

SMR 1585 - 3

WORKSHOP ON DESIGNING SUSTAINABLE ENERGY SYSTEMS
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MODELLING OF COMBINED HEAT AND POWER PLANTS

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

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,

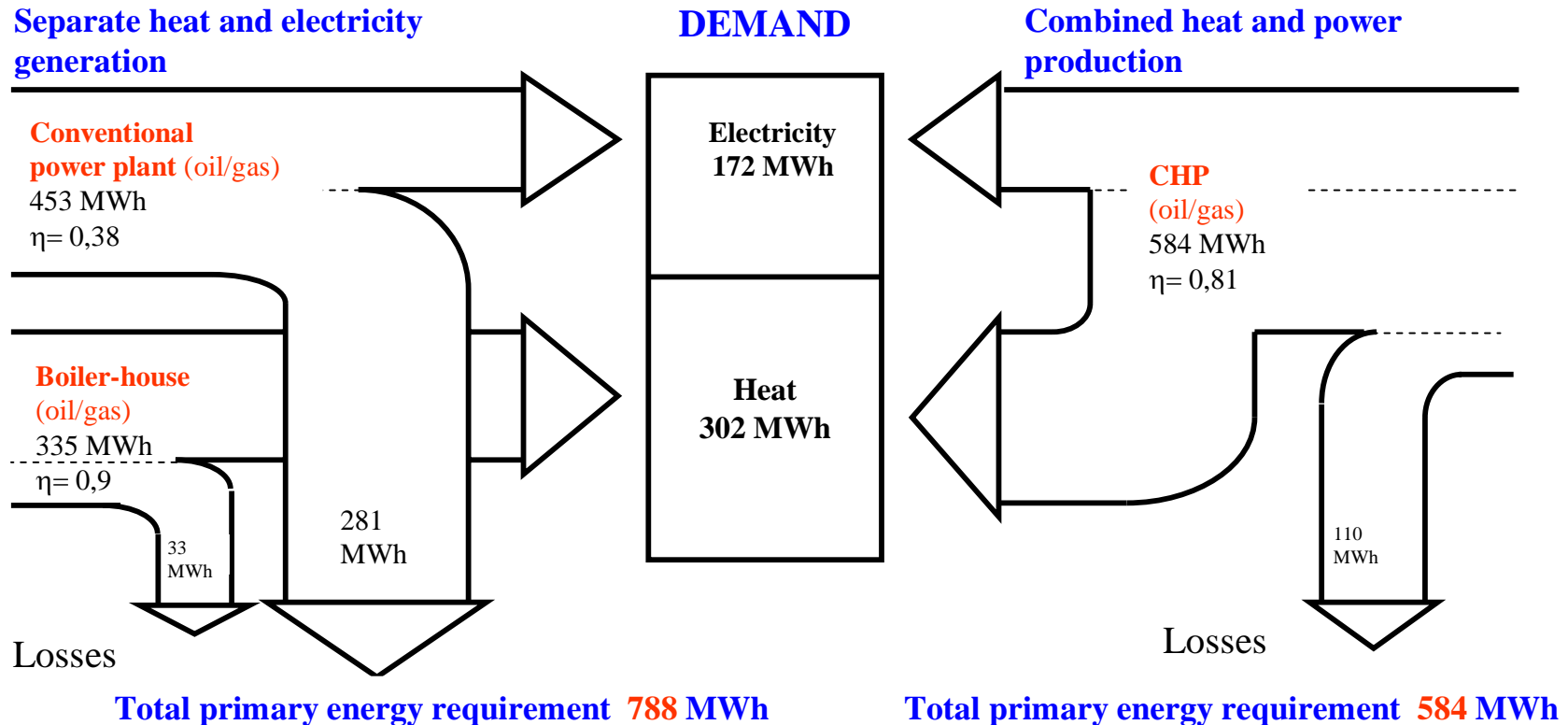
Multiple fuel extraction units,

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 (P_n),

Nominal thermal capacity (Q_n),

Total fuel efficiency η_{Σ}

Relation between heat and electricity output

Electricity
(P)

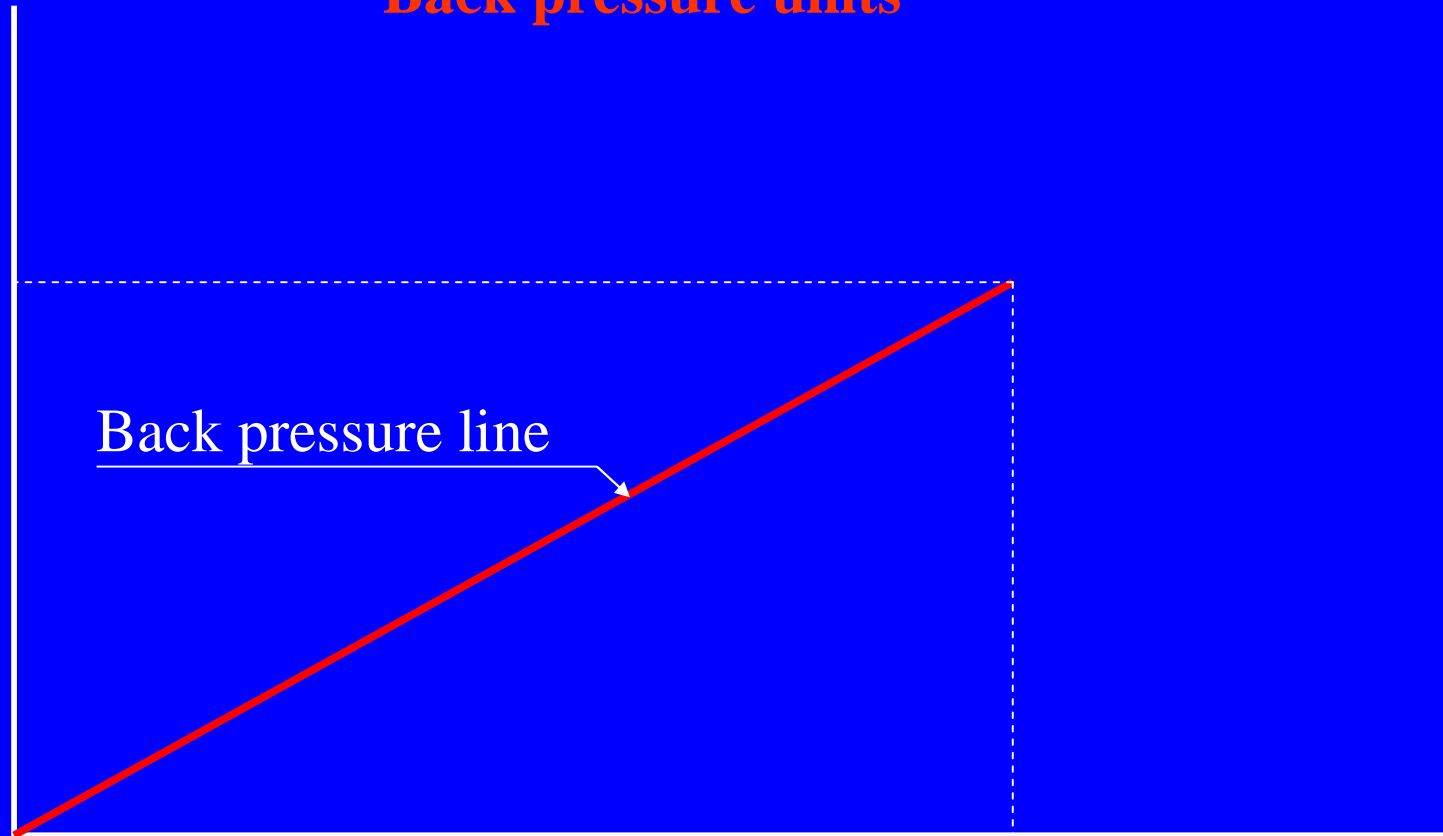
Back pressure units

P_n

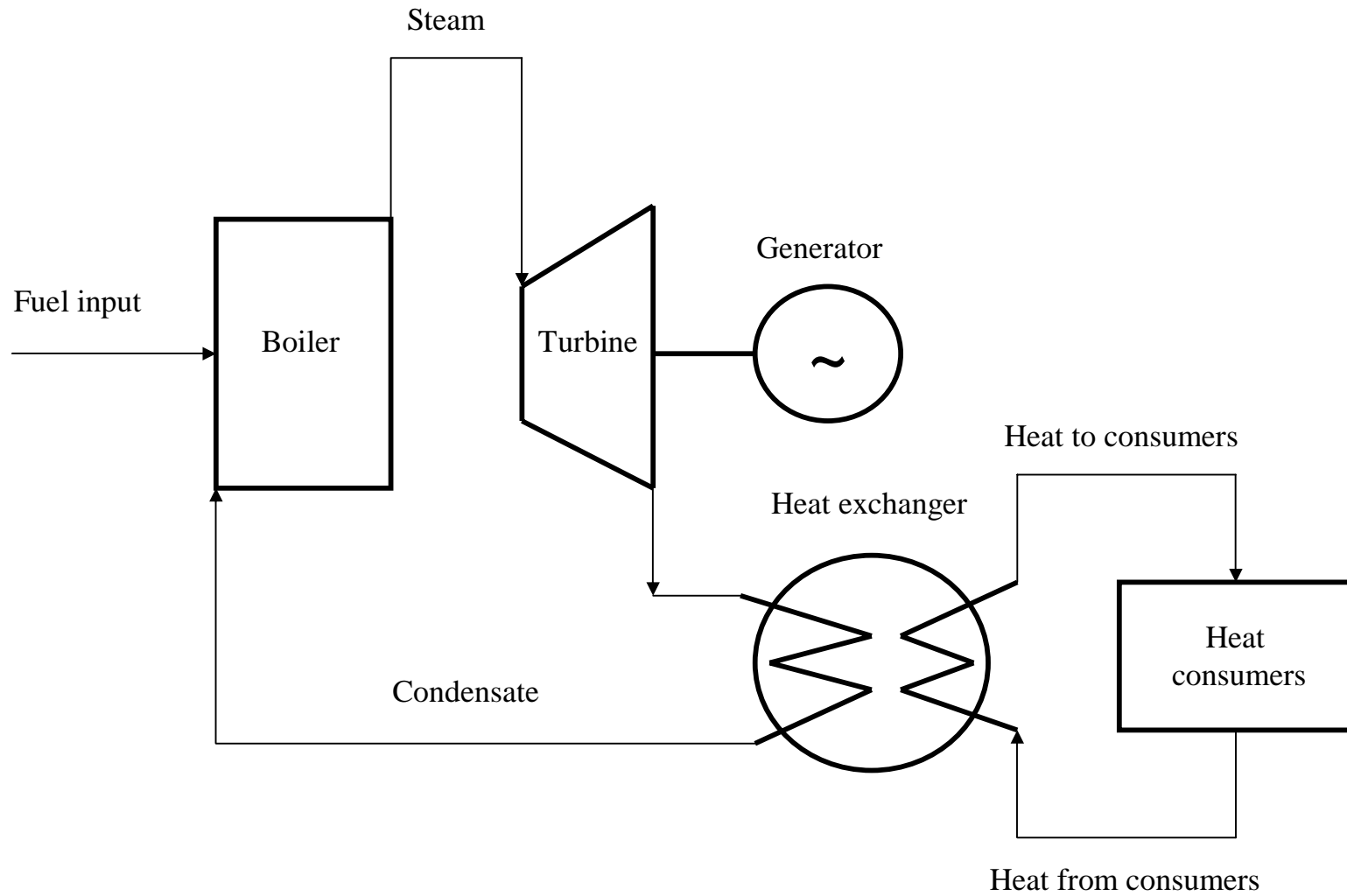
Back pressure line

Q_n

Heat (Q)

