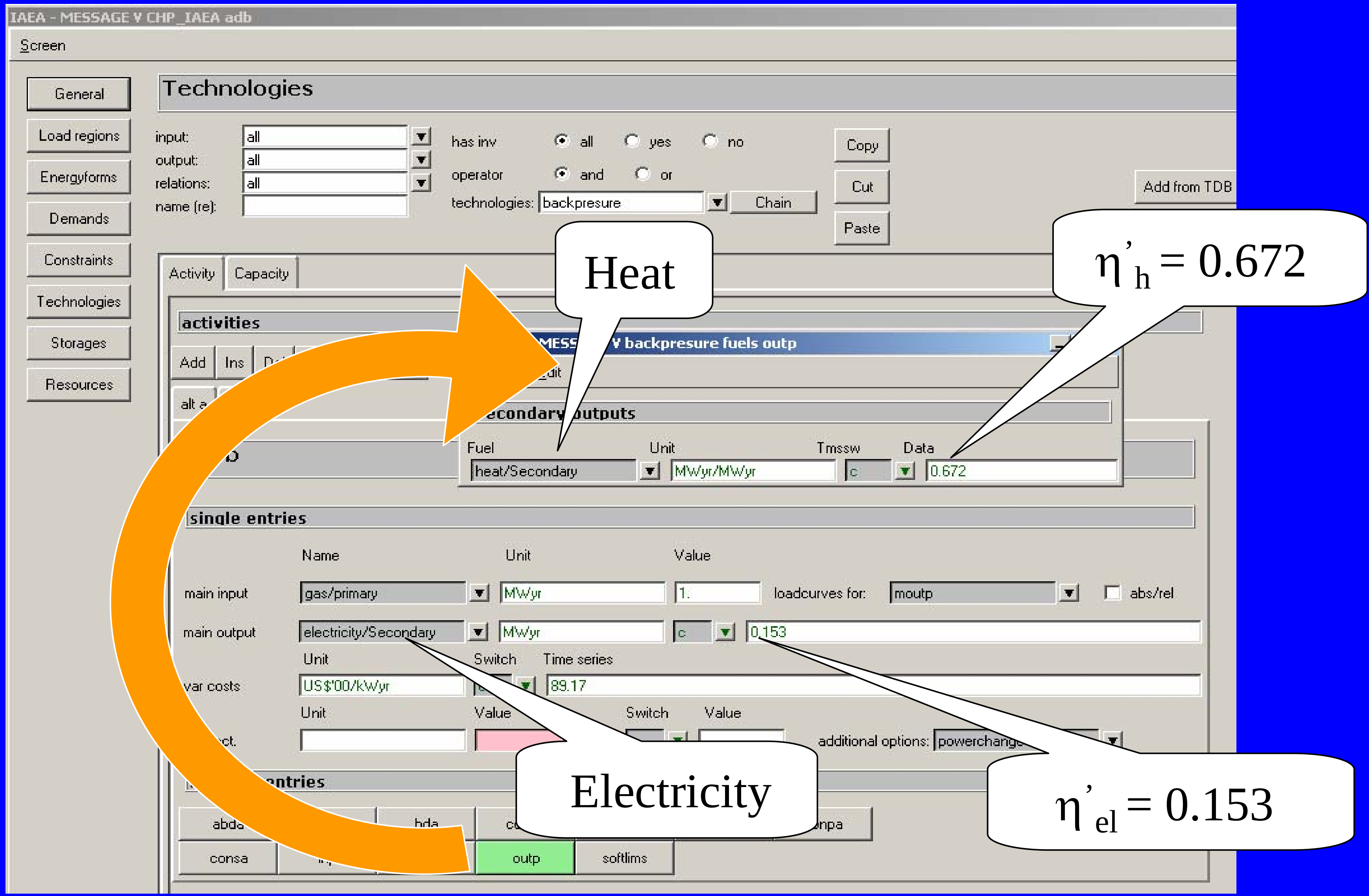
$P' = Pn = 23.3$ MW;

$$\eta'_{el} = \frac{Pn}{(Pn + Qn)/\eta_{\Sigma}} = \frac{23.3}{(23.3+102.3)/0.825} = 0.153;$$

$$\eta'_{h} = \frac{Qn}{(Pn + Qn)/\eta_{\Sigma}} = \frac{102.3}{(23.3+102.3)/0.825} = 0.672;$$

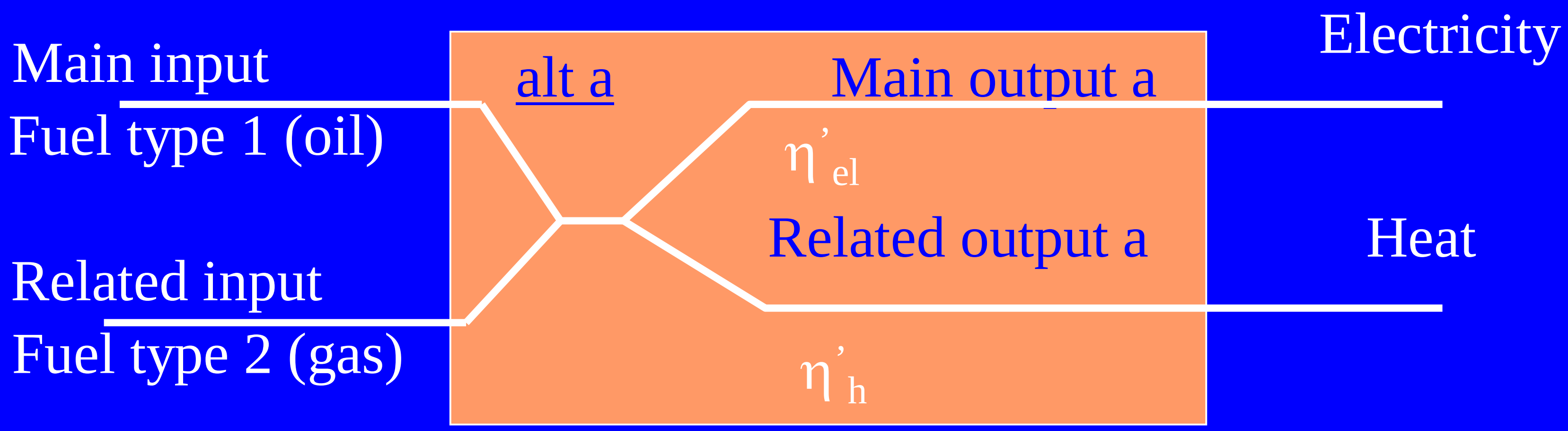
Representation of CHP in MESSAGE

Back pressure units



Representation of CHP in MESSAGE

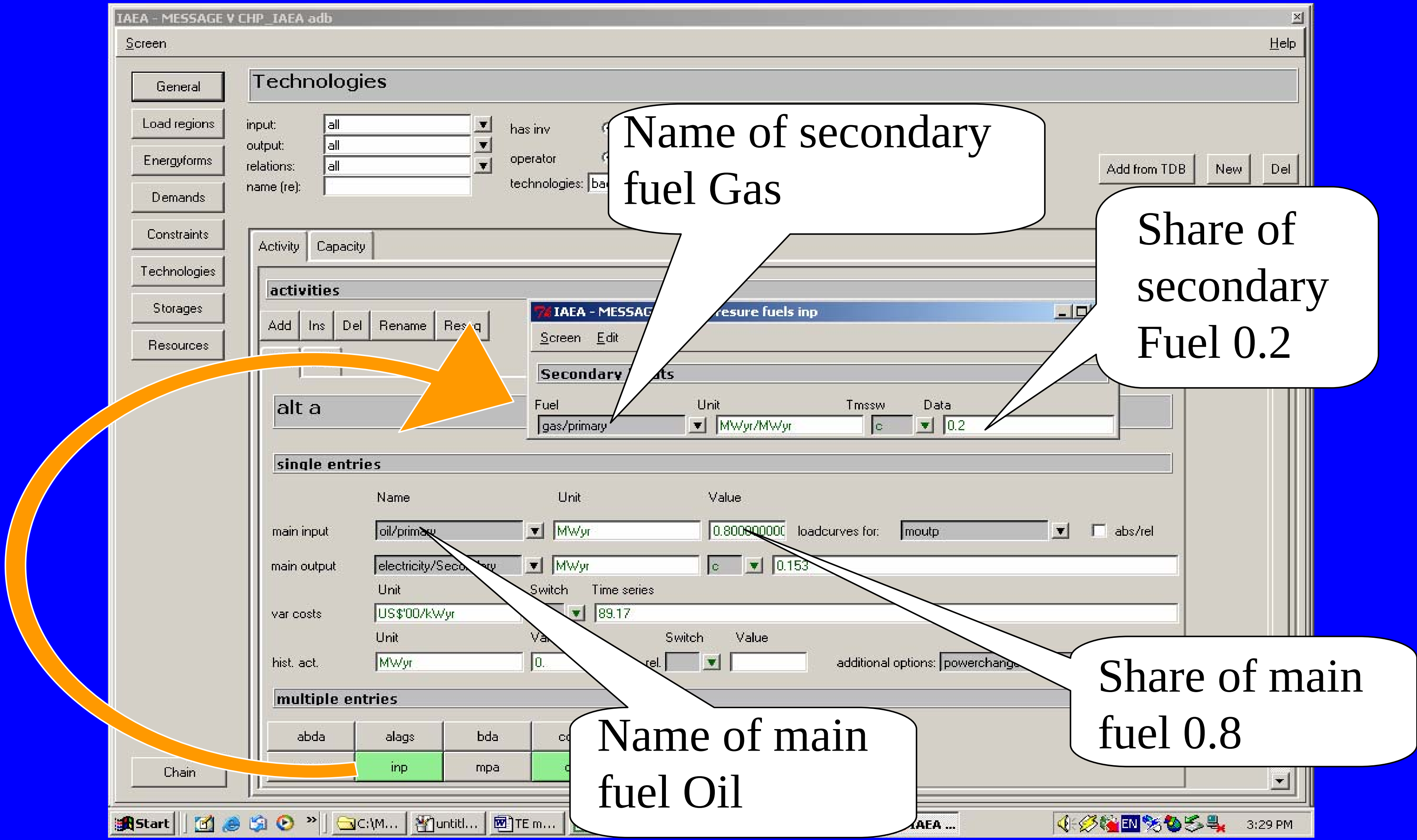
Back pressure unit with multiple fuel in input. Share of each fuel consumed is fixed



For example: Share of oil consumed makes 80%, while share of gas consumed corresponds to 20%.

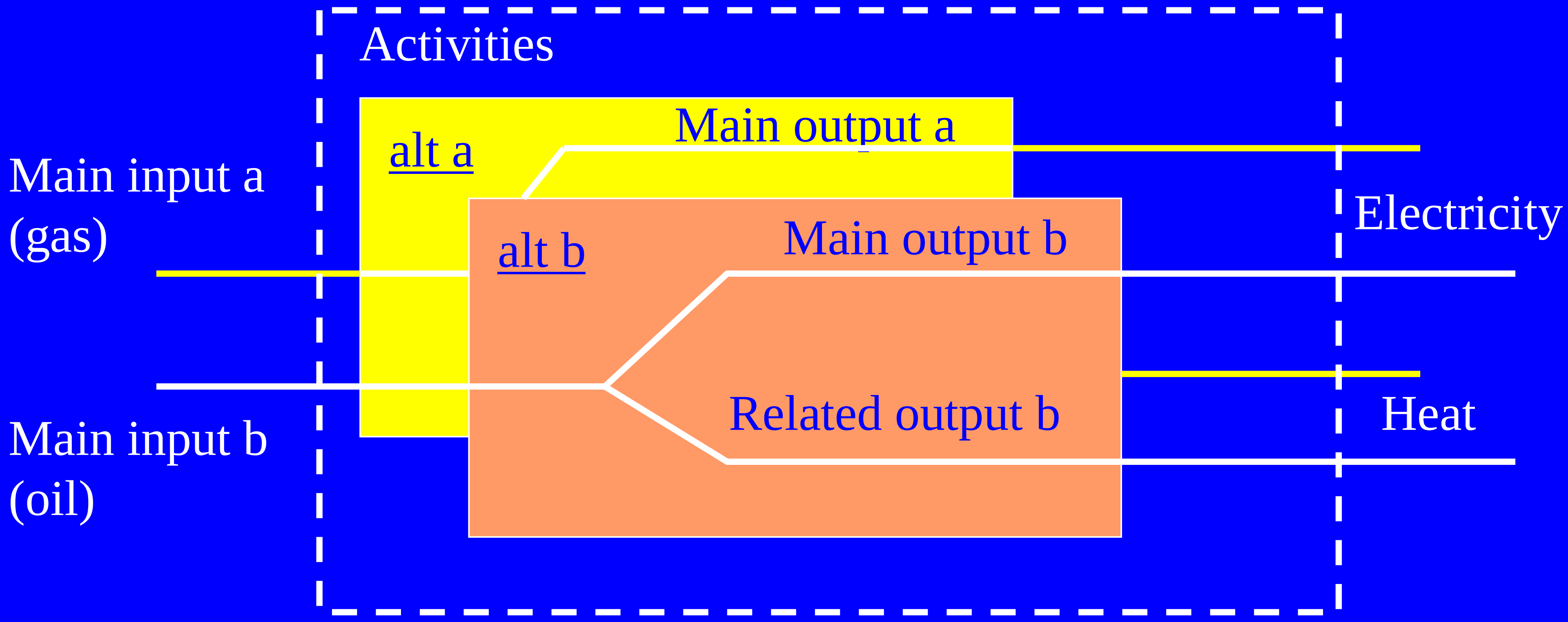
Representation of CHP in MESSAGE

Back pressure unit with multiple fuel in input. Share of each fuel consumed is fixed