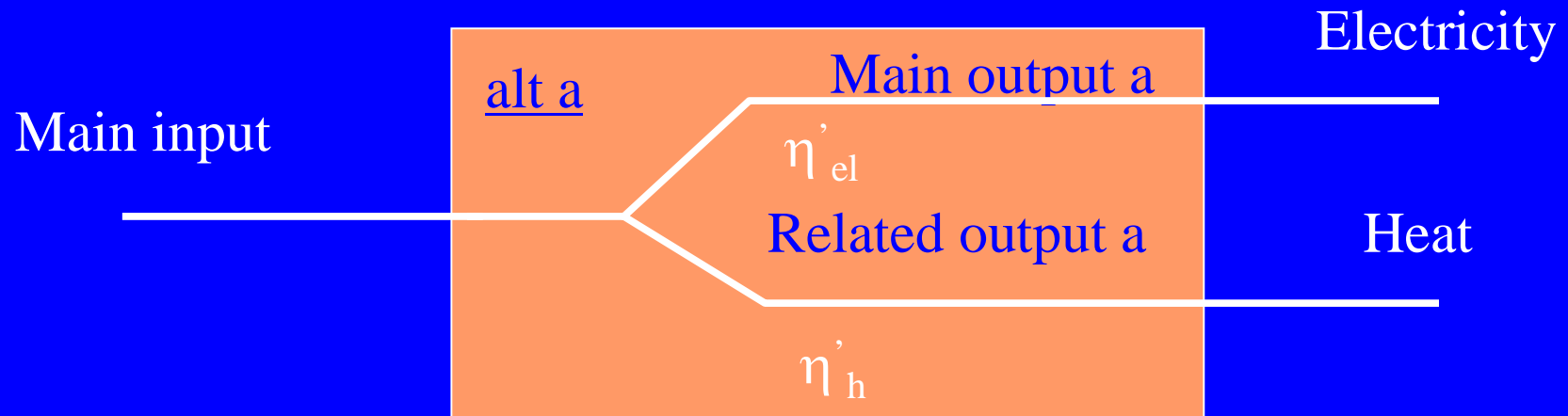


Back pressure units



Representation of CHP in MESSAGE

Back pressure unit



$$\eta'_{el} = \frac{P_n}{(P_n + Q_n)/\eta_\Sigma} ; \quad \eta'_h = \frac{Q_n}{(P_n + Q_n)/\eta_\Sigma} ; \quad \mathbf{P' = P_n} ;$$

Representation of CHP in MESSAGE

Back pressure unit

$$P_n = 23.3 \text{ MW}; \quad Q_n = 102.3 \text{ MW}; \quad \eta_\Sigma = 0.825;$$

$$P' = P_n = 23.3 \text{ MW};$$

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

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

Representation of CHP in MESSAGE

Back pressure units

The screenshot displays the MESSAGE software interface for a CHP technology. The 'Technologies' section is active, showing various parameters. A large orange arrow points from the 'Heat' callout to the 'secondary outputs' table. The 'secondary outputs' table has the following data:

Fuel	Unit	Tmssw	Data
heat/Secondary	MWyr/MWyr	c	0.672

The 'single entries' section shows the following parameters:

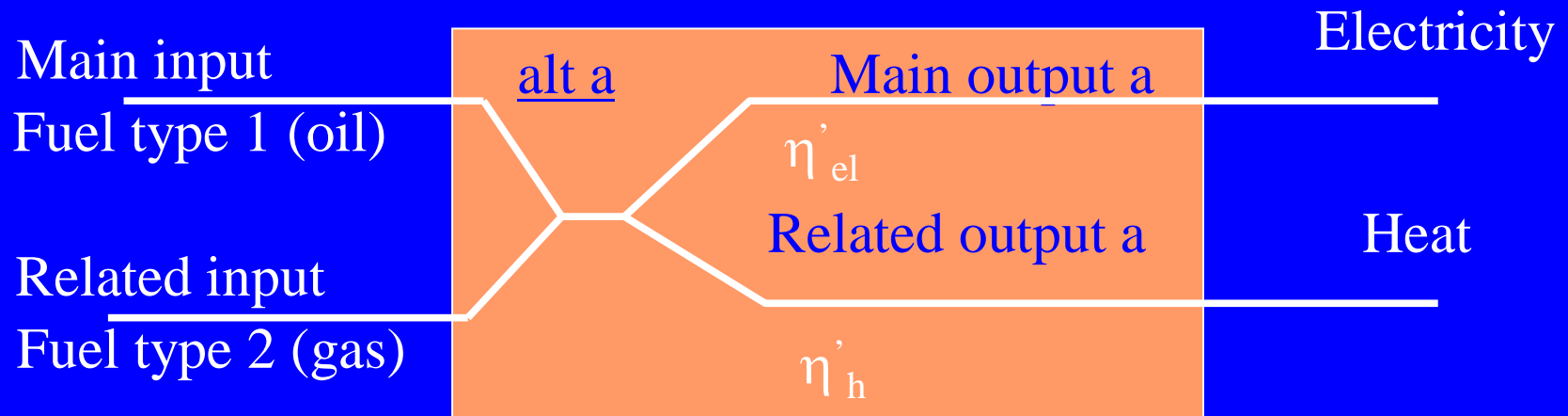
Name	Unit	Value		
main input	gas/primary	MWyr	1.	
main output	electricity/Secondary	MWyr	c	0.153
var costs	US\$'00/kWyr		89.17	

Callouts indicate efficiency values:

- Heat: $\eta'_h = 0.672$
- Electricity: $\eta'_{el} = 0.153$

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

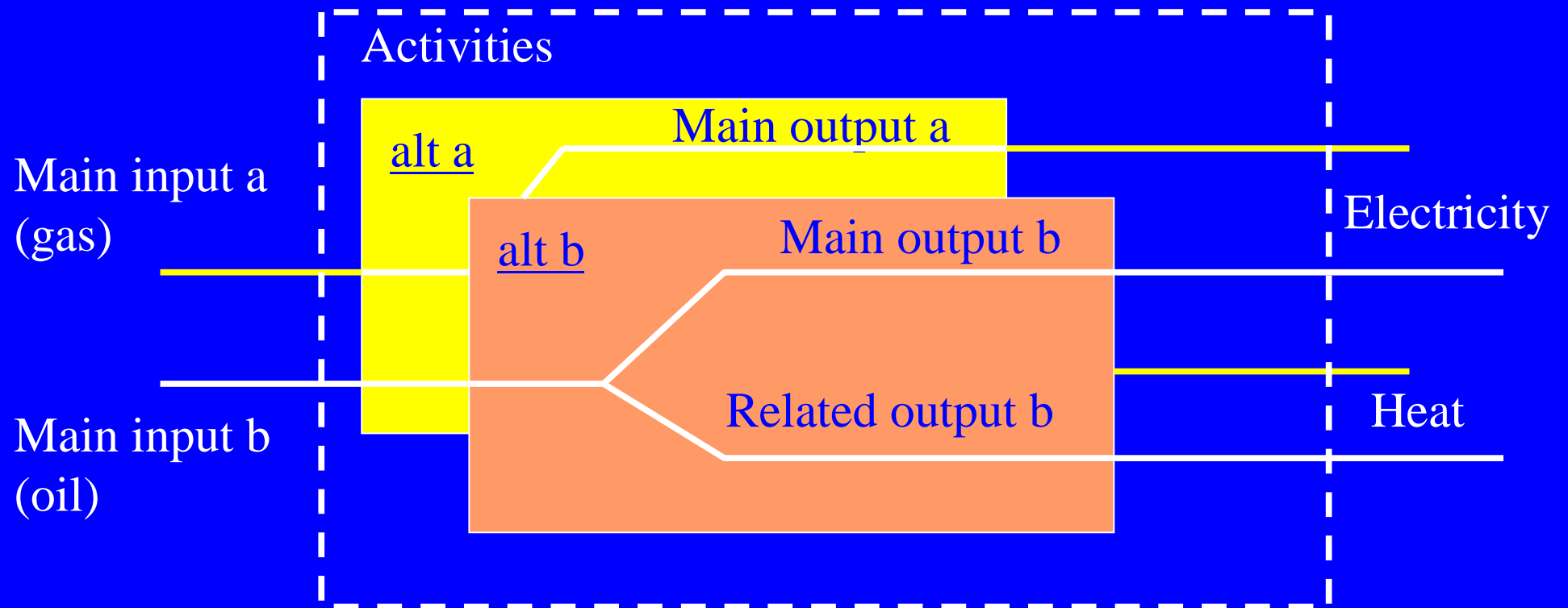
The screenshot displays the MESSAGE software interface for configuring a CHP technology. The 'Technologies' tab is active, showing a table of activities. The 'alt a' activity is selected, and its configuration is shown in the 'single entries' section. The 'main input' is 'oil/primary' with a value of 0.800800000. The 'main output' is 'electricity/Secondary' with a value of 0.153. The 'var costs' are set to 'US\$00/kWyr' with a value of 89.17. The 'hist. act.' is 'MWyr' with a value of 0. The 'multiple entries' section shows a table of activities, with 'inp' highlighted in green. Callouts provide additional information: 'Name of secondary fuel Gas' points to the 'gas/primary' fuel type in the 'Secondary' section; 'Share of secondary Fuel 0.2' points to the '0.2' value in the 'Data' field; 'Share of main fuel 0.8' points to the '0.800800000' value in the 'Value' field; and 'Name of main fuel Oil' points to the 'oil/primary' fuel type in the 'main input' field. An orange arrow points from the 'inp' activity in the 'multiple entries' table to the 'alt a' activity configuration.

Name	Unit	Value
main input	oil/primary	0.800800000
main output	electricity/Secondary	0.153
var costs	US\$00/kWyr	89.17
hist. act.	MWyr	0.

Activity	Capacity
abda	
alags	
bda	
inp	
mpa	

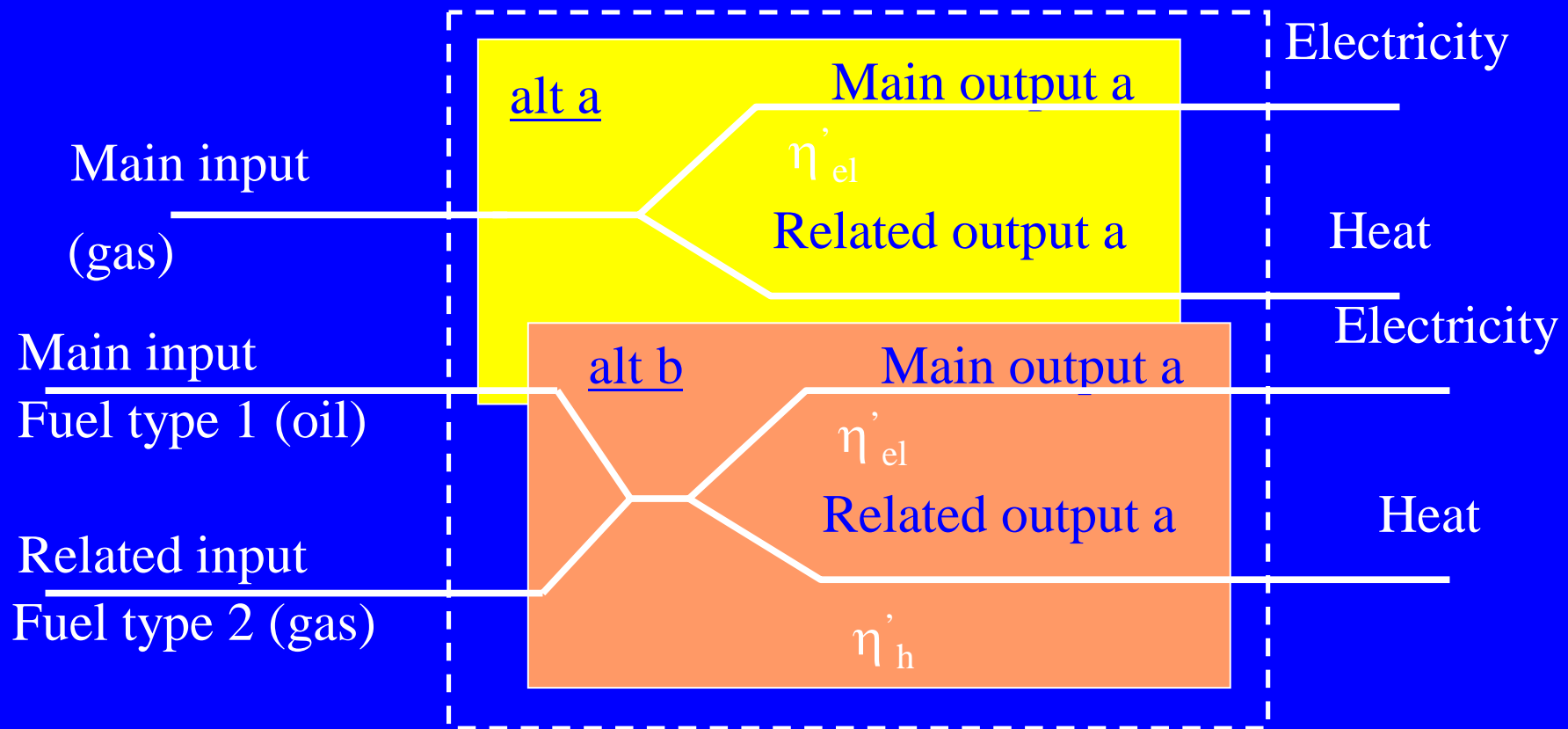
Representation of CHP in MESSAGE

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

The screenshot displays the MESSAGE software interface for configuring a CHP technology. The main window is titled "IAEA - MESSAGE V CHP_IAEA adb". The "Technologies" section is active, showing input, output, and relation settings. A callout box highlights two alternative technology boxes, "alt a" and "alt b", with "alt b" selected. A secondary window titled "IAEA - MESSAGE V backpressure fuels inp" is open, showing the "Secondary inputs" section. A callout box points to the "Fuel" dropdown menu, which is set to "gas/primary", with the text "Gas for alt b". Another callout box points to the "main input" dropdown menu, which is set to "oil/primary", with the text "Gas for alt a" and "Oil for alt b". The "single entries" table is visible, showing the main input and output settings. The "multiple entries" table at the bottom shows the technology's activity and capacity settings.

Name	Unit	Value
main input	oil/primary	0.800000000
main output	electricity/Secondary	0.153
var costs	US\$/kWhyr	89.17
hist. act.	MWyr	0.

Activity	Capacity
consa	inp
mpa	out

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 (P_n),

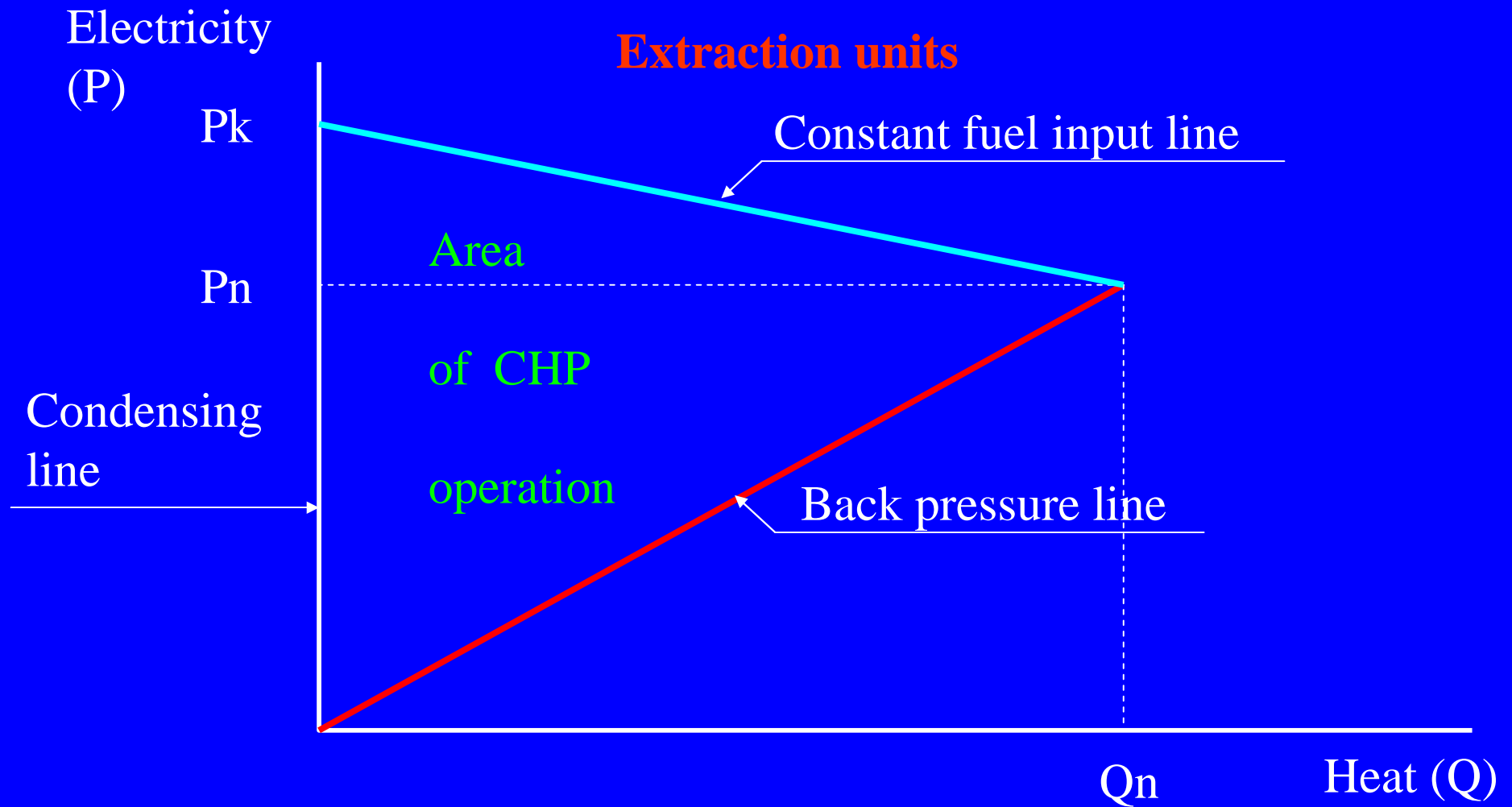
Nominal electrical capacity in condensing mode (P_k),

Nominal thermal capacity (Q_n),

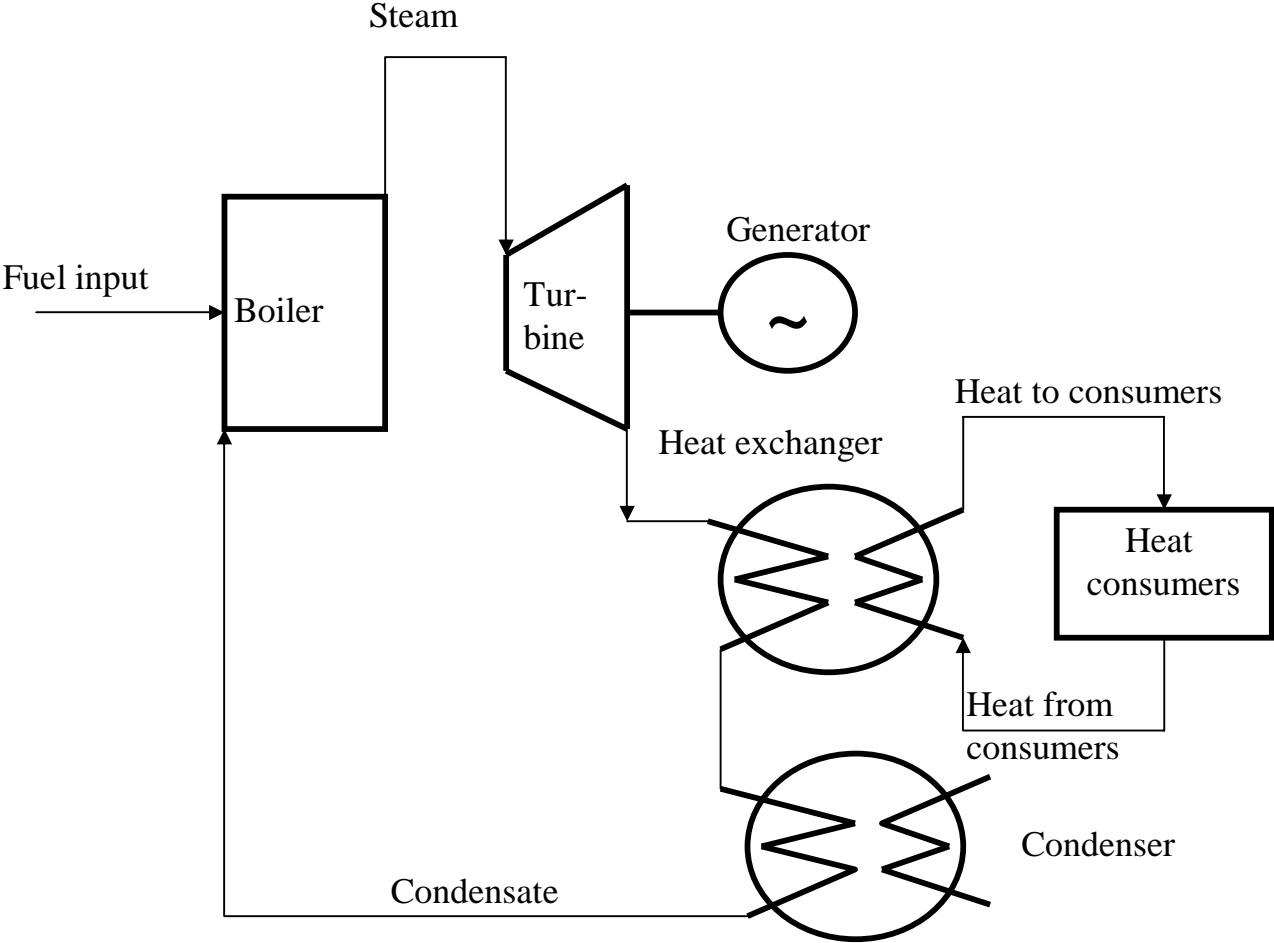
Fuel efficiency in condensing mode (η_k),

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

Relation between heat and electricity output

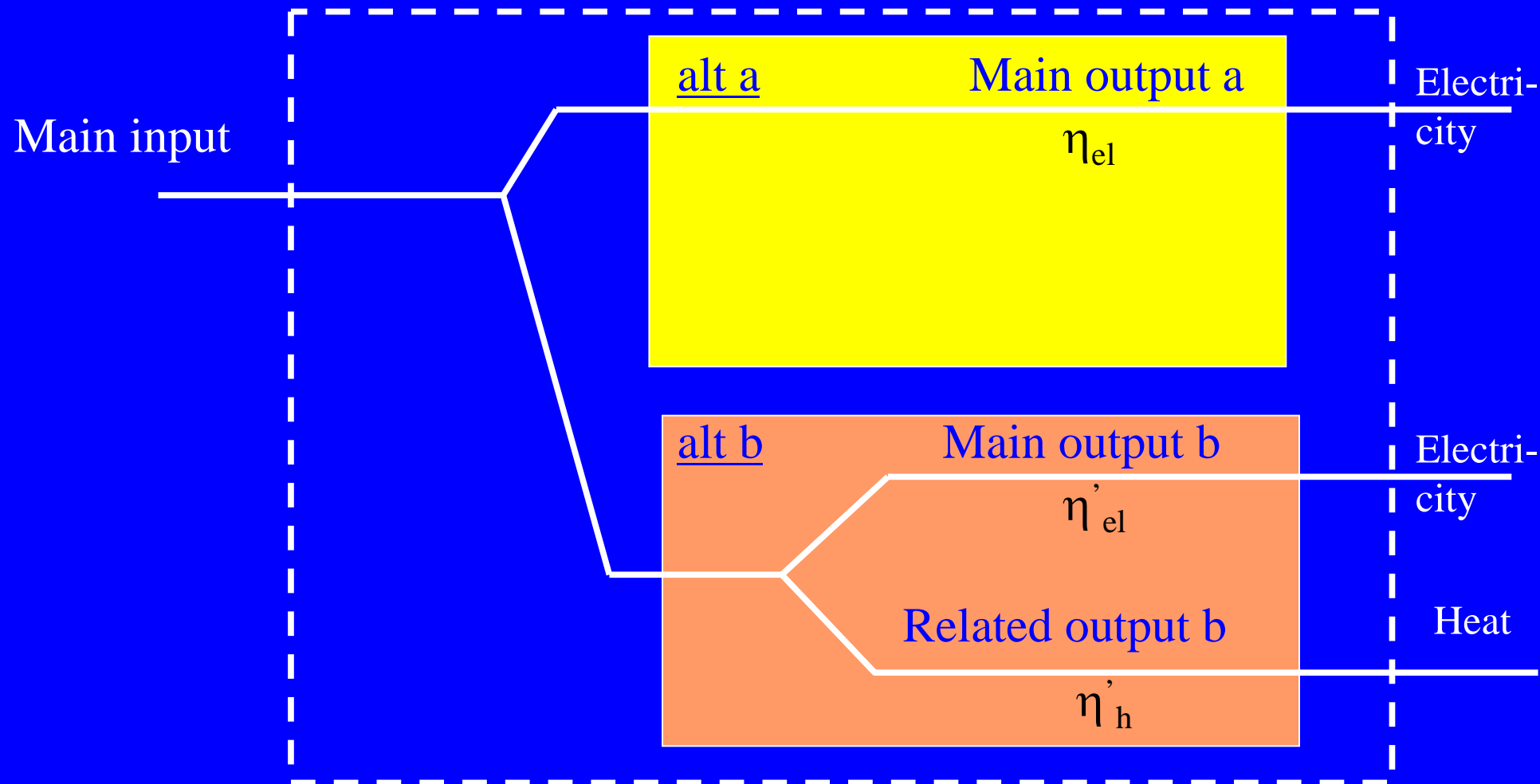


Extraction unit



Representation of CHP in MESSAGE

Extraction unit (single fuel)



Representation of CHP in MESSAGE

Extraction unit (single fuel)

$$P_n = 171.8 \text{ MW}; \quad P_k = 208 \text{ MW}; \quad Q_n = 302.3 \text{ MW}; \\ \eta_k = 0.357; \quad \eta_T = 0.81;$$

$$\eta_{el} = \eta_k = 0.357; \quad (\text{Power relation}) \text{ pow.rel.} = \frac{P_k}{P_n} = \frac{208}{171.8} = 1.21;$$

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

$$\eta'_h = \frac{Q_n}{(P_n + Q_n)/\eta_T} = \frac{302.3}{(171.8+302.3)/0.81} = 0.516;$$

Representation of CHP in MESSAGE

Extraction unit (single fuel)

Condensing operation mode

CHP operation mode

The screenshot displays the MESSAGE software interface for configuring a CHP unit. It is divided into two main sections: 'Condensing operation mode' on the left and 'CHP operation mode' on the right. The interface includes various tabs like 'General', 'Technologies', 'Activities', and 'Single entries'. Callouts provide specific efficiency and power ratio values for different configurations.