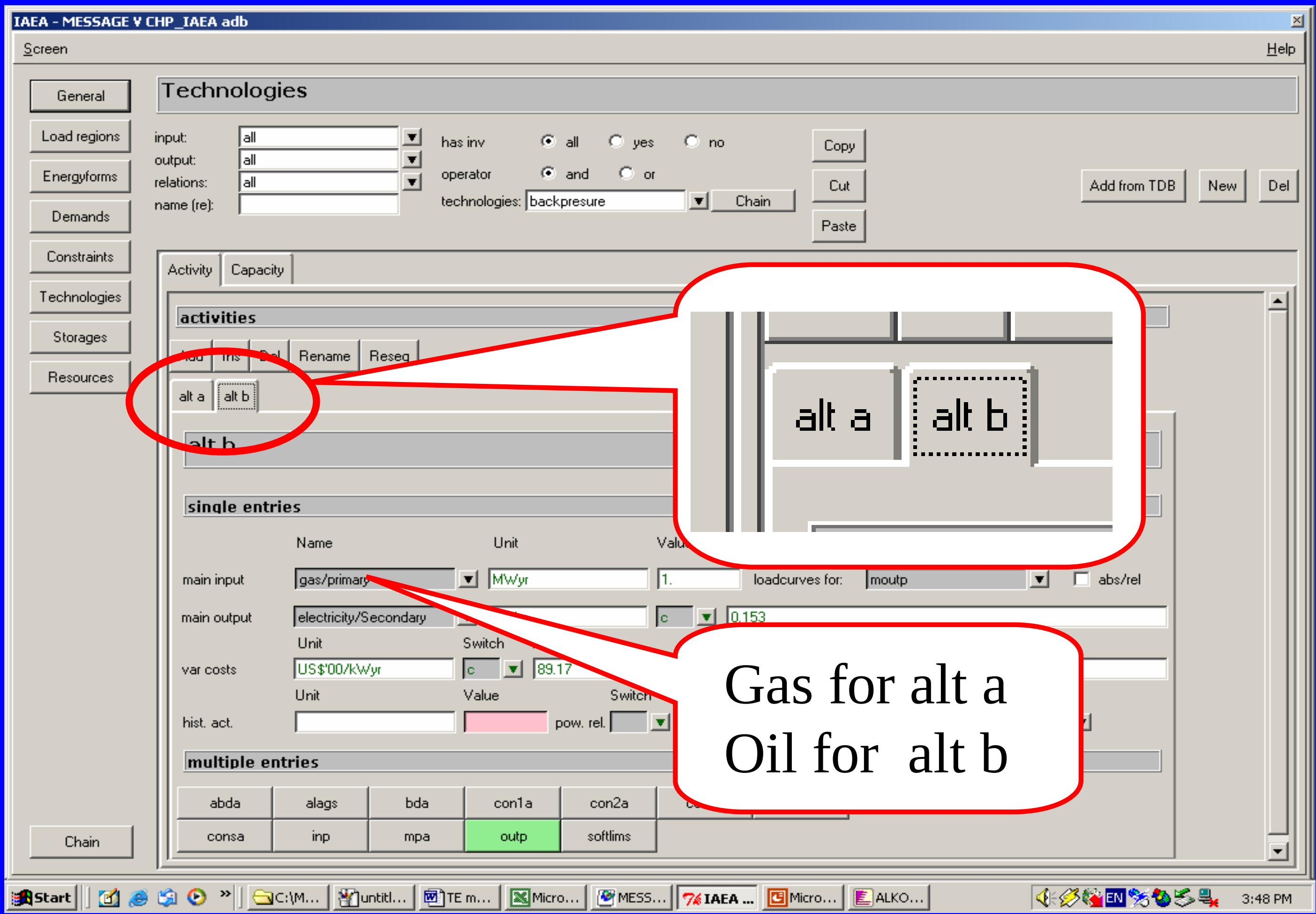
Representation of CHP in MESSAGE

Multi fuel back pressure unit. Share of each fuel consumed is not predetermined



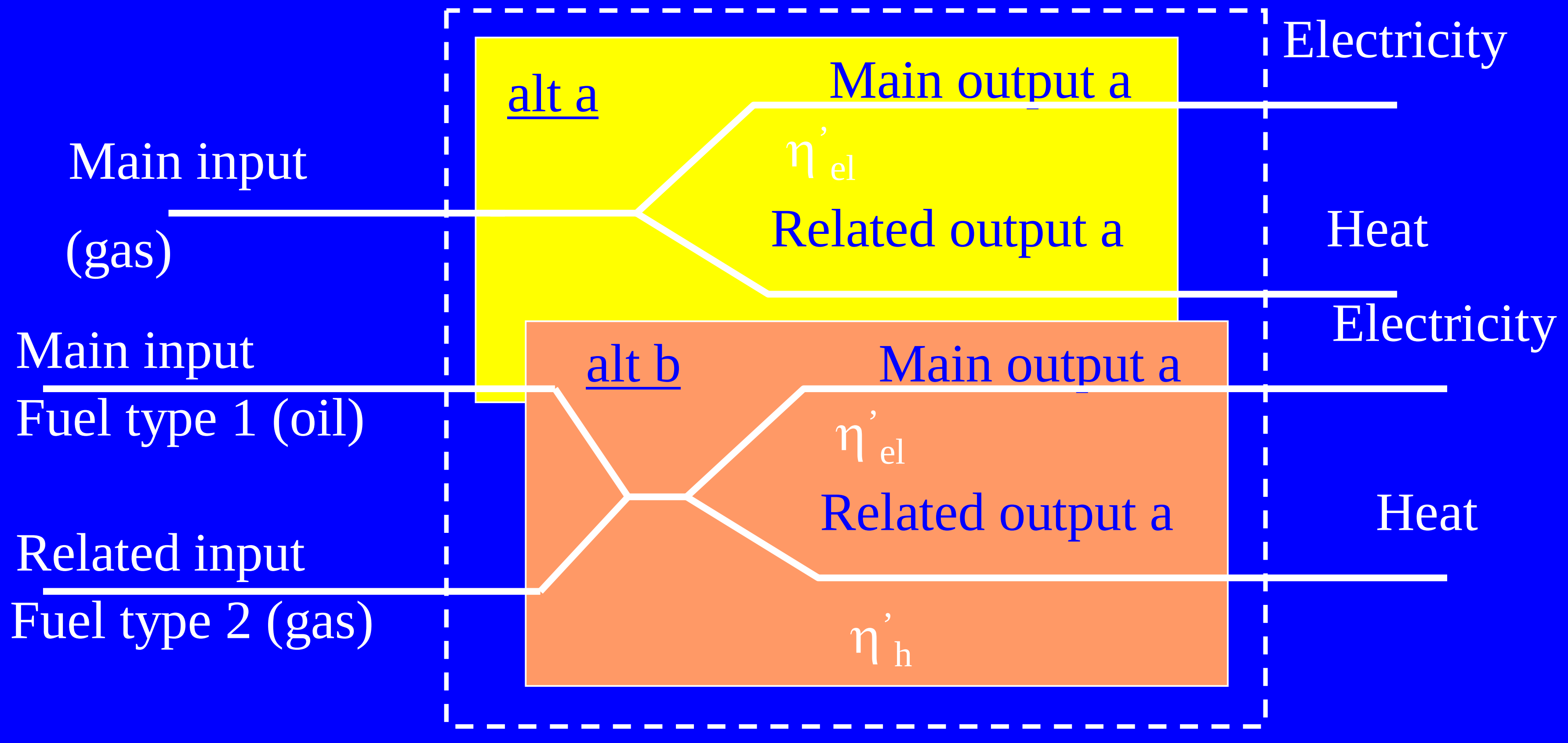
Representation of CHP in MESSAGE

Multi fuel back pressure unit. Share of each fuel consumed is not predetermined



Representation of CHP in MESSAGE

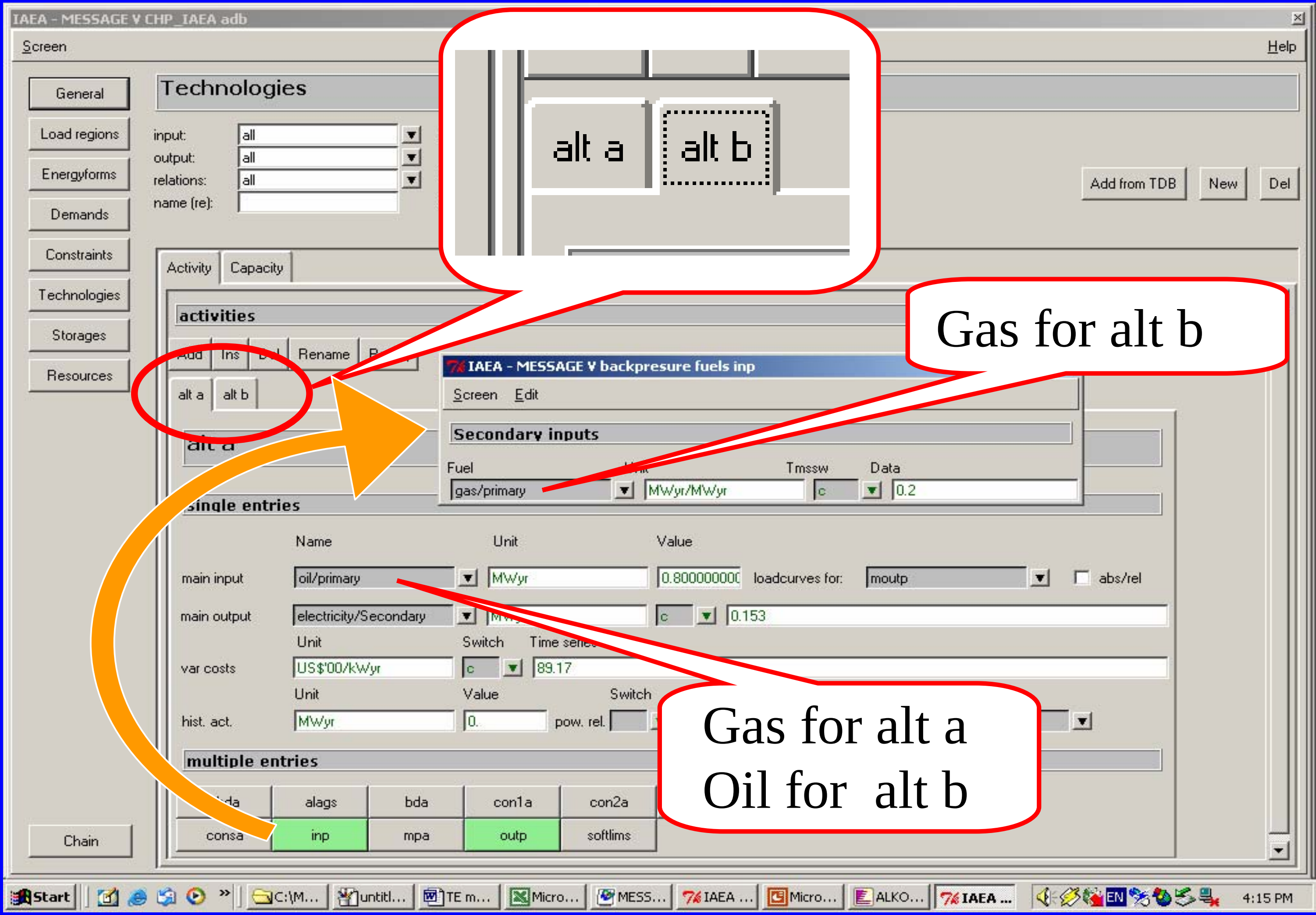
Back pressure unit. Different modes of fuel consumption



Any linear combination of alternative modes of operation in respect of fuel consumption is possible

Representation of CHP in MESSAGE

Back pressure unit. Different modes of fuel consumption



Cost data of CHP's

Back pressure units

Investment costs and fixed O&M costs are related to electrical capacity,

Variable O&M costs are related to electricity output.