Condensing operation mode (left):

- Technology: condensing
- Activity: alt c
- Efficiency: $\eta_{el} = 0.357$
- Power ratio: pow.rel.=1.0

CHP operation mode (right):

- Technology: IAEA - MESSAGE V condensing fuels outp
- Activity: alt d
- Efficiency: $\eta'_h = 0.516$
- Efficiency: $\eta'_{el} = 0.293$
- Power ratio: pow.rel.=1.21

Other callouts:

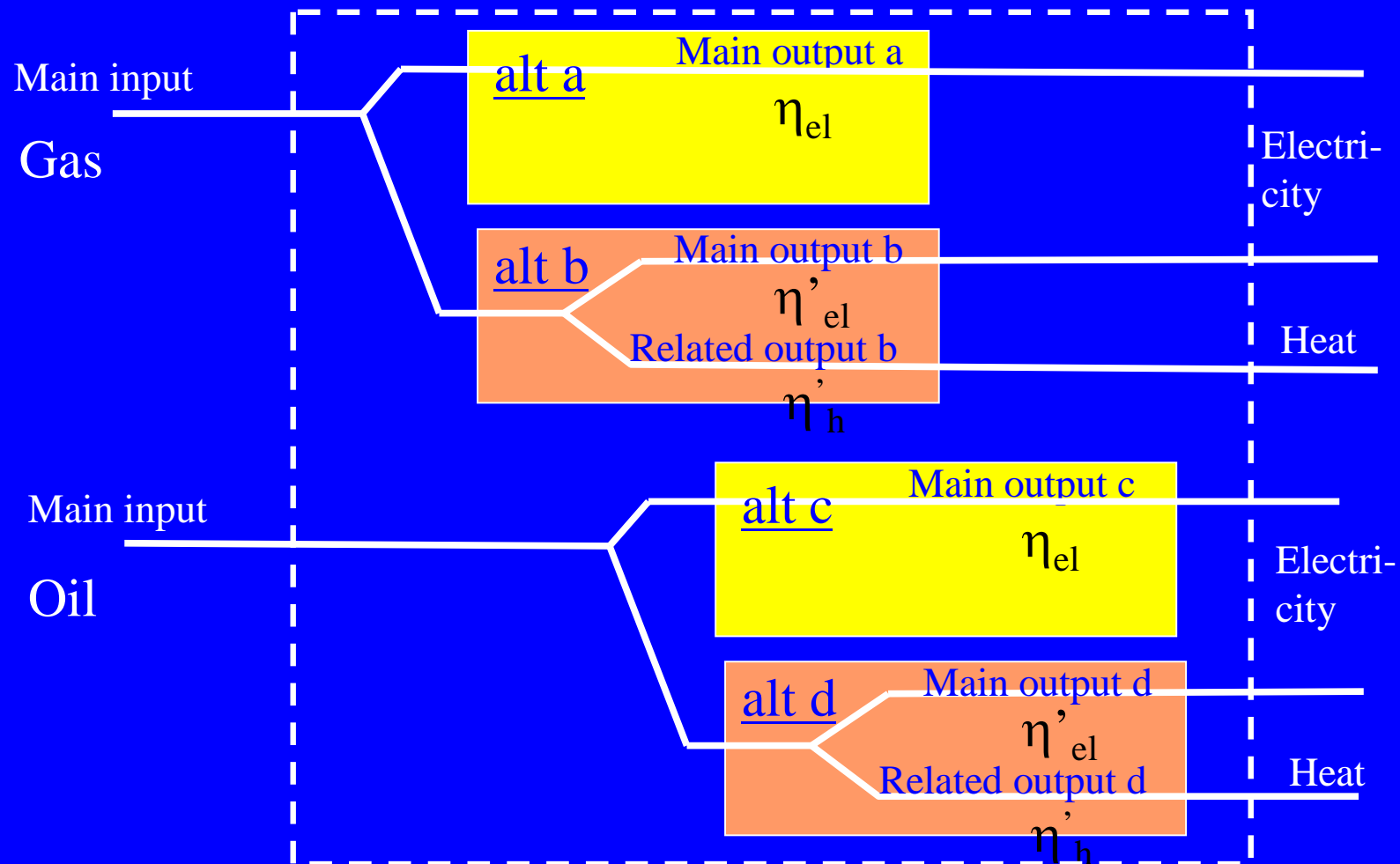
- alt a (points to the activity list)
- alt b (points to the technology selection)

Name	Unit	Value
main input	oil/primary	1
main output	electricity/Secondary	0.357
var costs	US\$'00/kWyr	5.547
hist. act.	MWyr	0

Name	Unit	Value
main input	oil/primary	1
main output	electricity/Secondary	0.293
var costs	US\$'00/kWyr	5.547
hist. act.	MWyr	0

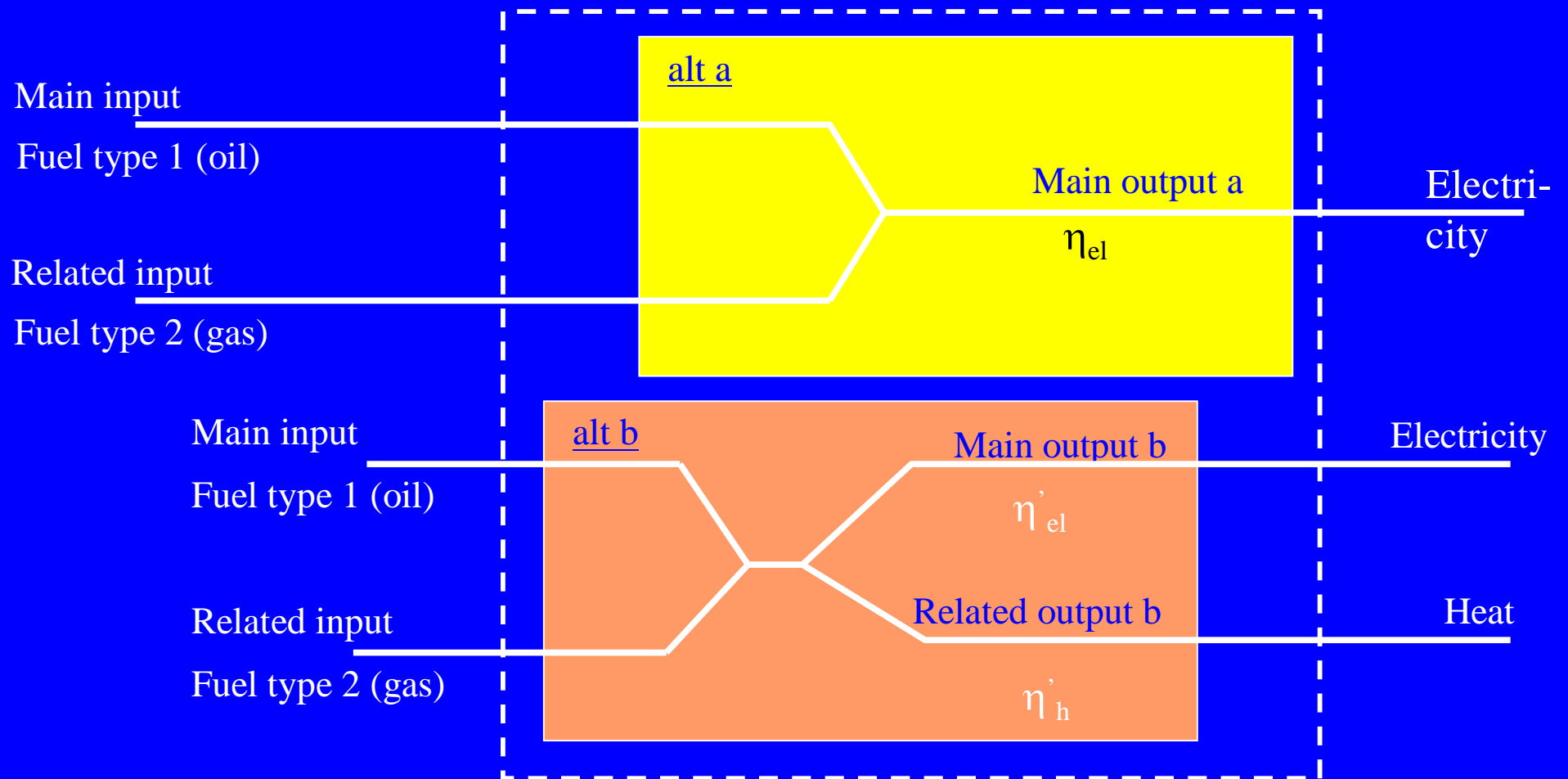
Representation of CHP in MESSAGE

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



Representation of CHP in MESSAGE

Extraction unit (multiple fuel, fuel shares are 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

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

$$\text{Cost-var}_{\text{CHP}} = \frac{\text{AVCEP}_{\text{CHP}} + \text{AVCHP}}{\text{W}_{\text{CHP}}}$$

$$\text{Cost-var}_{\text{COND}} = \frac{\text{AVCEP}_{\text{COND}}}{\text{W}_{\text{COND}}}$$

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:

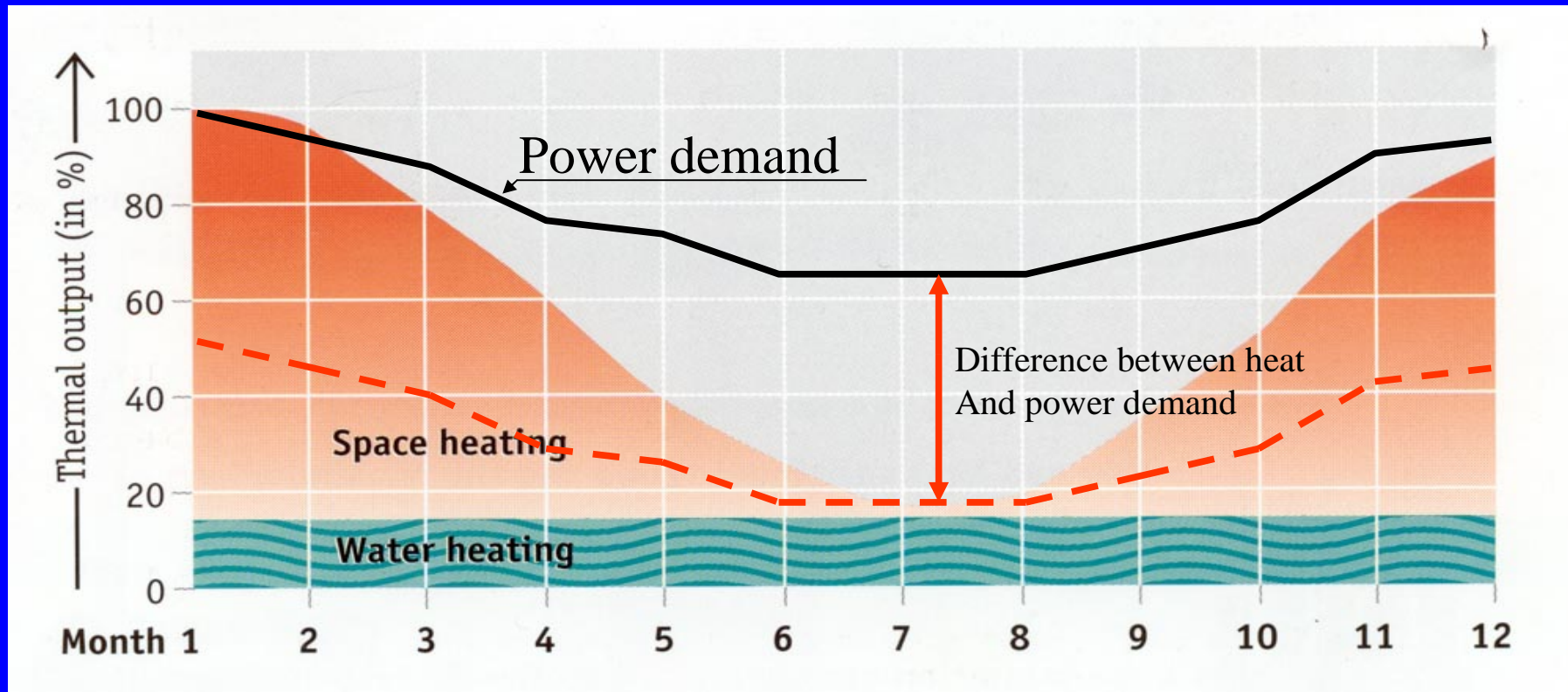
*heat in form of steam of some parameters,
heat in form of steam of other parameters,
heat in form of hot water,*

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

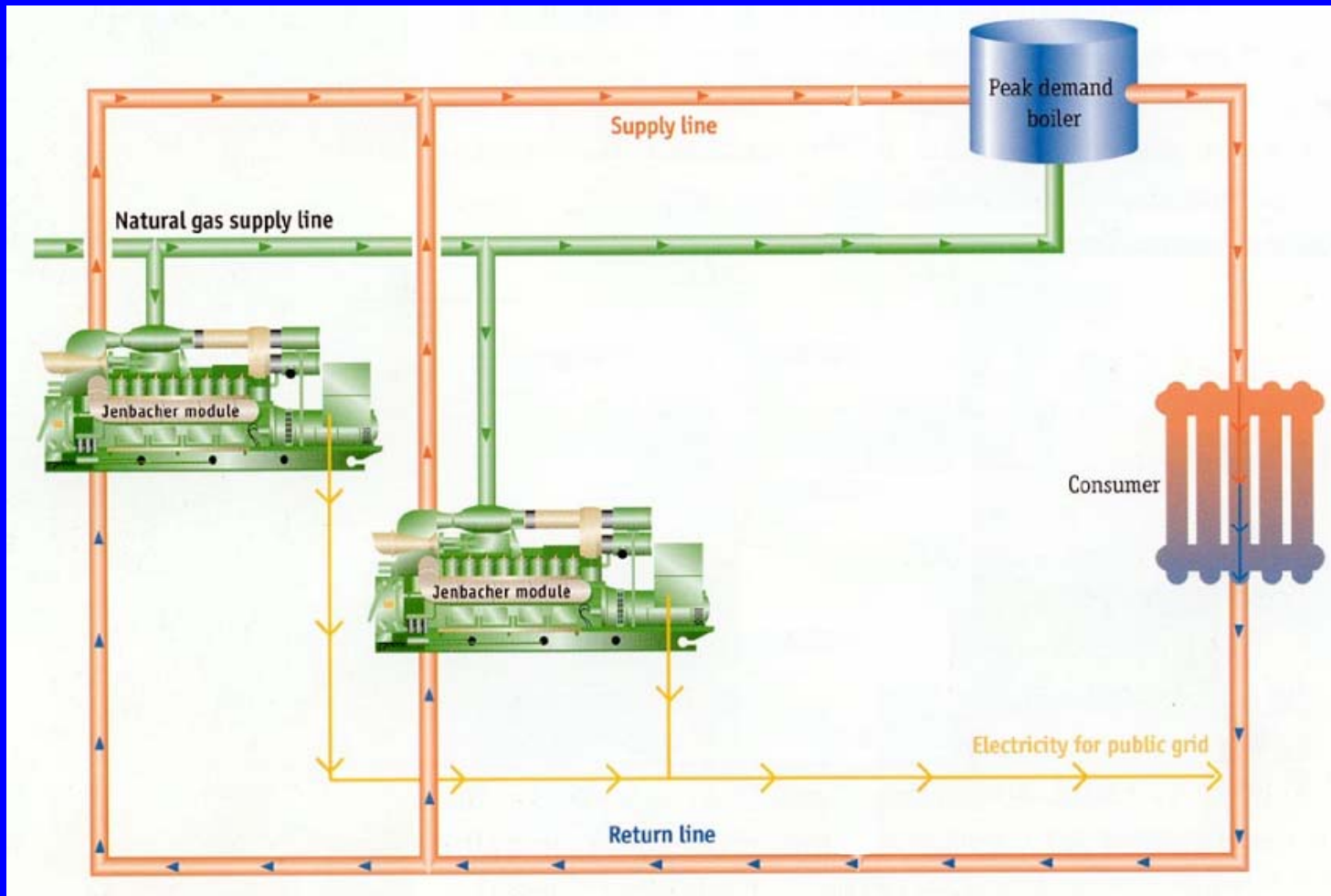
Consumers for those products are different;

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.

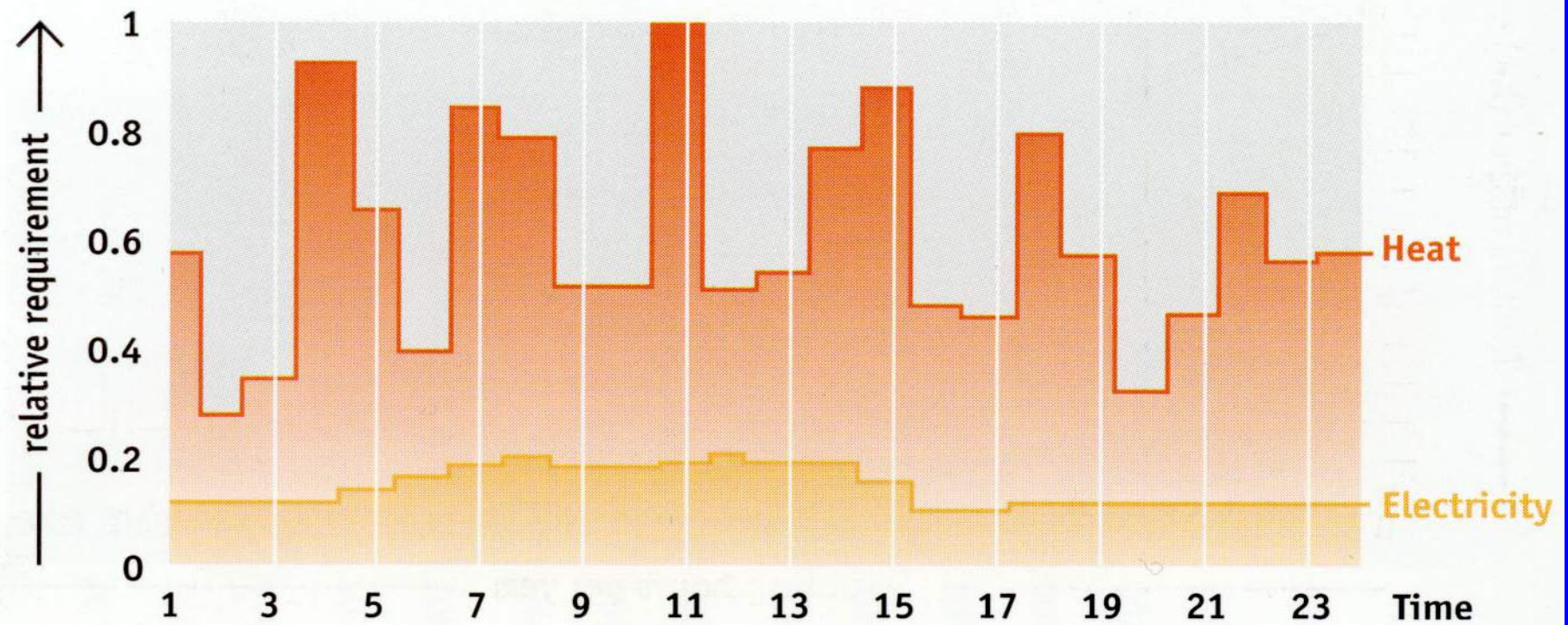
Ability of CHP to cover heat and power demand