Extraction units

Technical parameters of CHP's

Extraction units

Nominal electrical capacity in CHP mode (Pn),

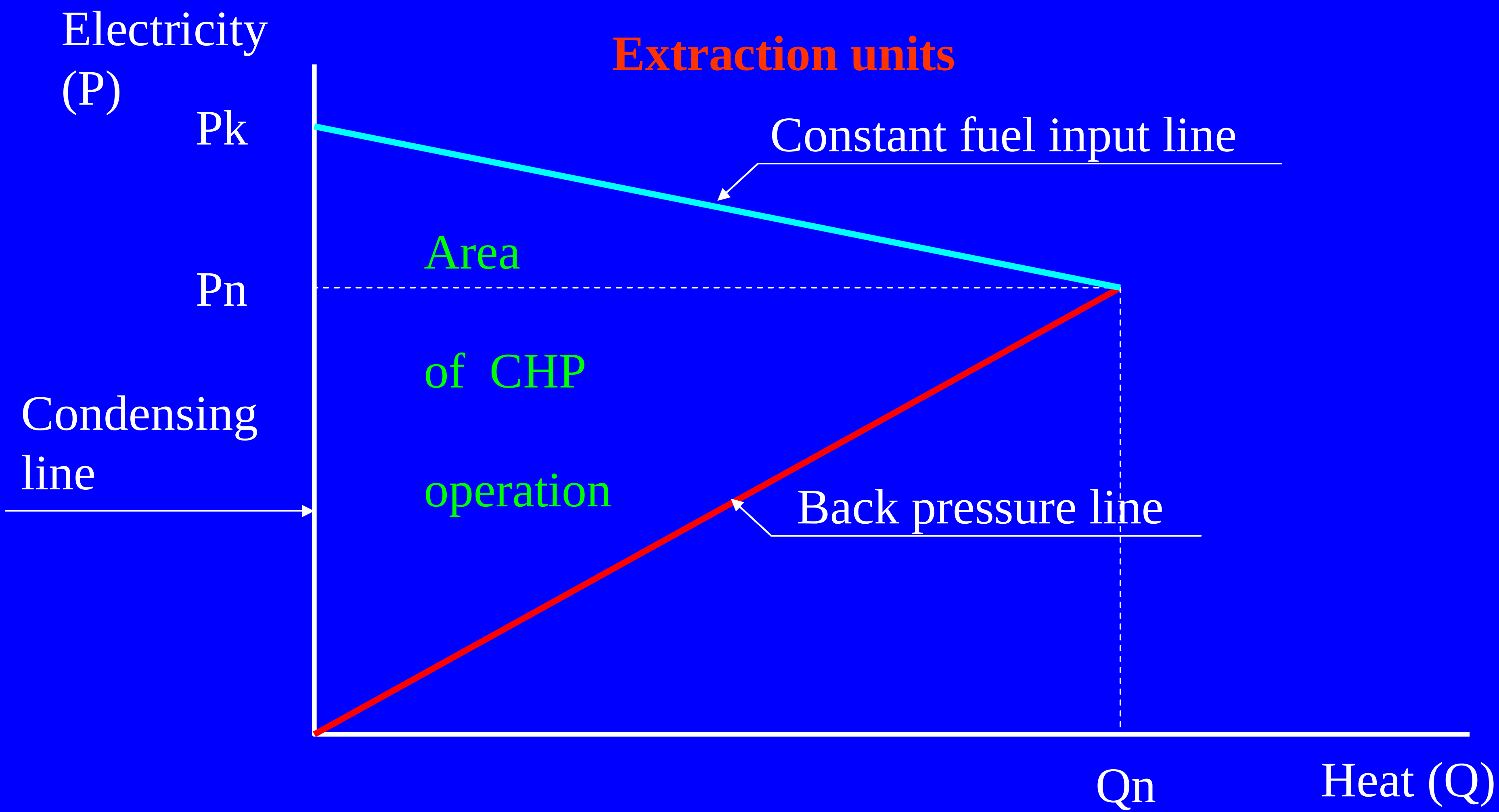
Nominal electrical capacity in condensing mode (Pk),

Nominal thermal capacity (Qn),

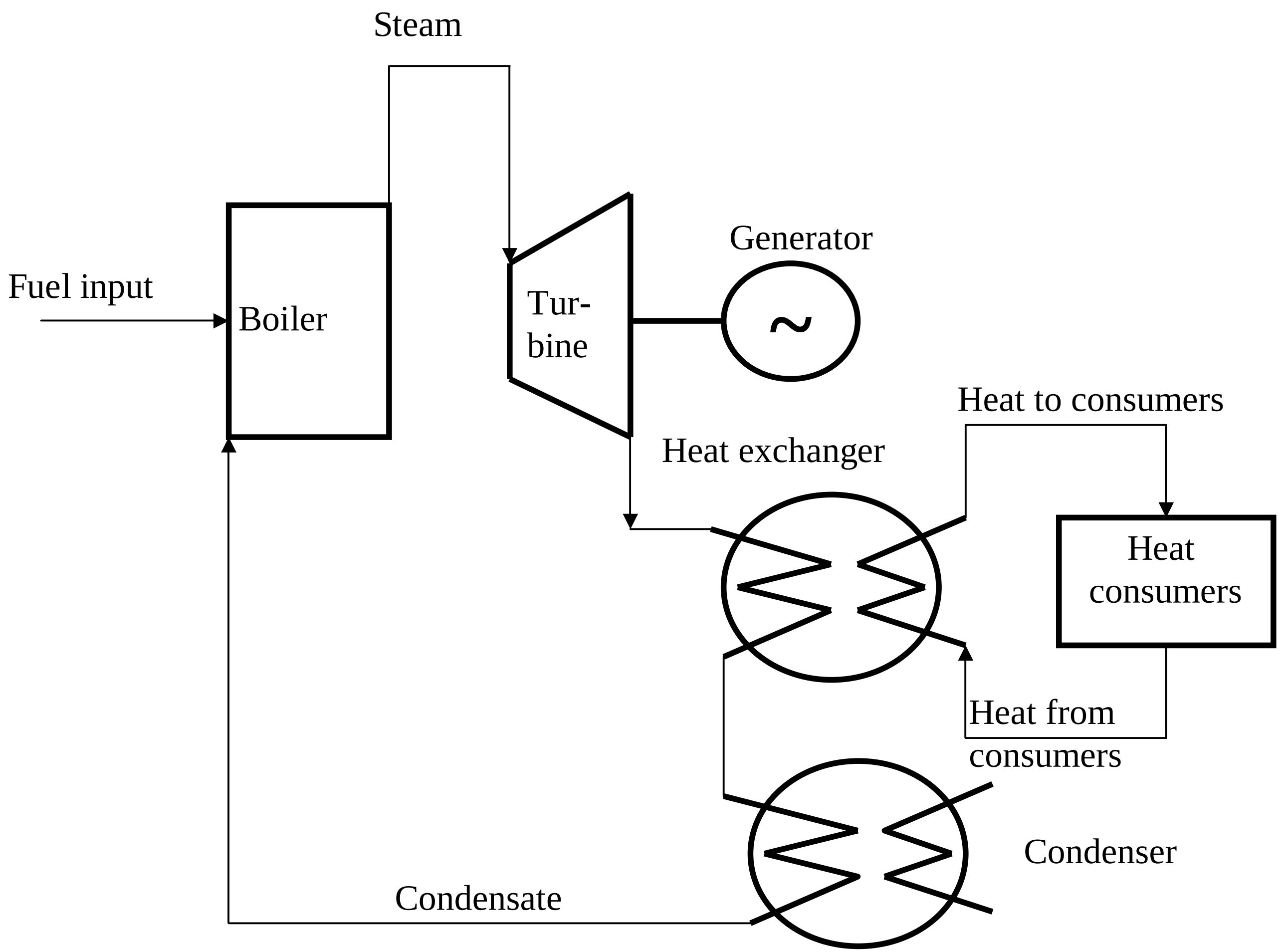
Fuel efficiency in condensing mode (ηk),

Fuel efficiency in CHP mode (Total efficiency) (η_T).

Relation between heat and electricity output

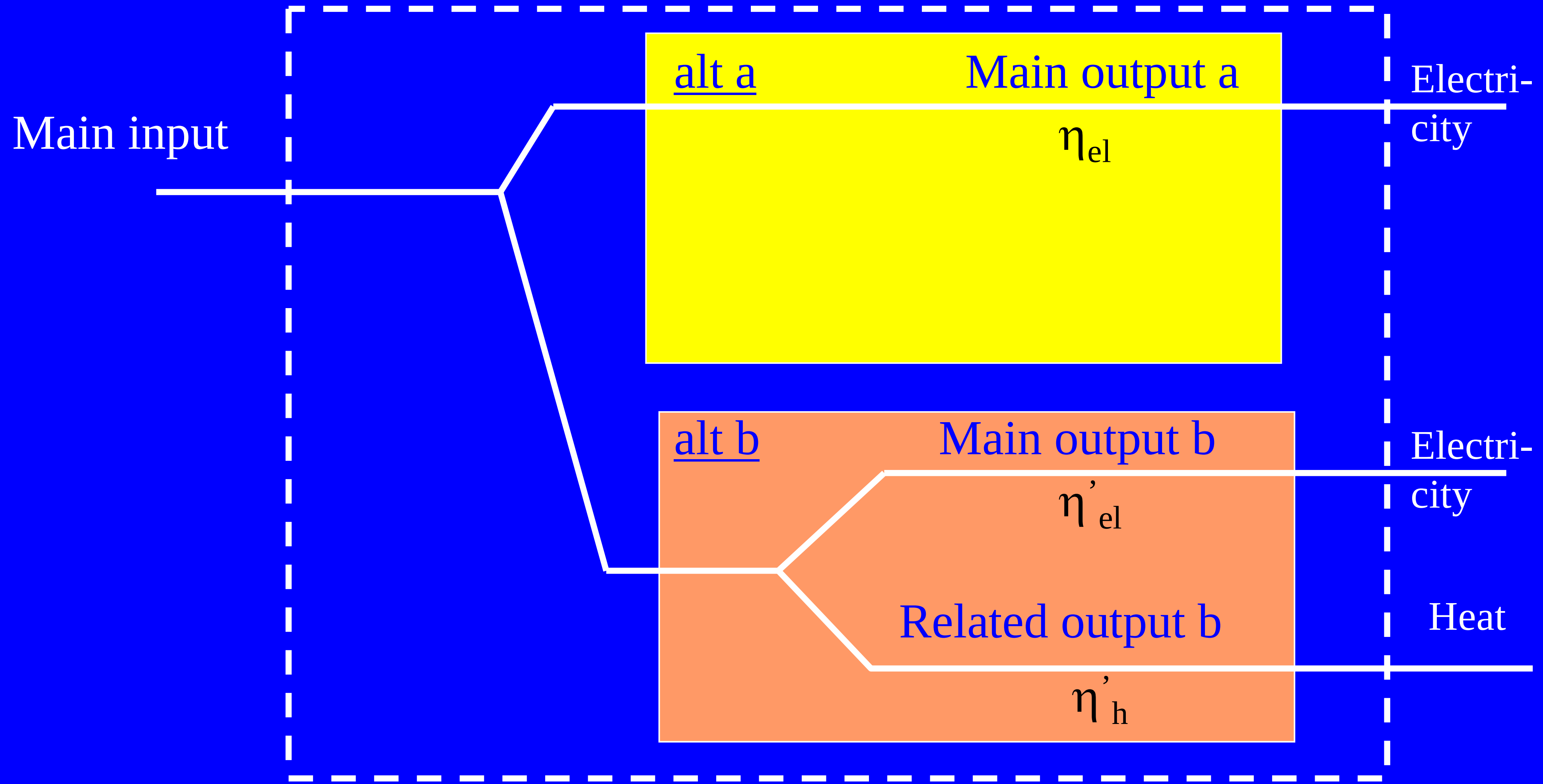


Extraction unit



Representation of CHP in MESSAGE

Extraction unit (single fuel)



Representation of CHP in MESSAGE

Extraction unit (single fuel)

Pn = 171.8 MW; Pk = 208 MW; Qn = 302.3 MW;

$\eta_k = 0.357$; $\eta_T = 0.81$;

$\eta_{el} = \eta_k = 0.357$; (Power relation) pow.rel. = $\frac{Pk}{Pn} = \frac{208}{171.8} = 1.21$;

$$\eta'_{el} = \frac{Pn}{(Pn + Qn)/\eta_T} = \frac{171.8}{(171.8+302.3)/0.81} = 0.293;$$

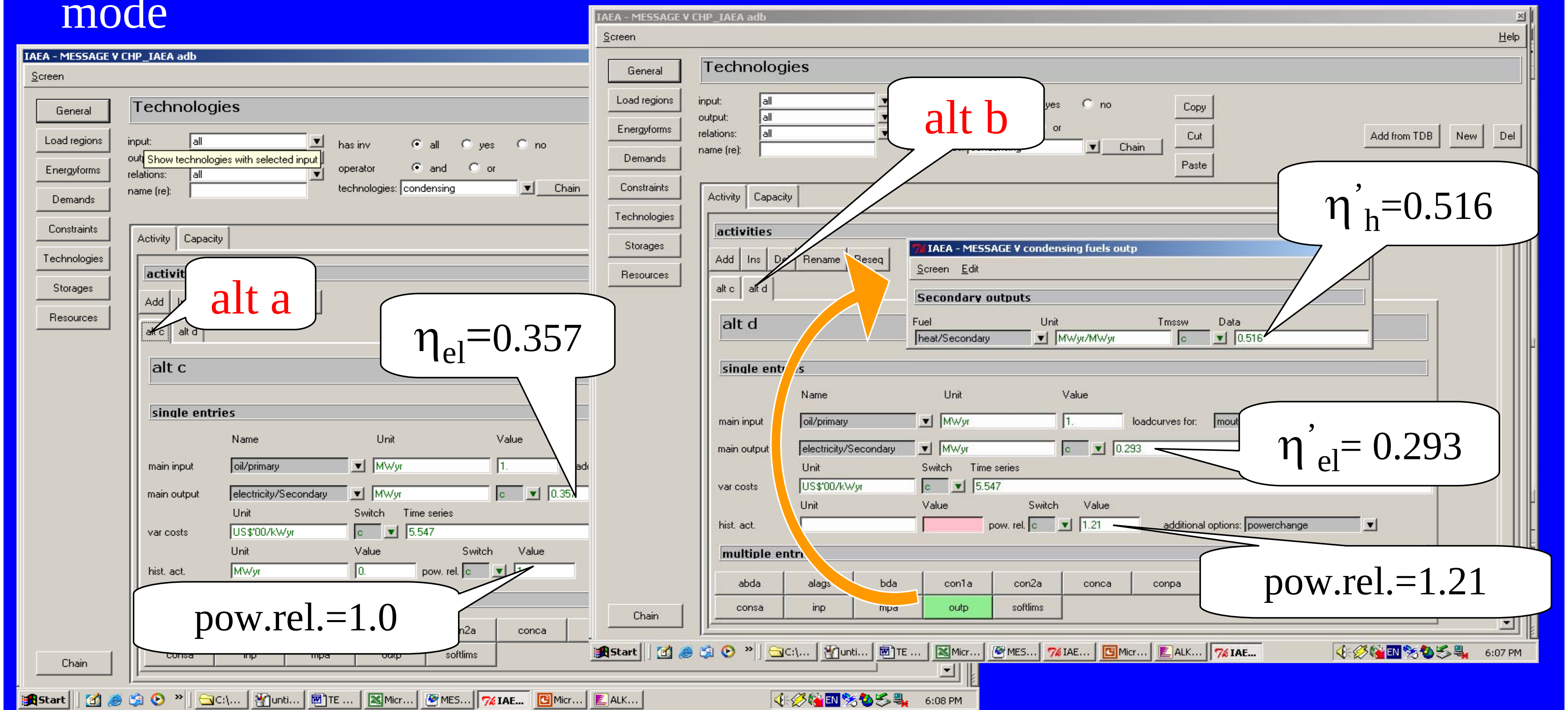
$$\eta'_{h} = \frac{Qn}{(Pn + Qn)/\eta_T} = \frac{302.3}{(171.8+302.3)/0.81} = 0.516;$$