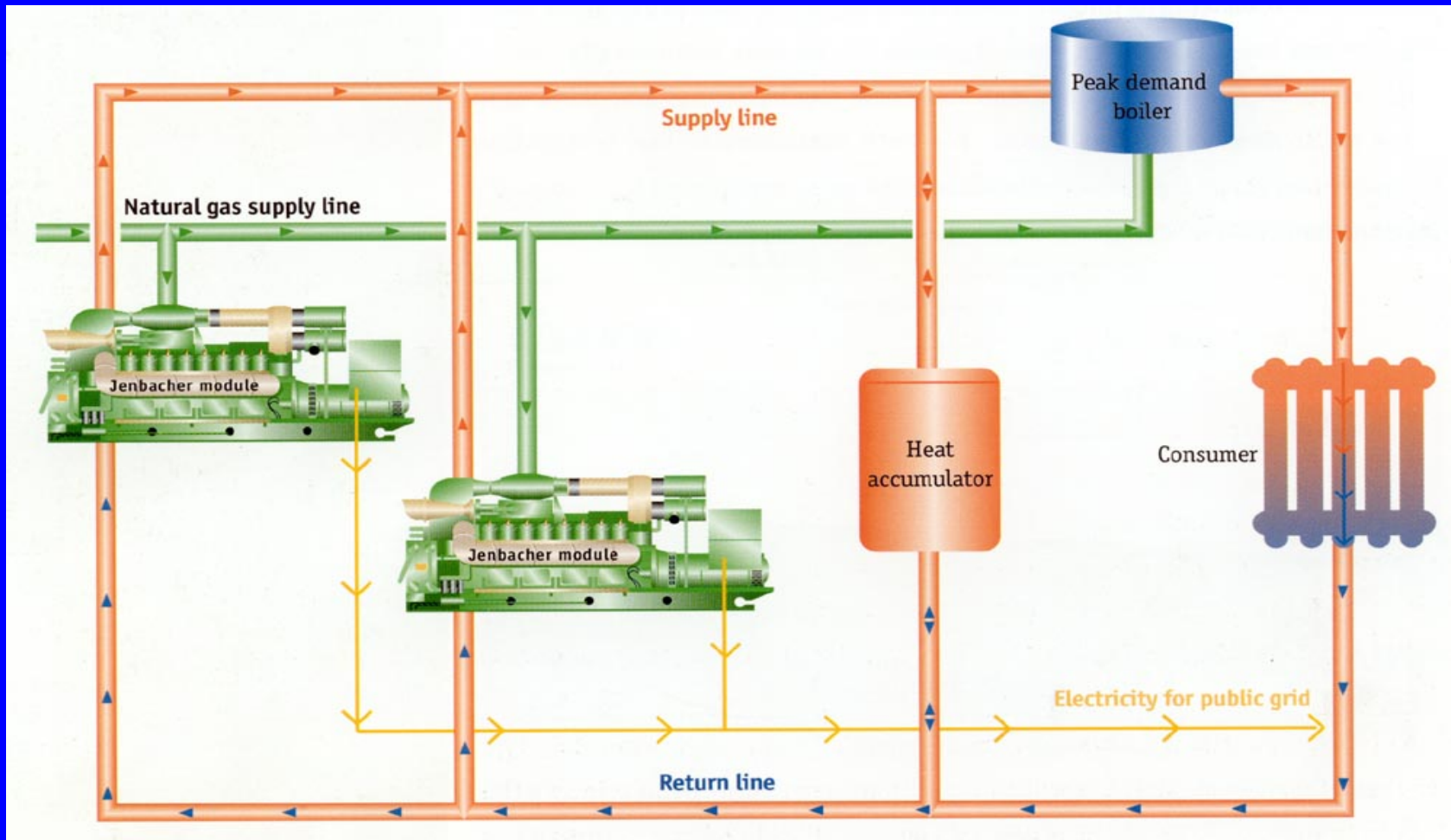
Joining of CHP's with heat only boilers



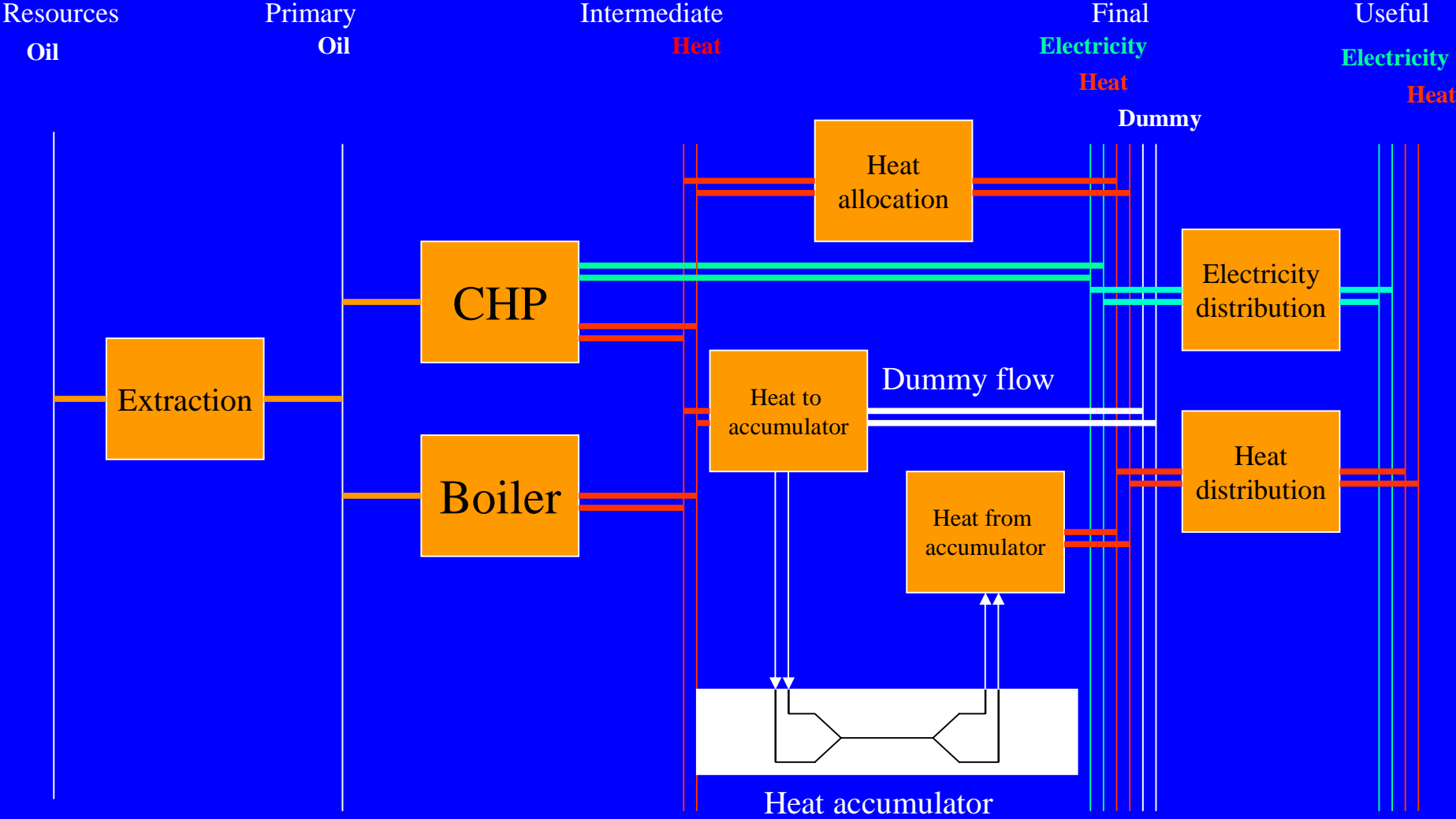
Heat load fluctuations



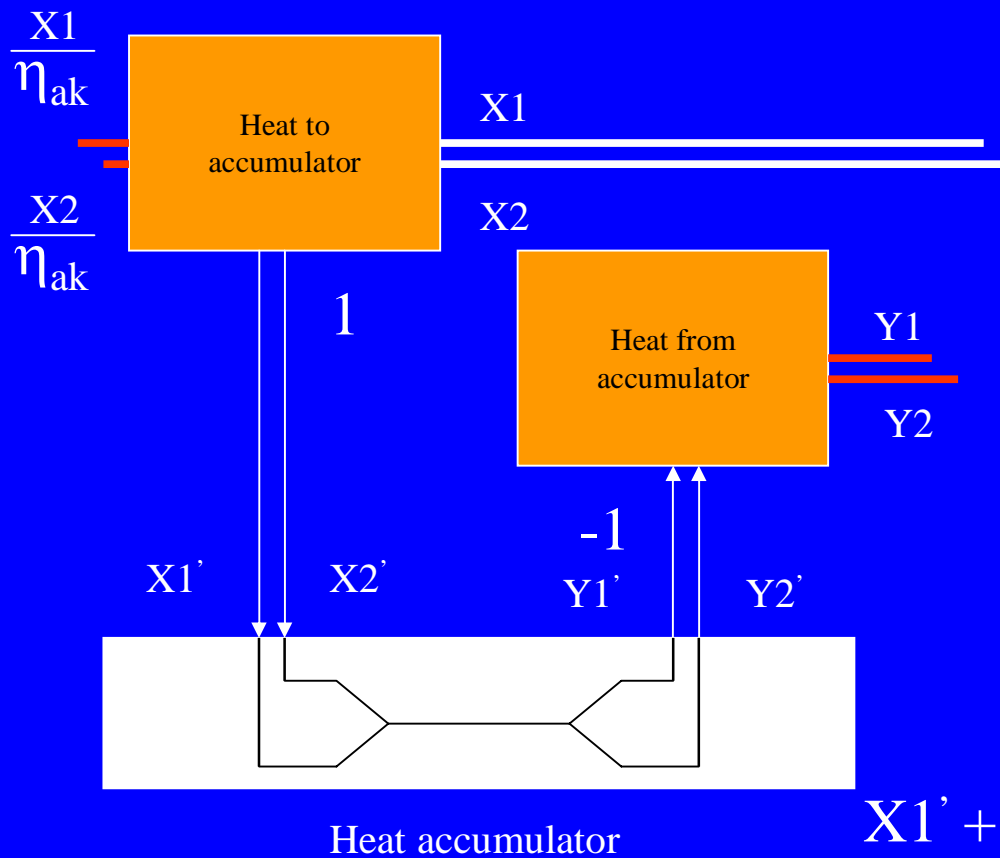
CHP with heat accumulator



Modeling of CHP with heat storage



Principle equations for heat accumulator



$$X1' = X1; \quad X2' = X2;$$

$$Y1 = Y1'; \quad Y2 = Y2';$$

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

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

Representation of heat storage in MESSAGE

IAEA - MESSAGE V CHP_IAEA adb

Screen Help

General

Load regions

Energyforms

Demands

Constraints

Technologies

Storages

Resources

storage: heat_stor

Copy Edit **New** Delete

Storage technologies

single entries

storage name: heat_stor storage short name: **heat** rel to input/output: o load curves for: storage cost abs/rel

storage type: continuous unit type: energy

Unit	Switch	Time series	Unit	Switch	Time series
plant life	yr	c	15	unit size	MW
inv_cost	US\$'00/kW	c	10	constr. time	yr
fixed costs	US\$'00/kW/yr	c	1	storage cost	US\$'00/kW/yr
hist. cap.	MW	hc	1990 100	Storage losses	%
retention time	yr			hist. additions	MW/yr

Entries in relation heat_stor

2 Technologies in Relation heat_stor

other technologies:

other storages:

name	type	for	ldr	tssw	data
to_stor	tec	act		c	1
from_stor	tec	act		c	-1

Save Quit

Chain description

Start | C:\... | Unti... | TE ... | Micr... | MES... | 7% IAE... | Micr... | ALK... | 7:06 PM

Heat to accumulator

Heat from accumulator

1

-1

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,

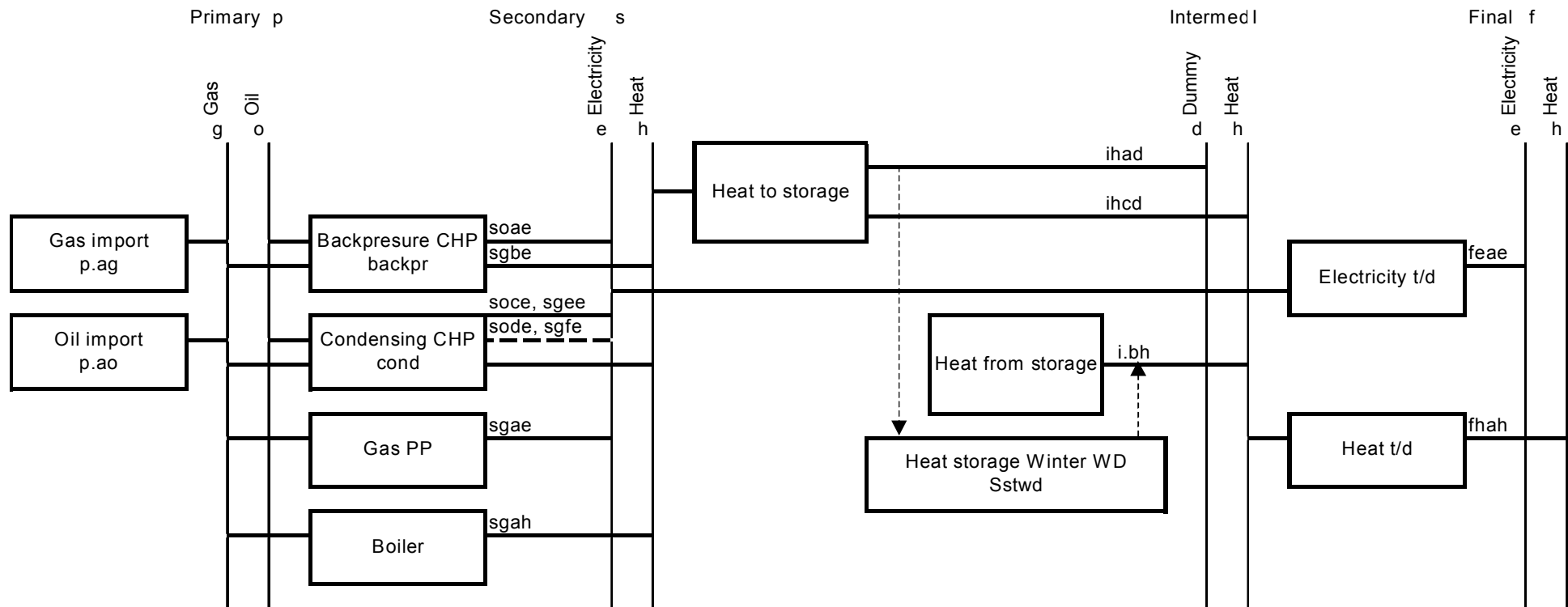
availability and conditions of heat distribution network,

availability and conditions of other heat generation sources;

availability of gas distribution network for decentralized heat generation sources;

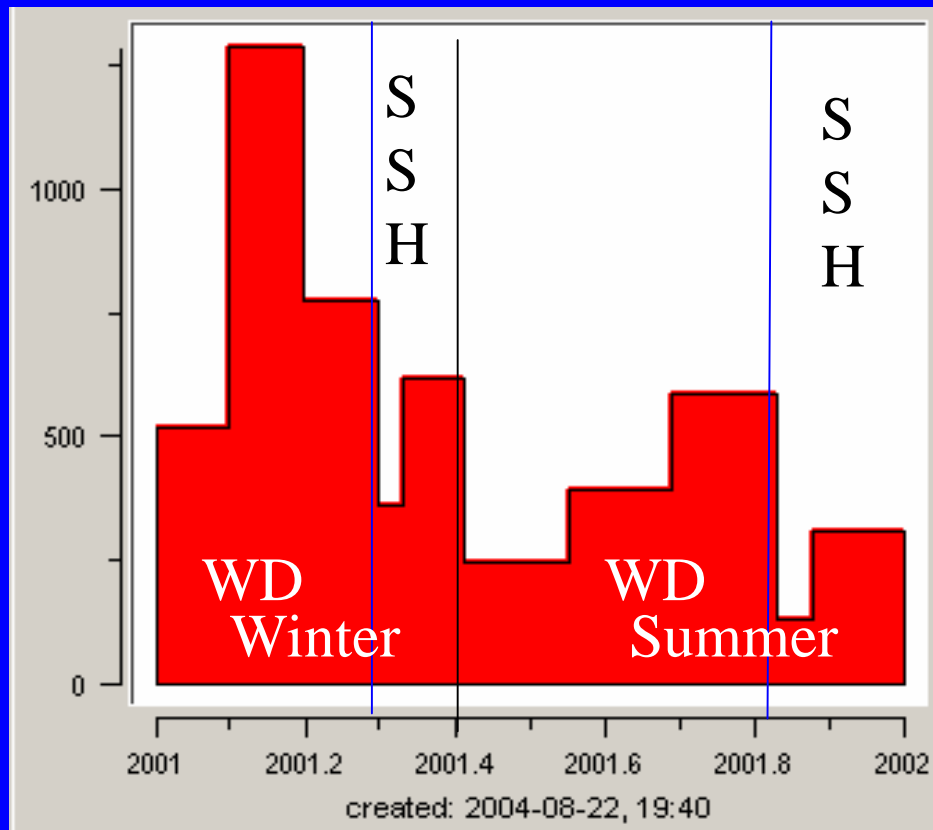
other factors.