Representation of CHP in MESSAGE

Extraction unit (single fuel)

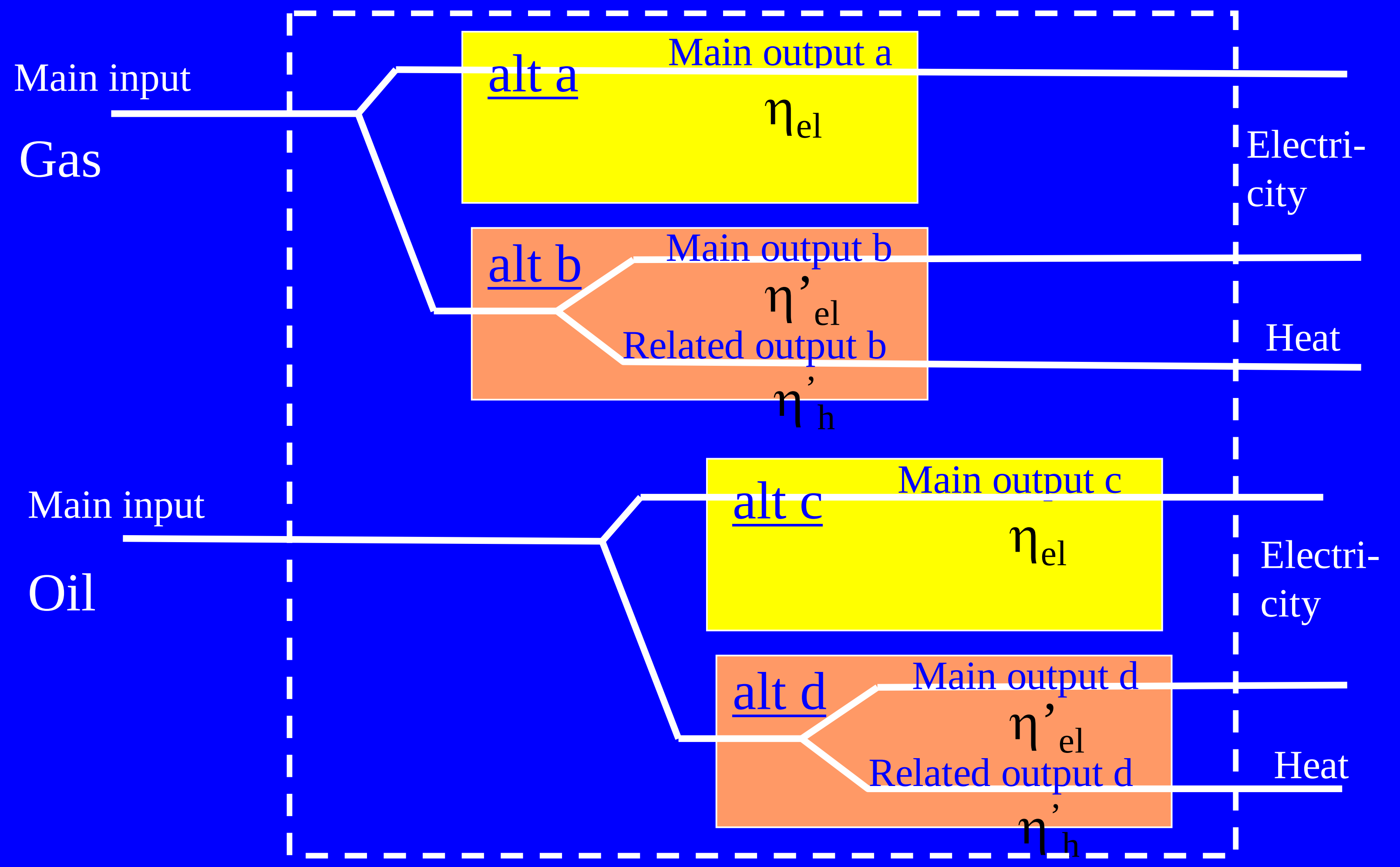
Condensing operation mode

CHP operation mode



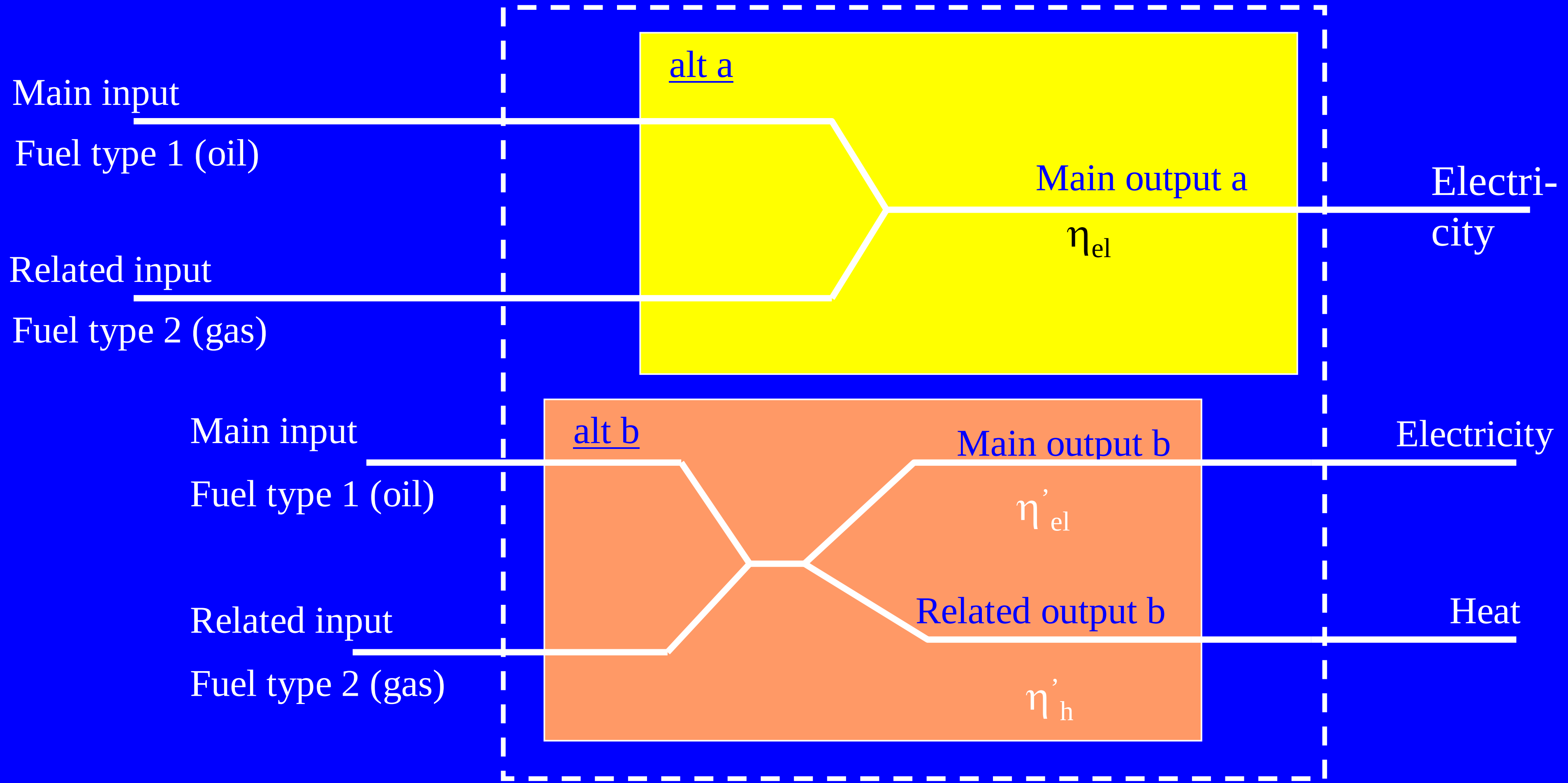
Representation of CHP in MESSAGE

Extraction unit (multiple fuel, fuel shares ere not fixed)



Representation of CHP in MESSAGE

Extraction unit (multiple fuel, fuel shares ere fixed)



Cost data of CHP’s

Extraction units

Investment costs and fixed O&M costs are related to electrical capacity in condensing mode,

Variable O&M costs are related to electricity output in condensing regime.

Cost calculation for extraction CHP

$$\text{Cost-fix} = \frac{AFCEP + AFCHP}{Pk}$$

$$\text{Cost-var}_{CHP} = \frac{AVCEP_{CHP} + AVCHP}{W_{CHP}}$$

$$\text{Cost-var}_{COND} = \frac{AVCEP_{COND}}{W_{COND}}$$

AFCEP – annual fixed O&M cost for electricity production;

AFCHP – annual fixed O&M cost for heat production;

Pk – installed capacity for condensing operation mode;

$AVCEP_{CHP}$, $AVCEP_{COND}$- annual variable O&M cost for electricity production in CHP and COND mode respectively;

AVCHP - annual variable O&M cost for heat production;

W_{CHP} – annual electricity production in combined heat and electricity production mode;

W_{COND} – annual electricity production in condensing mode;

Other CHP features

Diversity of heat output:

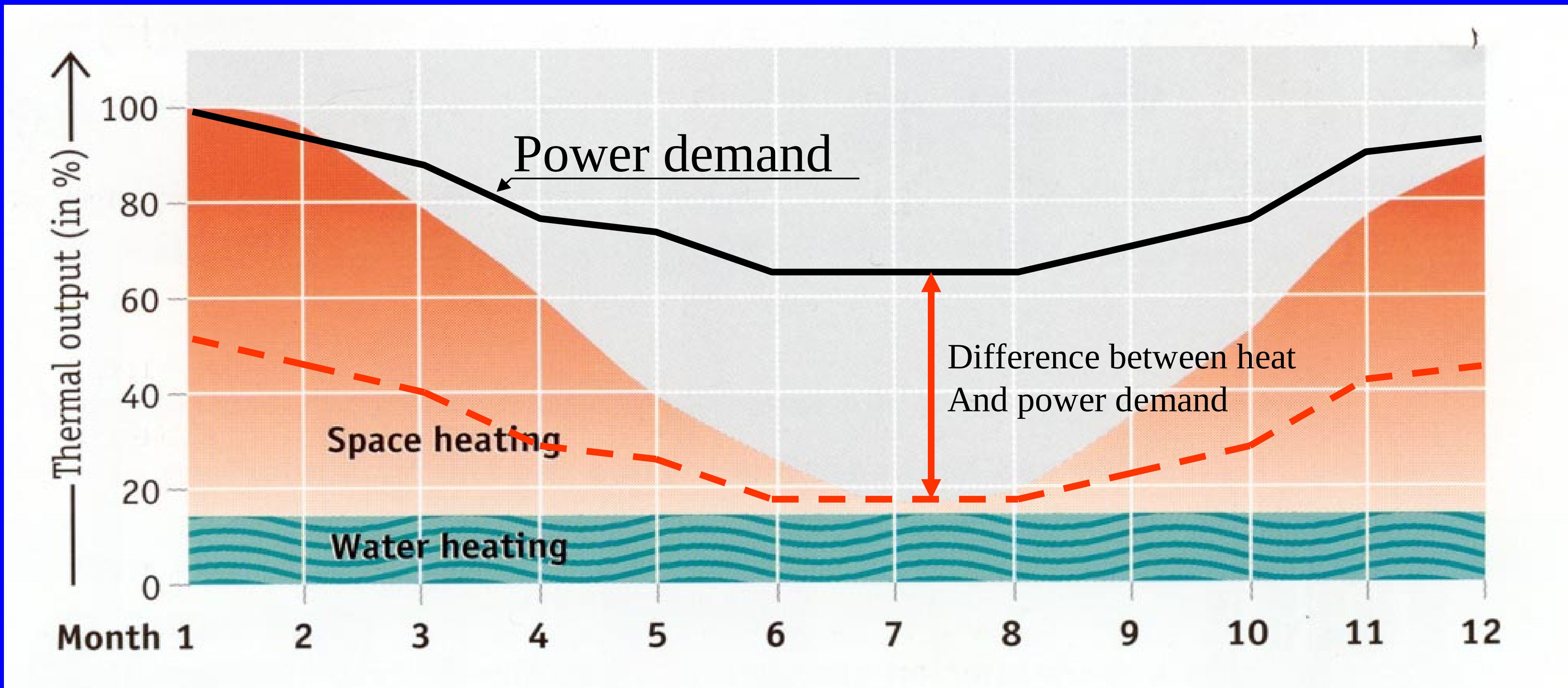
> ***heat in form of steam of some parameters,***
> ***heat in form of stem of other parameters,***
> ***heat in form of hot water,***

Proportion of heat output in form of steam and hot water may wary or may be in fixed proportion;

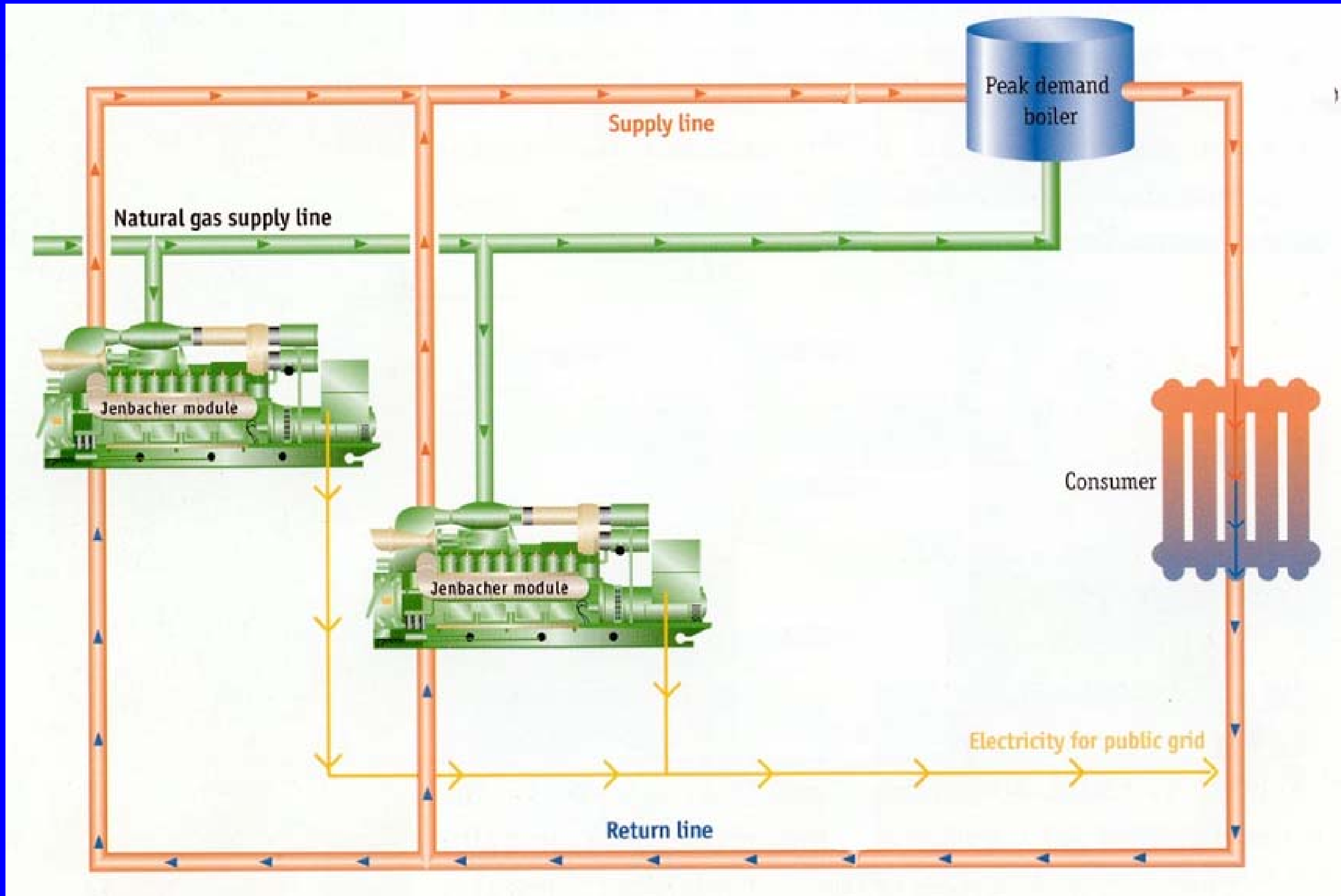
Consumers for those products are different;

All this requires to use more complicated modelling approach but always it is necessary to think is it worth to increase complexity of the model.

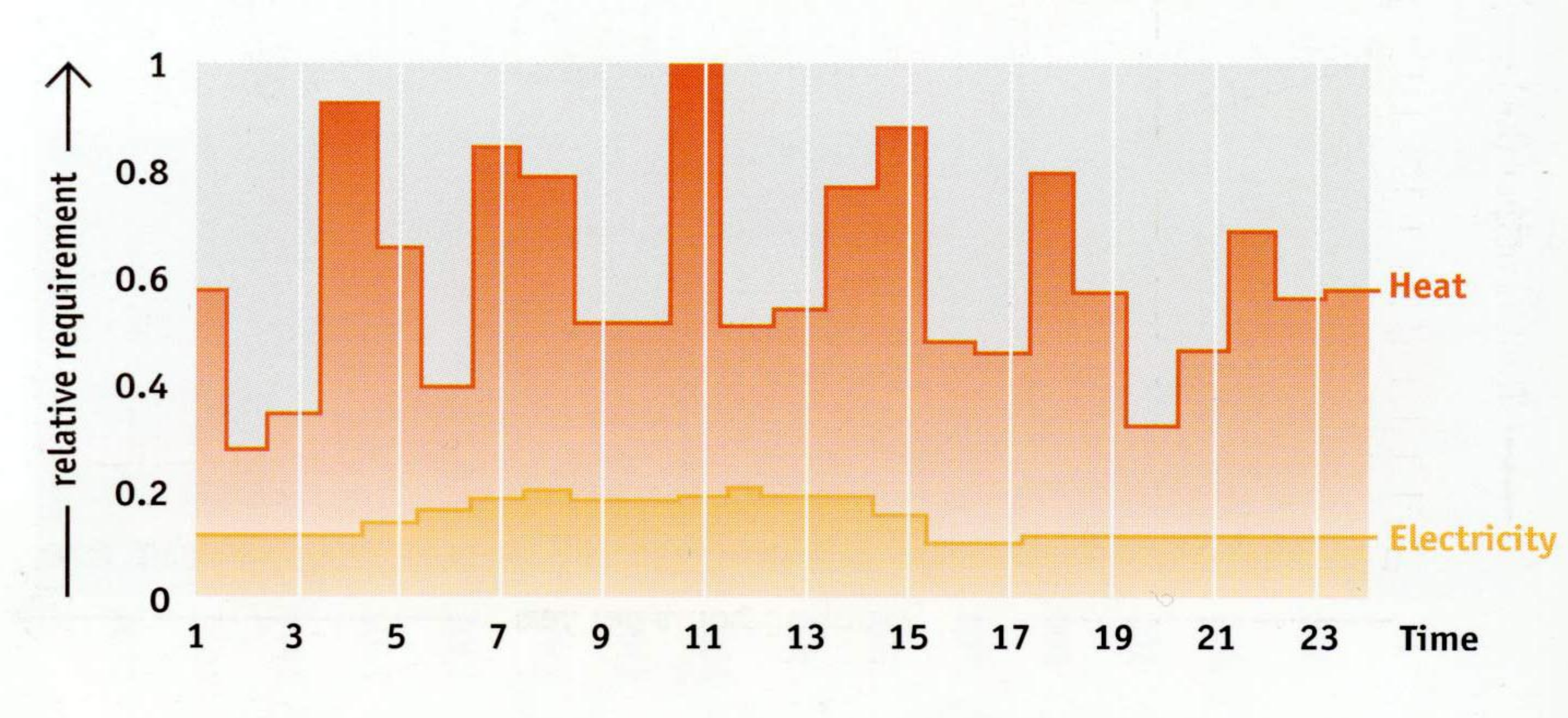
Ability of CHP to cower heat and power demand