Modeling of CHP with heat storage (1)

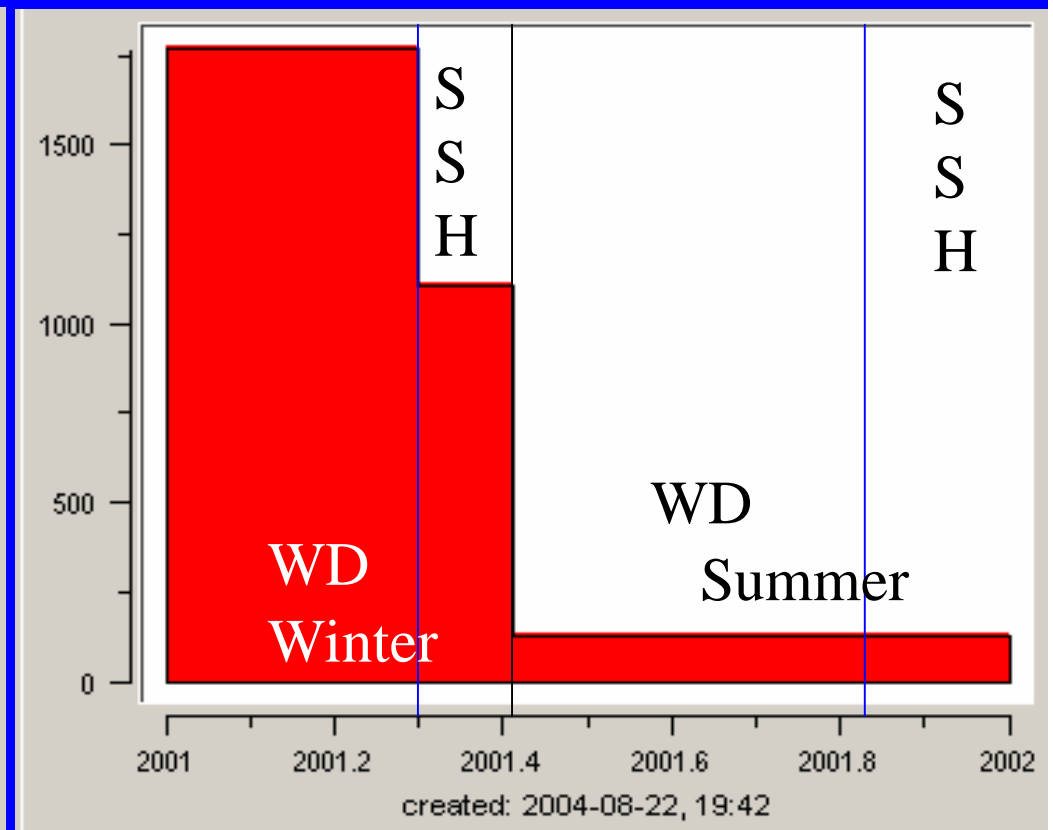


Modeling of CHP with heat storage (2)

Electricity demand

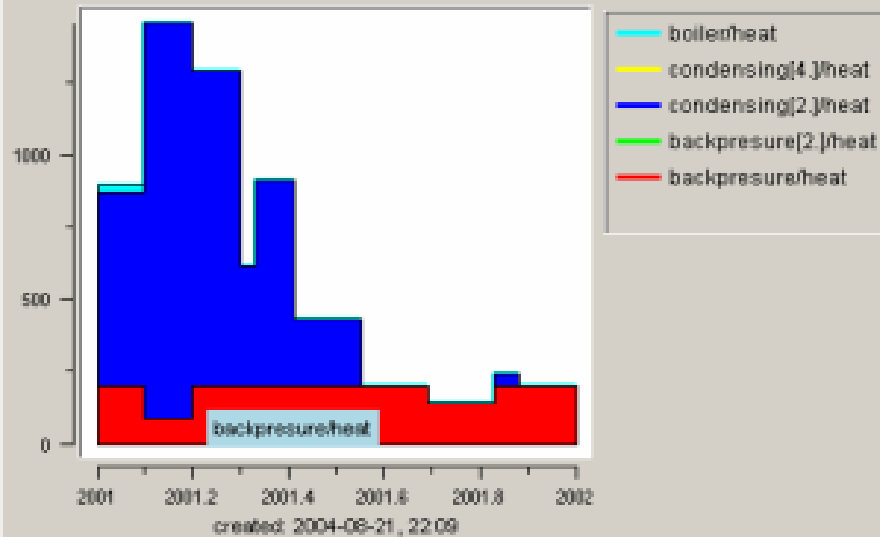


Heat demand

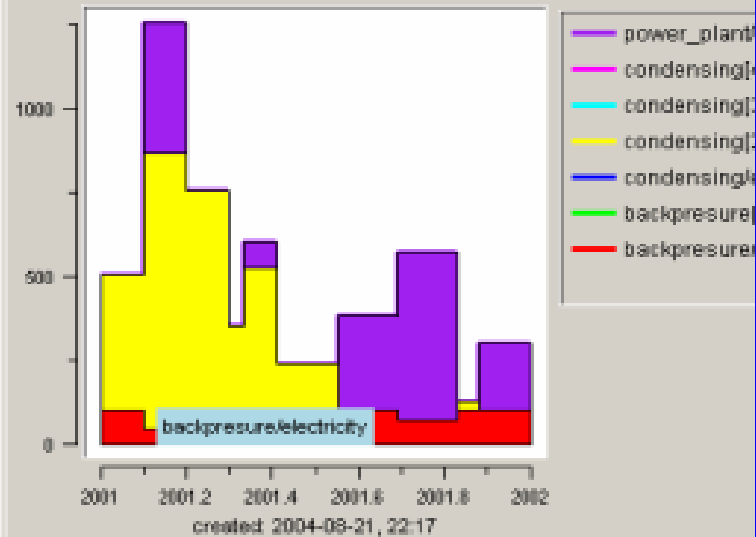


Modeling of CHP with heat storage (3)

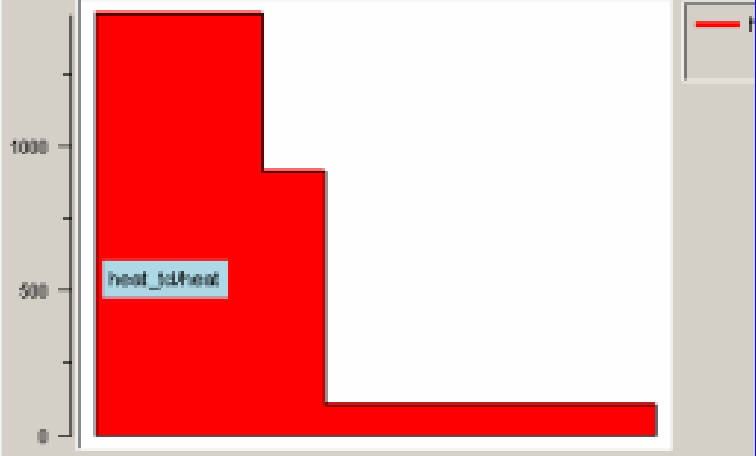
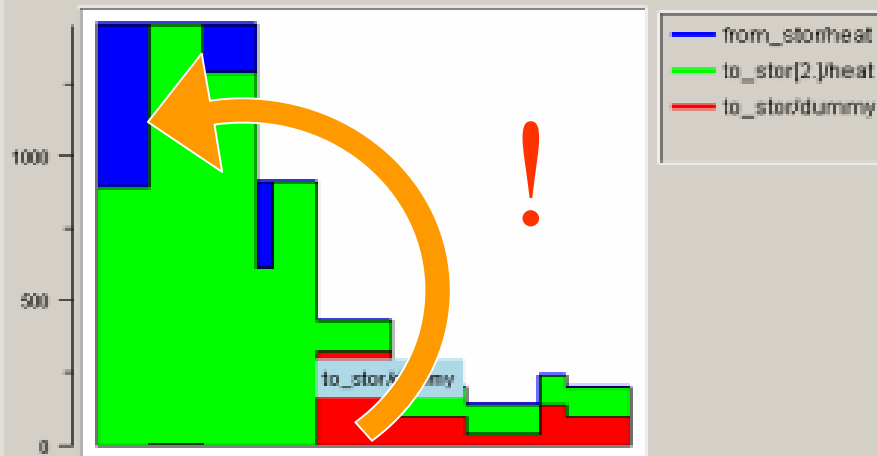
producers of fuel heat on level Secondary
Region: CHP_IAEA, Scenario: adb
Unit: MWyr



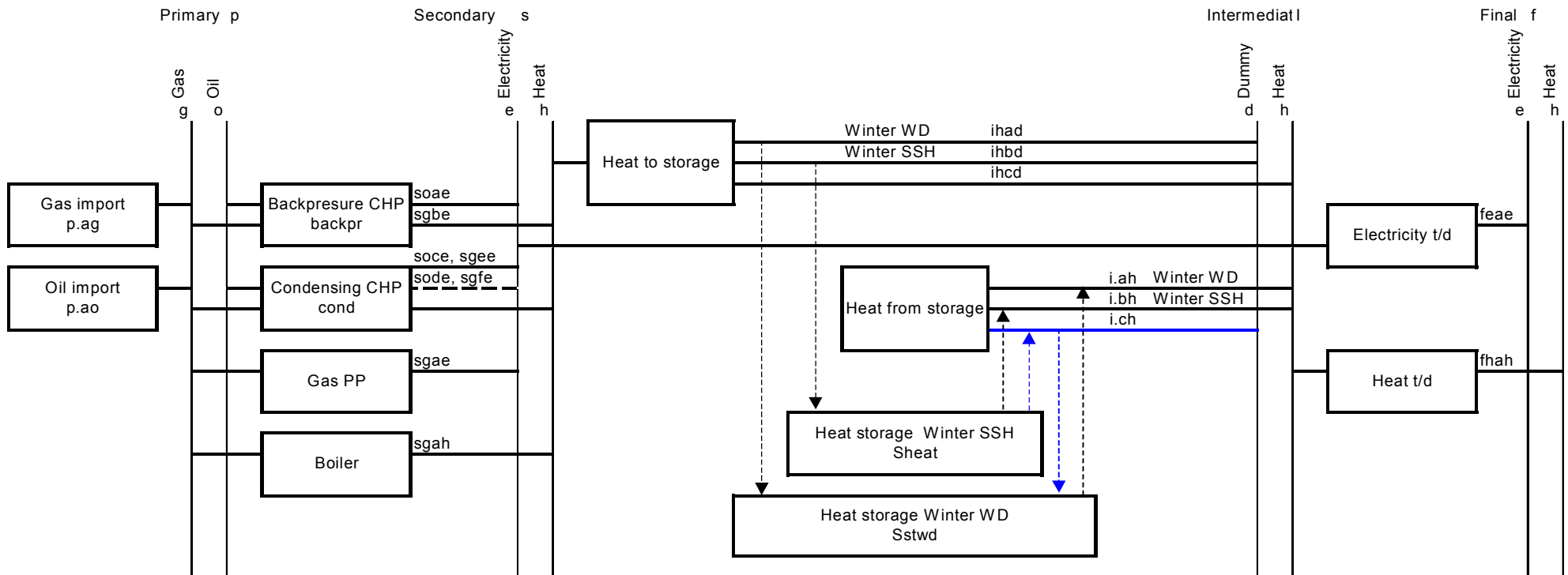
producers of fuel electricity on level Secondary
Region: CHP_IAEA, Scenario: adb
Unit: MWyr