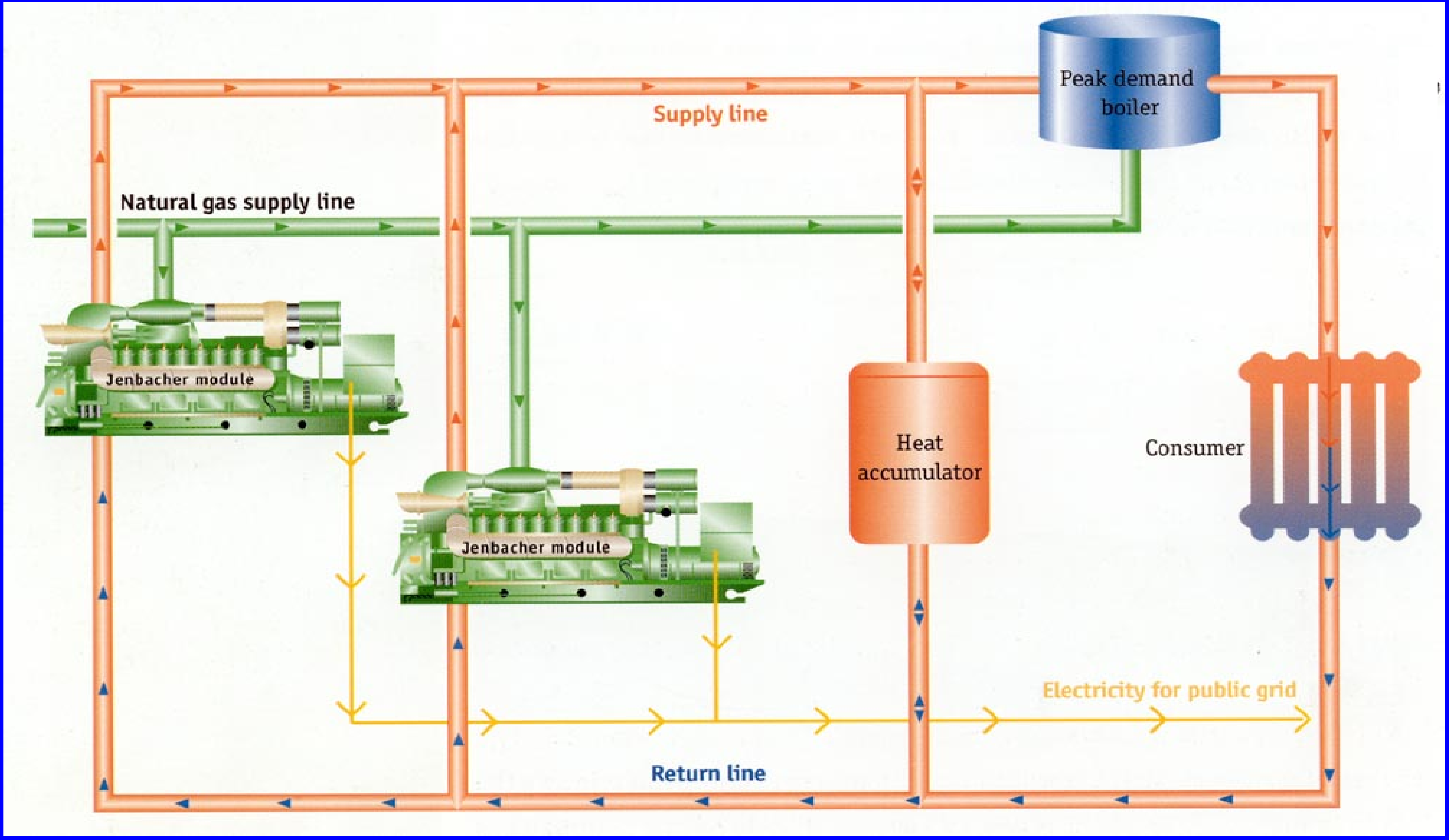
Joining of CHP's with heat only boilers



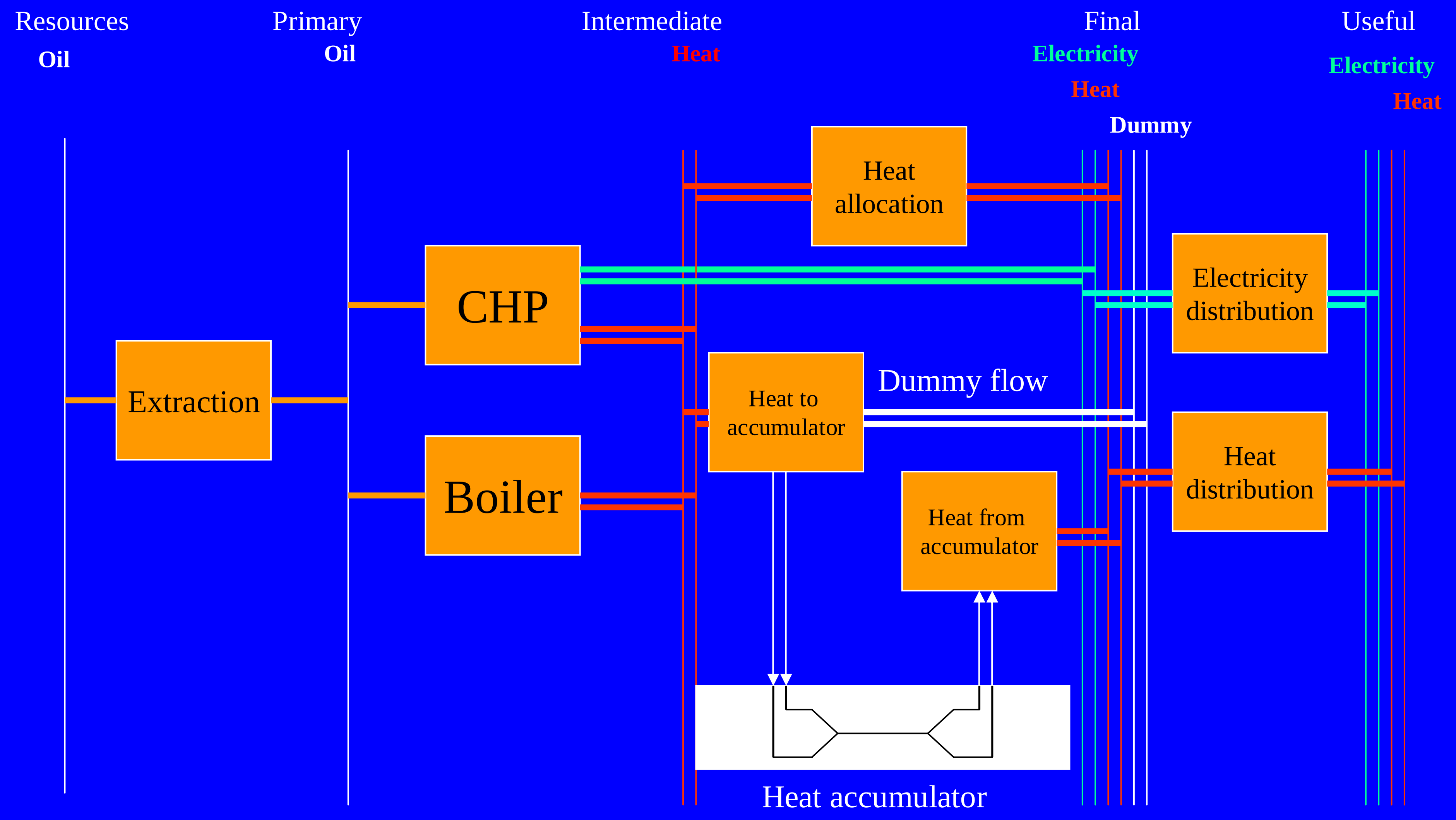
Heat load fluctuations



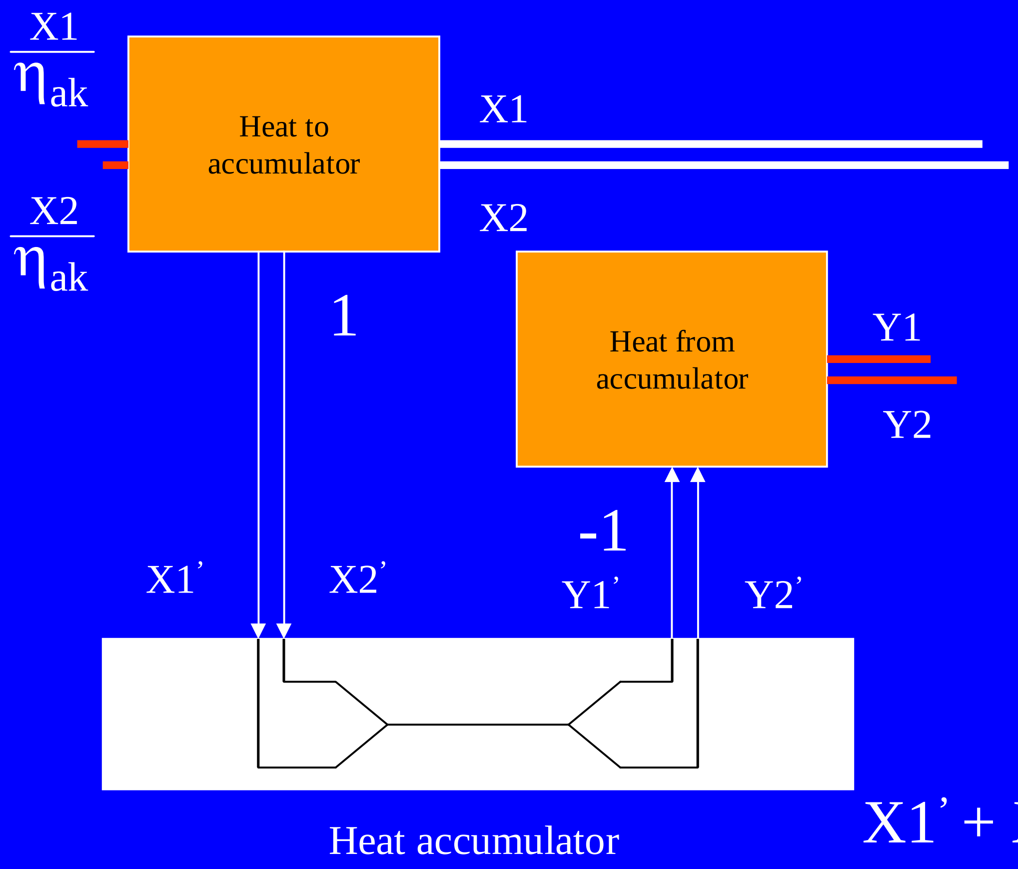
CHP with heat accumulator



Modeling of CHP with heat storage



Principle equations for heat accumulator



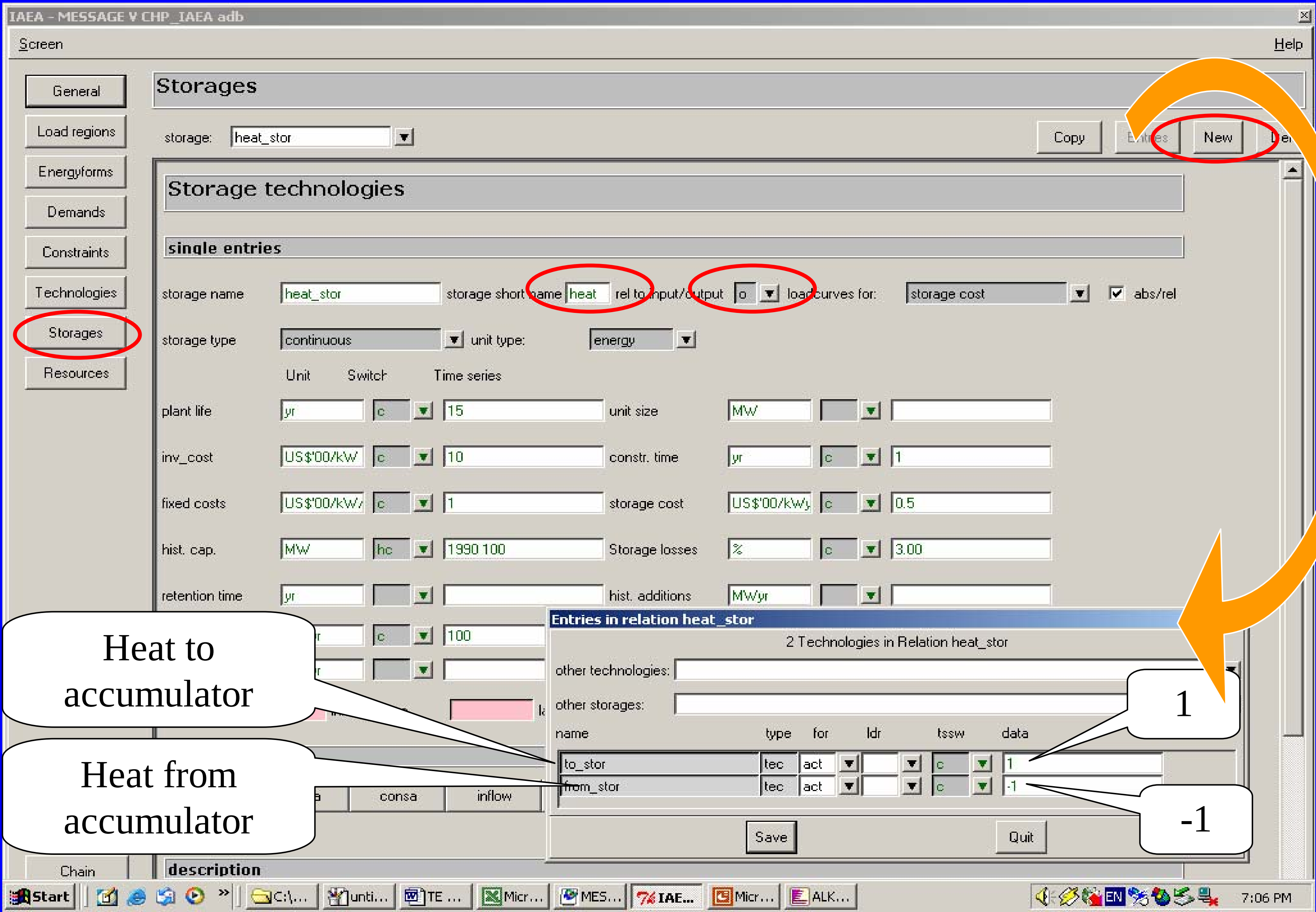
$X1' = X1;$ $X2' = X2;$

$Y1 = Y1';$ $Y2 = Y2';$

$X1' - Y1' <= \text{active volume};$

$X1' + X2' - Y1' - Y2' <= \text{active volume};$

Representation of heat storage in MESSAGE



Items that should be taken into account when CHP are analyzed

Heat market is local while electricity market is common for the country or region;

Heat markets are different in respect of:

density of heat load,

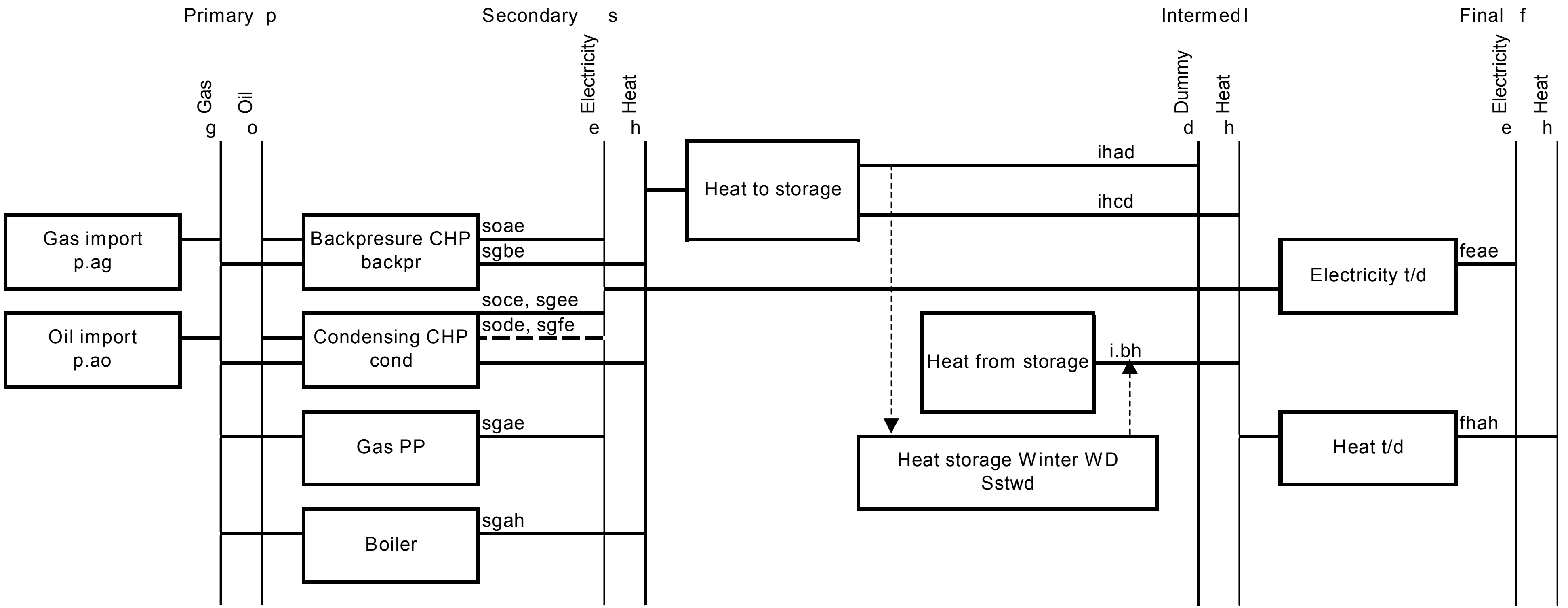
heat load curve,

availability and conditions of heat distribution network,

availability and conditions of other heat generation sources;

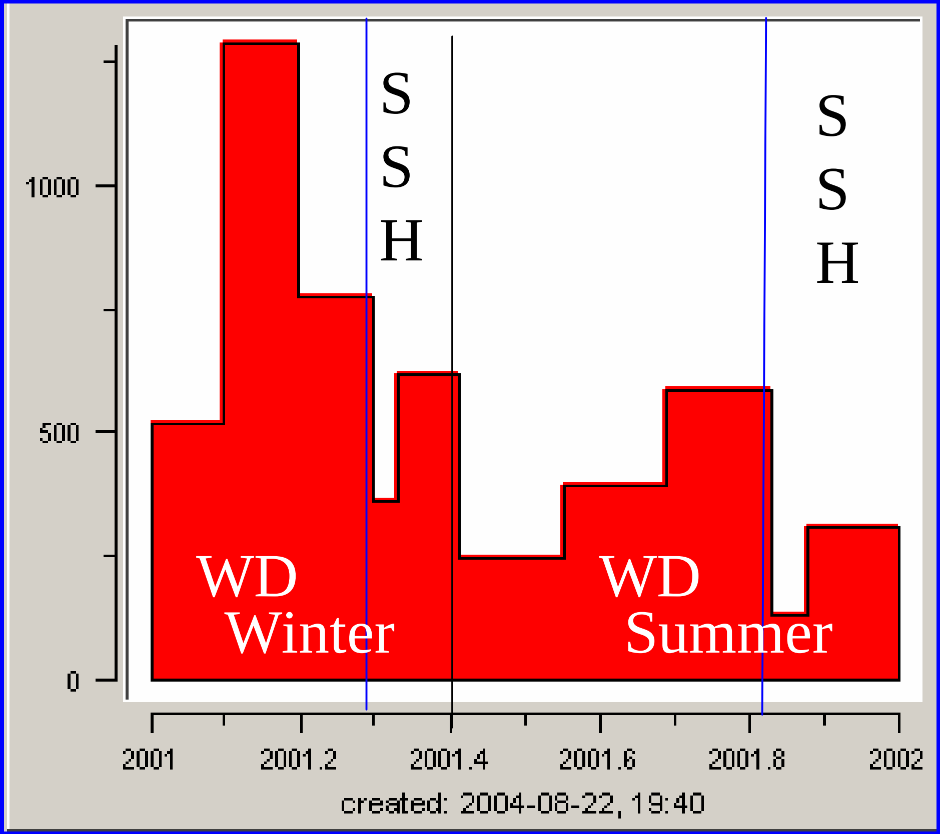
availability of gas distribution network for decentralized heat generation sources;
other factors.