CHP (MWyr)



Modeling of CHP with heat storage (6)

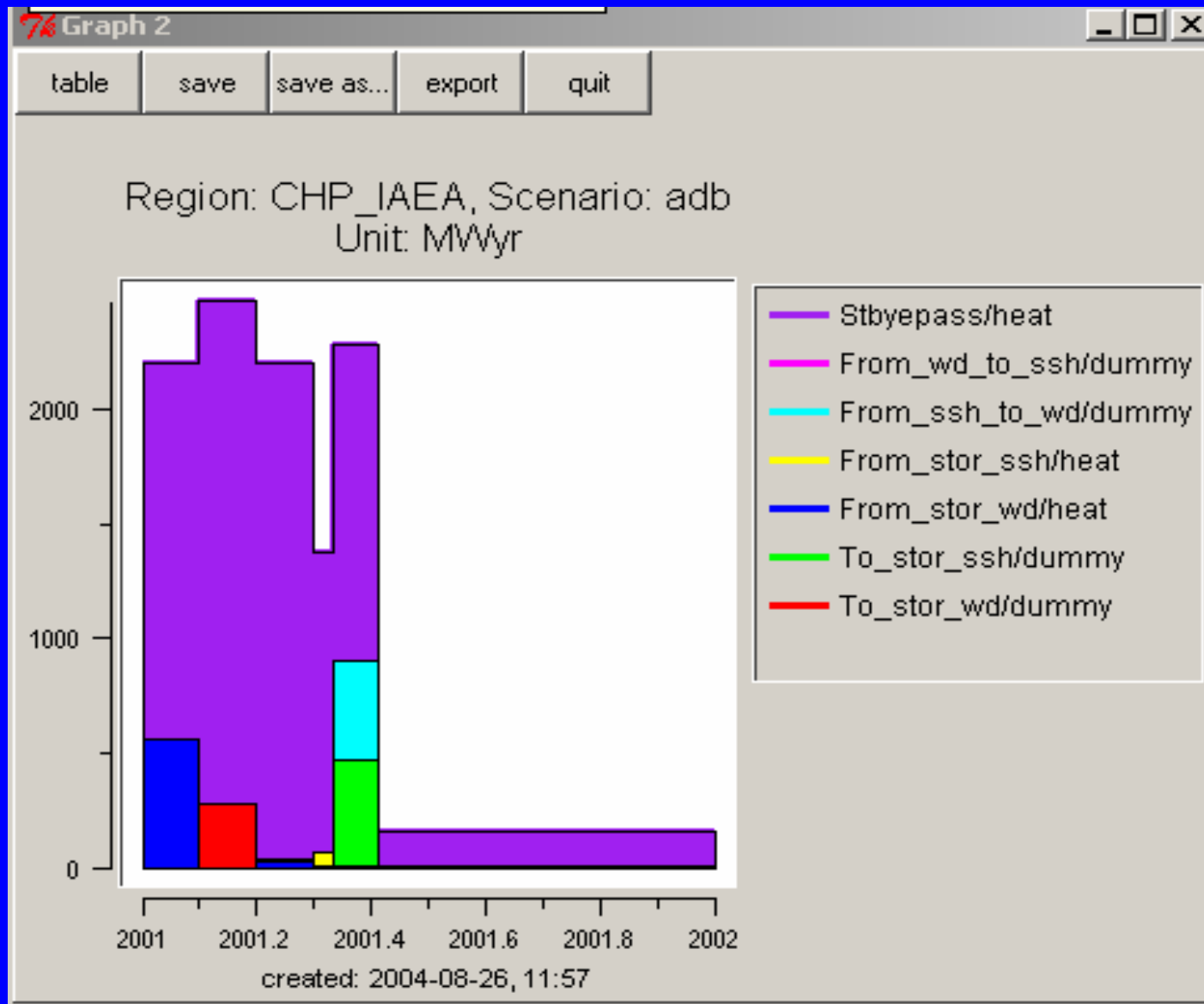


Modeling of CHP with heat storage (7)

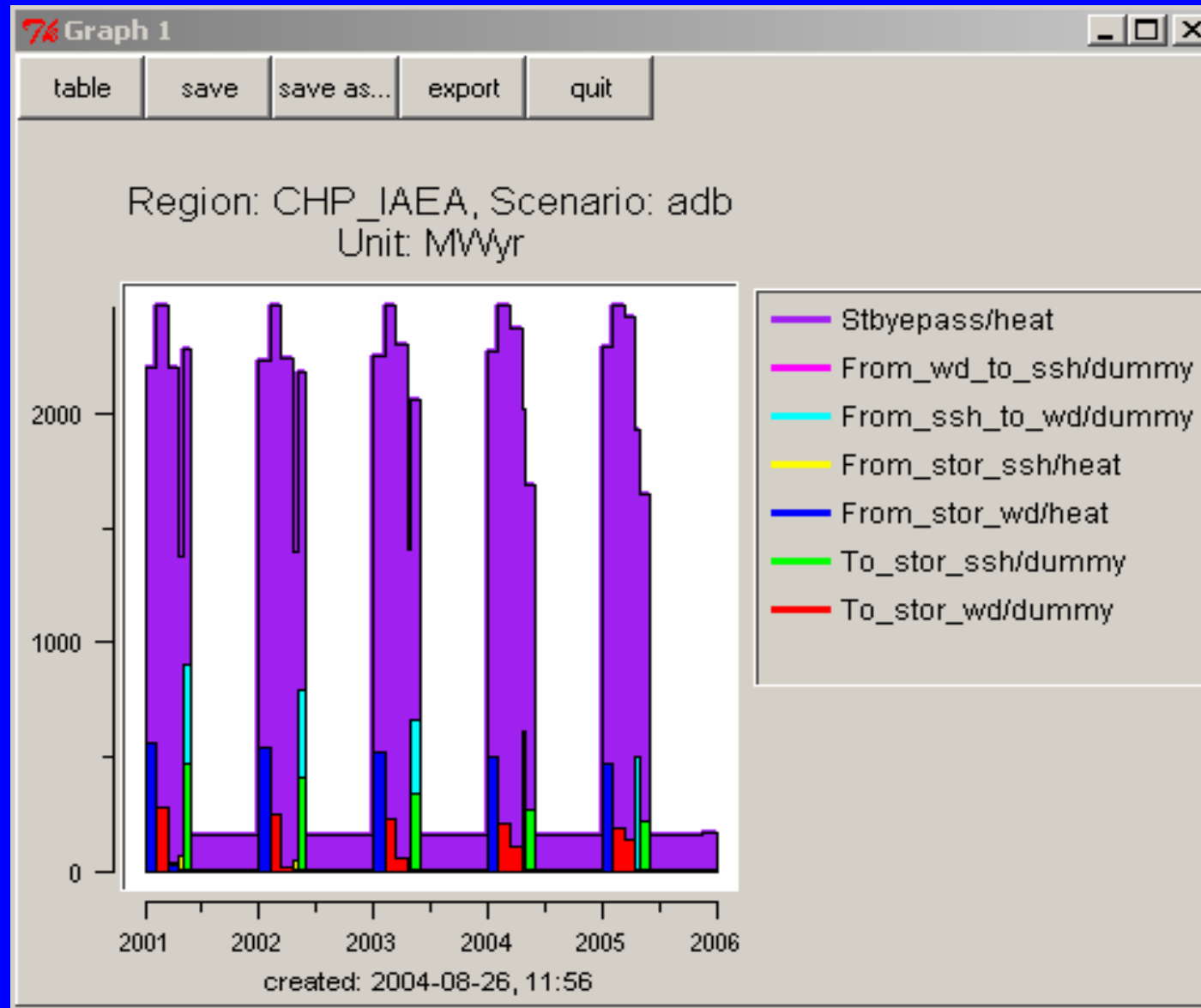
Allowed operation of technologies

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)

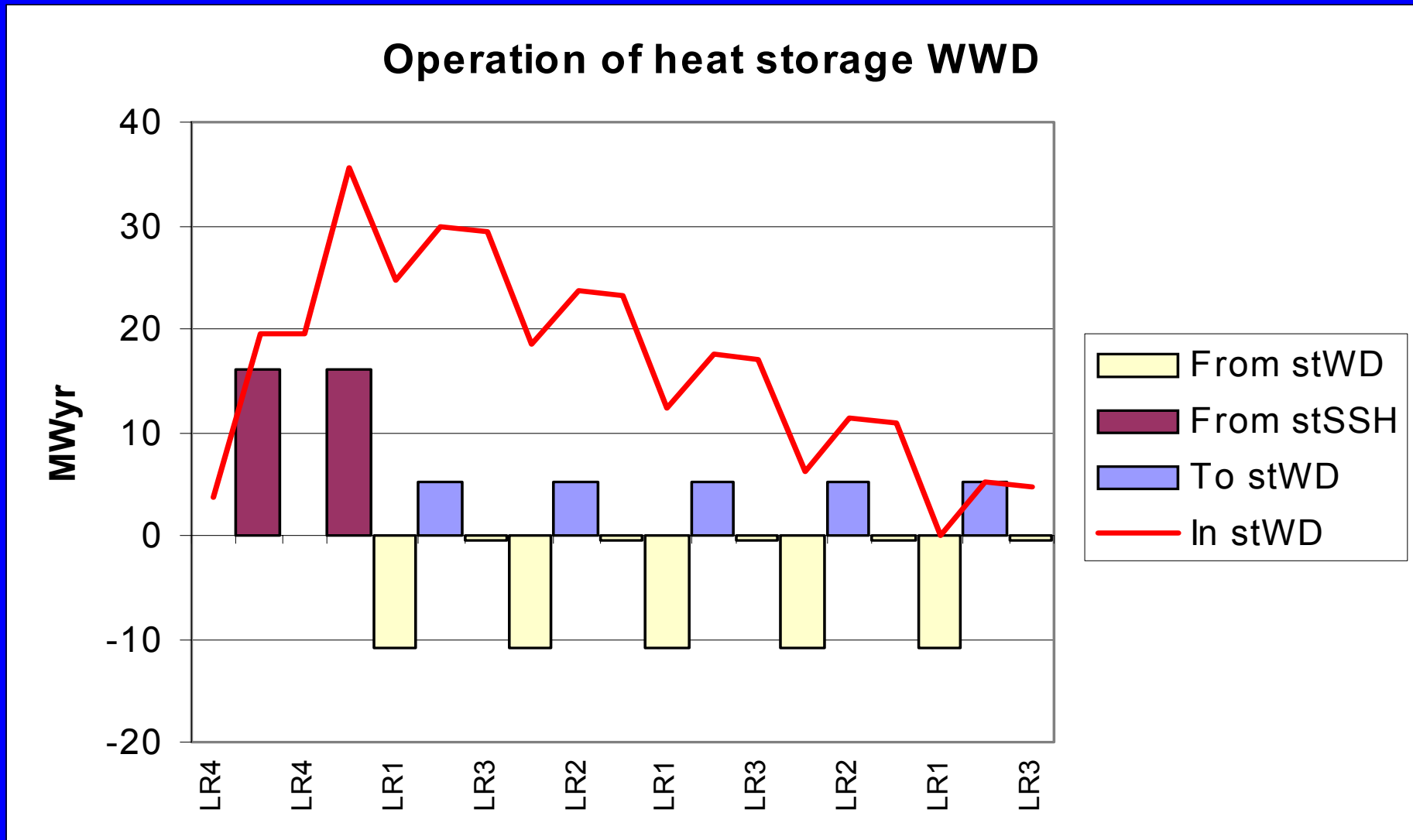


Modeling of CHP with heat storage (9)



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 be 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 pressure 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 (total)	%	85,8	85,7	81,9	85,6	87,4	87,2	87,2	87,2	87,2
Gas consumption at 100% capacity	m 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	m 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	m 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	°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