Modeling of CHP with heat storage (1)

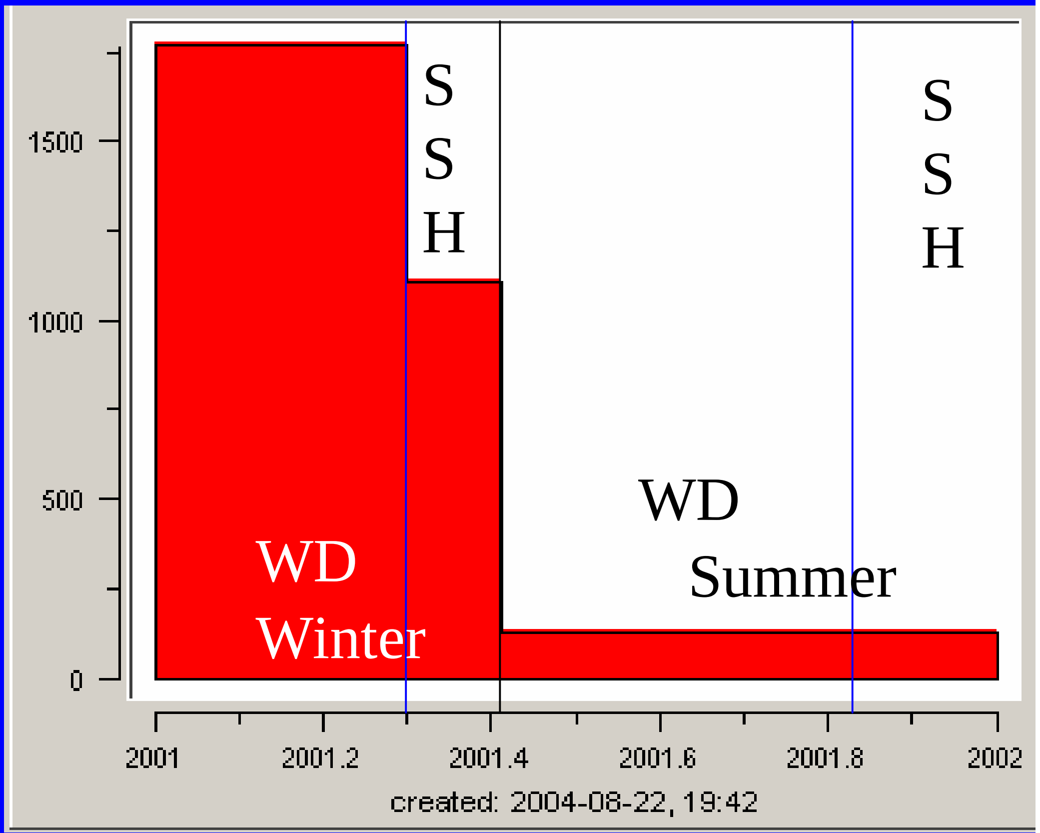


Modeling of CHP with heat storage (2)

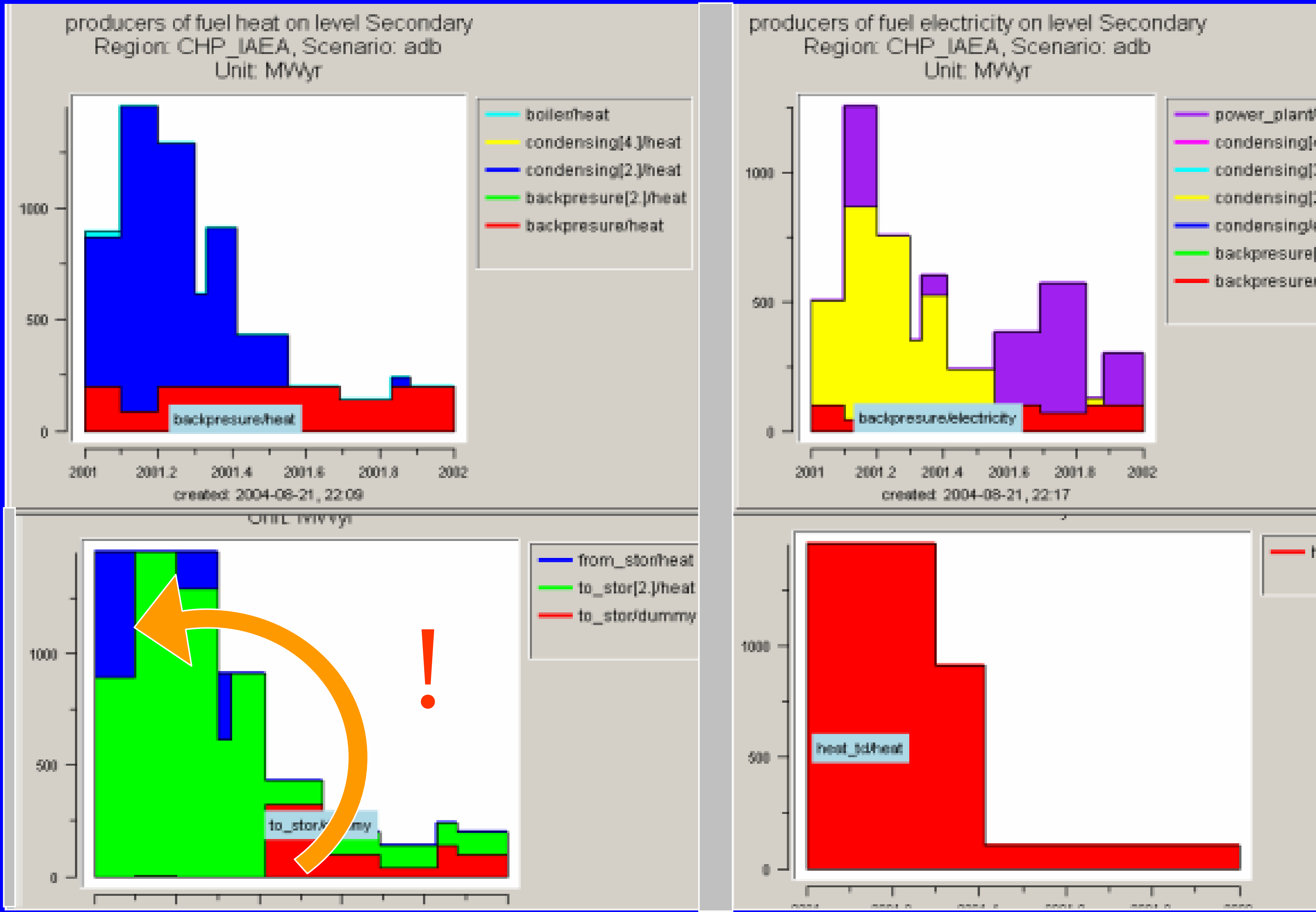
Electricity demand



Heat demand



Modeling of CHP with heat storage (3)



Modeling of CHP with heat storage (4)

Mathematical equations for modeling of heat storage

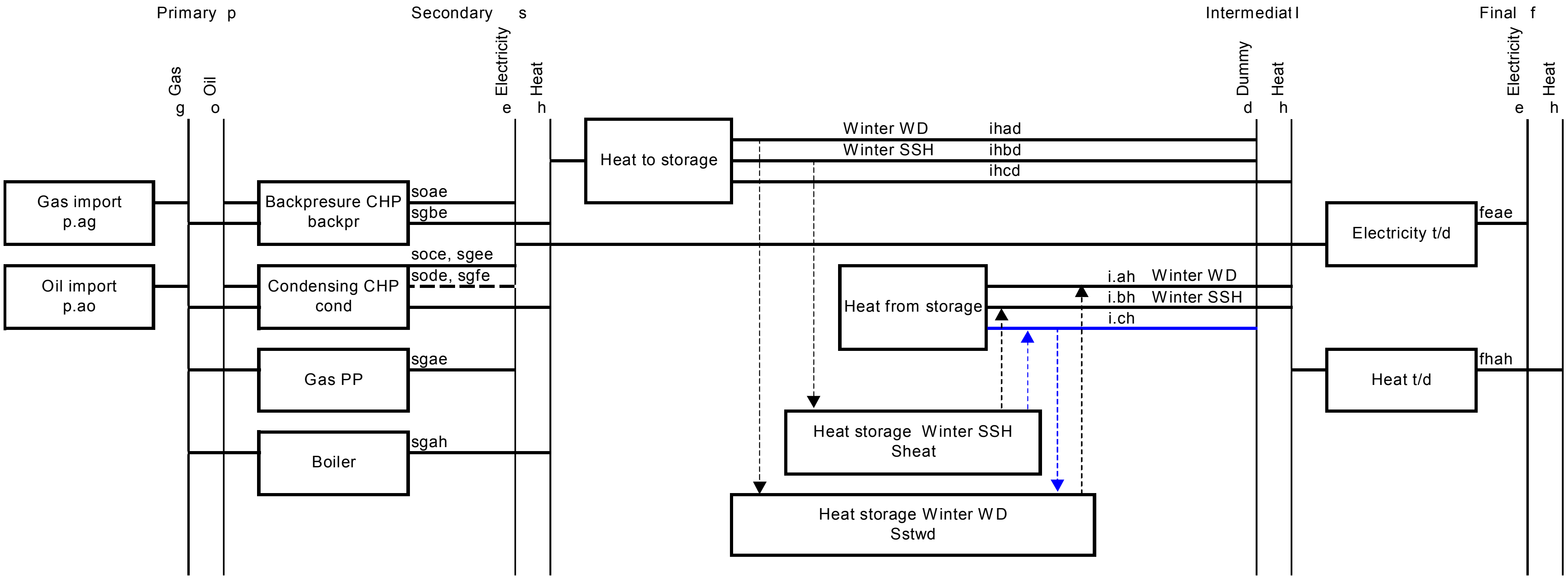
		To year +1	In 1t	In 2t	In 3t	In 4t	In 5t	In 6t	In 7t	In 8t	In 9t	In 10t	Out 1t	Out 2t	Out 3t	Out 4t	Out 5t	Out 6t	Out 7t	Out 8t	Out 9t	Out 10t	In from SSH 1t	In from SSH 2t	In from SSH 3t	In from SSH 4t	In from SSH 5t	In from SSH 6t	In from SSH 7t	In from SSH 8t	In from SSH 9t	In from SSH 10t	Out to SSH 1t	Out to SSH 2t	Out to SSH 3t	Out to SSH 4t	Out to SSH 5t	Out to SSH 6t	Out to SSH 7t	Out to SSH 8t	Out to SSH 9t	Out to SSH 10t	
	Stor WDa	-1	1	1	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1																					=0
	Stor WDb	0.97	1	1	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1																					=0
Winter	Stor WDa	-1	1	1	1	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	-1	-1	-1	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~																					=0
WD	Stor WDb	0	1	1	1	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	-1	-1	-1	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~																					=0
Winter	Stor WDa	-1	~~1~~	~~1~~	~~1~~	1	1	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~-1~~	~~-1~~	~~-1~~	-1	-1	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~																					=0
SSH	Stor WDb	0	~~1~~	~~1~~	~~1~~	1	1	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~-1~~	~~-1~~	~~-1~~	-1	-1	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~																					=0

Modeling of CHP with heat storage (5)

Mathematical equations for modeling of heat storage

		To year +1	In 1t	In 2t	In 3t	In 4t	In 5t	In 6t	In 7t	In 8t	In 9t	In 10t	Out 1t	Out 2t	Out 3t	Out 4t	Out 5t	Out 6t	Out 7t	Out 8t	Out 9t	Out 10t	In from SSH 1t	In from SSH 2t	In from SSH 3t	In from SSH 4t	In from SSH 5t	In from SSH 6t	In from SSH 7t	In from SSH 8t	In from SSH 9t	In from SSH 10t	Out to SSH 1t	Out to SSH 2t	Out to SSH 3t	Out to SSH 4t	Out to SSH 5t	Out to SSH 6t	Out to SSH 7t	Out to SSH 8t	Out to SSH 9t	Out to SSH 10t	
	StorWDa	-1	1	1	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1																					=0
	StorWDb	0.97	1	1	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1																					=0
Winter	StorWDa	-1	1	1	1	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	-1	-1	-1	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~0.9~~	~~0.9~~	~~0.9~~	0.9	0.9	~~0.9~~	~~0.9~~	~~0.9~~	~~0.9~~	~~0.9~~	-1	-1	-1	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	=0
WD	StorWDb	0	1	1	1	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	-1	-1	-1	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~0.9~~	~~0.9~~	~~0.9~~	0.9	0.9	~~0.9~~	~~0.9~~	~~0.9~~	~~0.9~~	~~0.9~~	-1	-1	-1	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	=0
Winter	StorWDa	-1	~~1~~	~~1~~	~~1~~	1	1	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~-1~~	~~-1~~	~~-1~~	-1	-1	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	-1	-1	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	0.9	0.9	0.9	~~0.9~~	~~0.9~~	~~0.9~~	~~0.9~~	~~0.9~~	~~0.9~~	~~0.9~~	=0
SSH	StorWDb	0	~~1~~	~~1~~	~~1~~	1	1	~~1~~	~~1~~	~~1~~	~~1~~	~~1~~	~~-1~~	~~-1~~	~~-1~~	-1	-1	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	-1	-1	~~-1~~	~~-1~~	~~-1~~	~~-1~~	~~-1~~	0.9	0.9	0.9	~~0.9~~	~~0.9~~	~~0.9~~	~~0.9~~	~~0.9~~	~~0.9~~	~~0.9~~	=0

Modeling of CHP with heat storage (6)

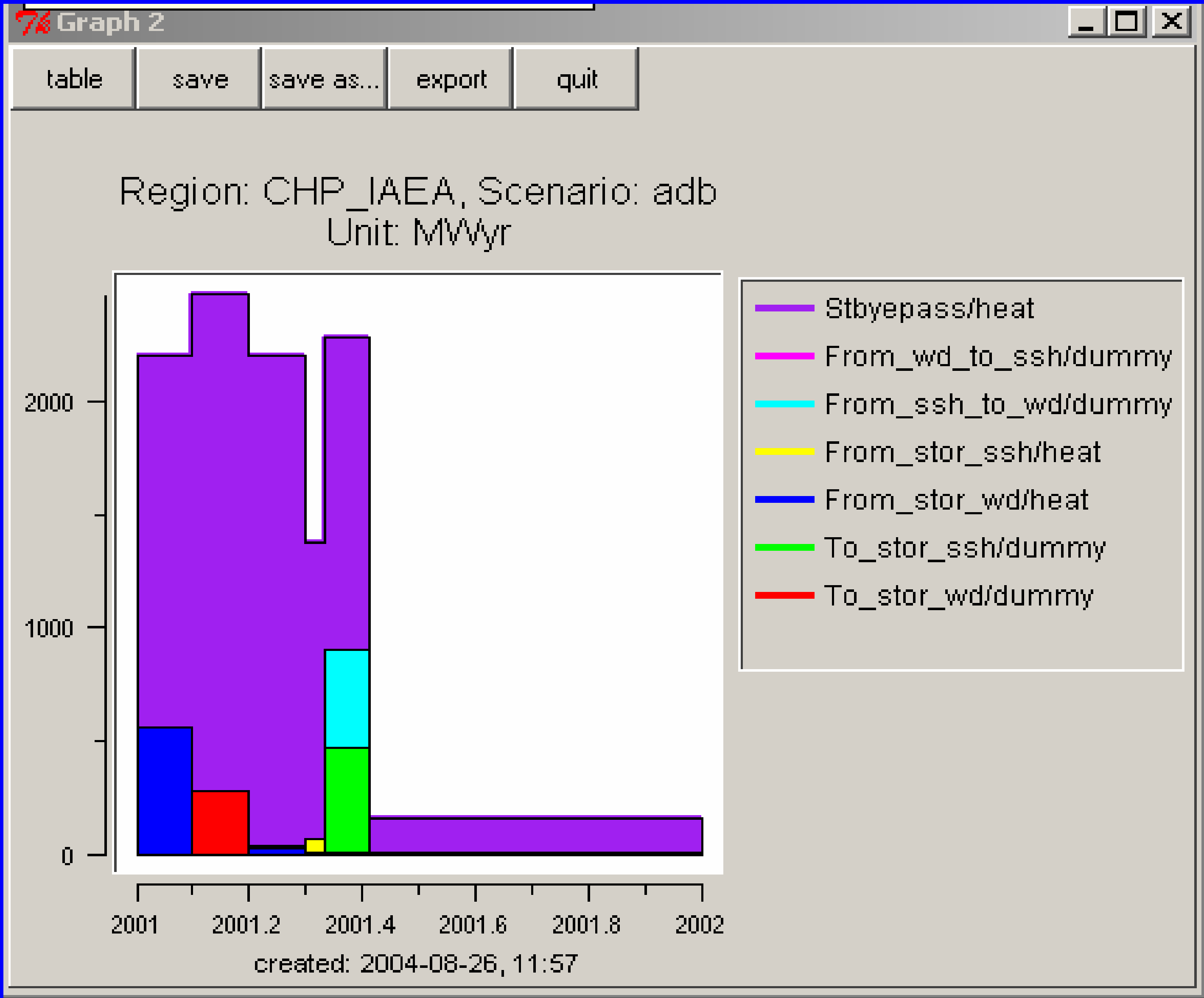


Modeling of CHP with heat storage (7)

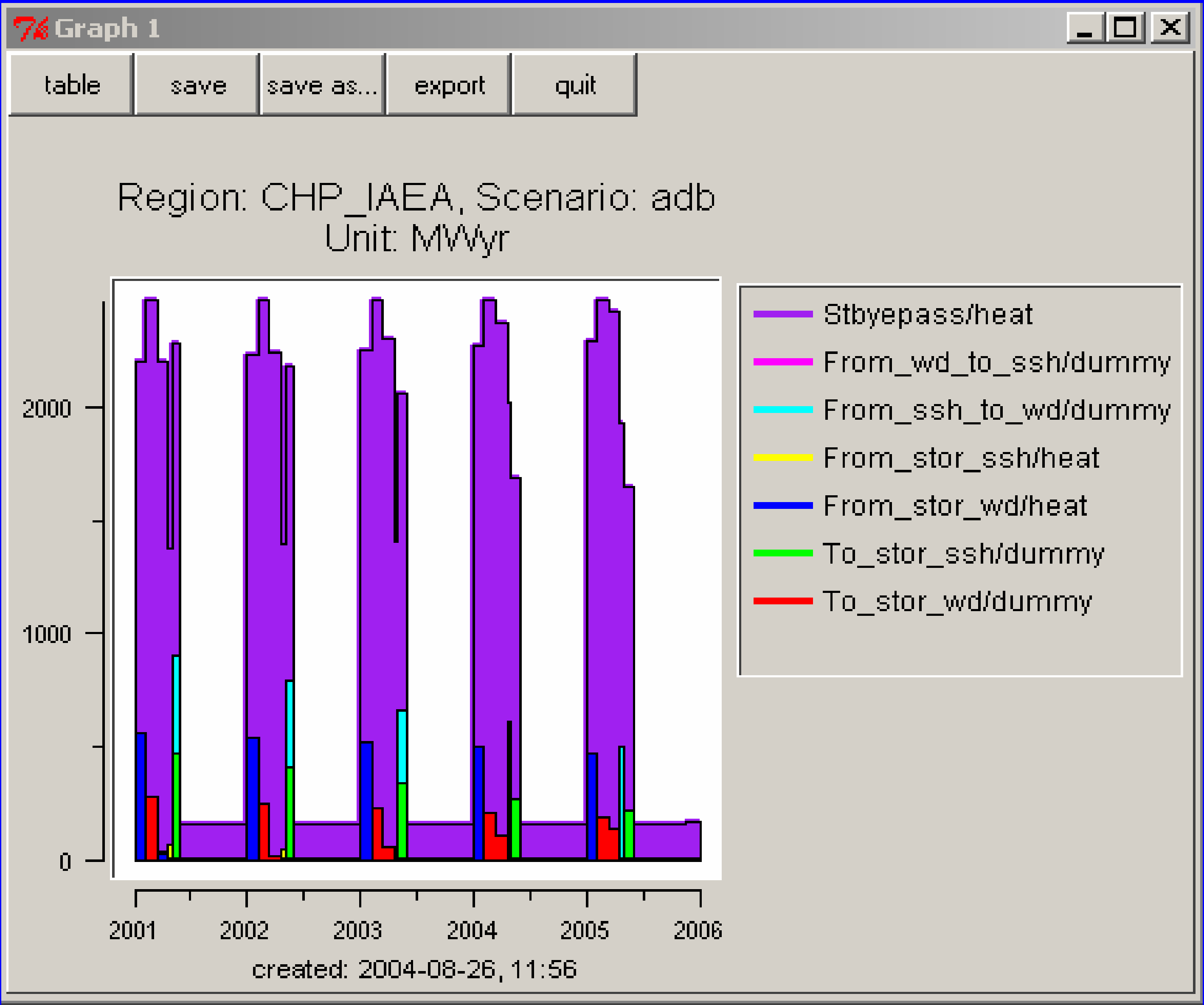
Allowed operation of technologies

Technology	Winter					Summer				
	WD			SSH		WD			SSH	
	LR1	LR2	LR3	LR4	LR5	LR6	LR7	LR8	LR9	LR10
Storage bye-pass	x	x	x	x	x	x	x	x	x	x
Load storage WWD	x	x	x							
Discharge storage WWD	x	x	x							
Load storage WSSH				x	x					
Discharge storage WSSH				x	x					
Transfer from WWD to WSSH	x	x	x							
Transfer from WSSH to WWD				x	x					

Modeling of CHP with heat storage (8)

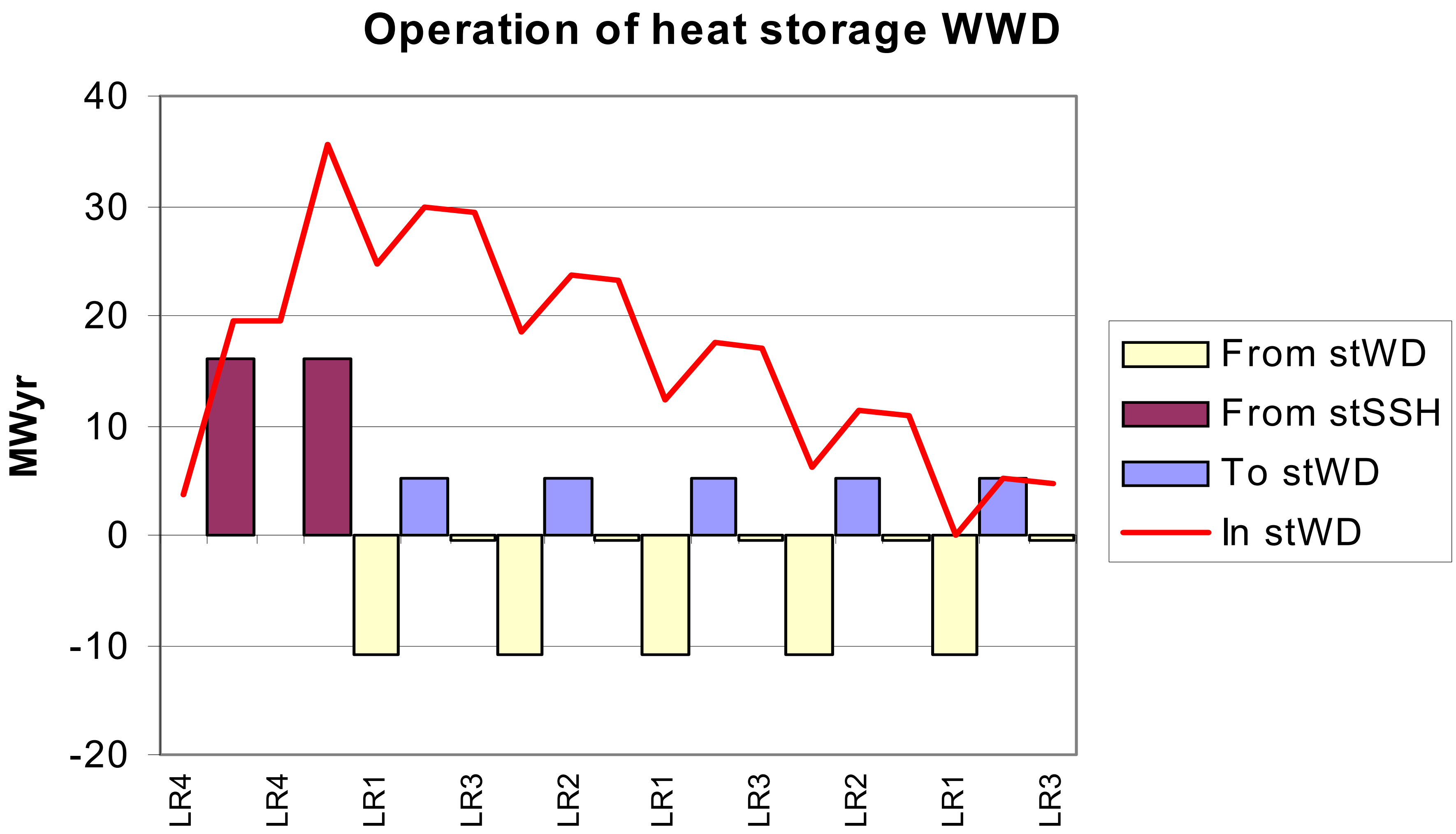


Modeling of CHP with heat storage (9)



Modeling of CHP with heat storage (10)

Interpretation of results achieved



Observations

Storage losses are not counted when load regions present for storage;

It may by sufficient to have (time related) energy storage losses between load regions in order to model correctly storage;

When load regions are added for storage in scenario DB related information appears also in adb file;

Data given for construction time of the storage makes problems related with information saving in storage screen;

***.ggi files still are missing in model backup file;**

Load region specification problems for bda in multiple output technologies.

Parameters of small back presure CHP based on natural gas

		Cento 42 AP	Cento 65 AP	Cento 75 AP	Cento 100 SP	Cento 140 SP	Plus twin 44 AP	Plus twin 88 AP	Premi 22 AP	Premi vari 22 AP
Electrical capacity	kW	42	65	75	100	150	44	88	22	22
Thermal capacity	kW	64,5	97	125	161	226	91	182	45,5	45,5
Input (fuel) capacity	kW	124	189	244	305	430	155	310	77,5	77,5
Efficiency (electrical)	%	33,8	34,4	30,7	32,8	34,8	28,4	28,4	28,4	28,4
Efficiency (thermal)	%	52,0	51,3	51,2	52,8	52,8	58,8	58,8	58,8	58,8
Efficiency (totall)	%	85,8	85,7	81,9	85,6	87,4	87,2	87,2	87,2	87,2
Gas consumption at 100% capacity	м^3/h	13,2	20,0	25,8	32,3	45,5	16,4	32,8	8,2	8,2
Gas consumption at 75% capacity	м^3/h	10,8	16,3	20,6	26,8	39,8	13,2	26,4	6,6	6,6
Gas consumption at 50% capacity	м^3/h	8,3	12,5	16,4	20,3	31,5	10,4	20,8	5,2	5,2
Temperature of water input/output	^{o}C	70/90	70/90	70/90	70/90	70/90	70/90	70/90	70/90	70/90
Investment cost	K$	43.800	52.300	44.200	68.000	82.800	25.000	50.000	12.500	11.500