Power generation technologies, fuel options and renewable energy sources

Dr. Andreas Poullikkas

Electricity Authority of Cyprus

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Contents

1. The electricity sector in Cyprus

Present status

1. Small isolated island power system

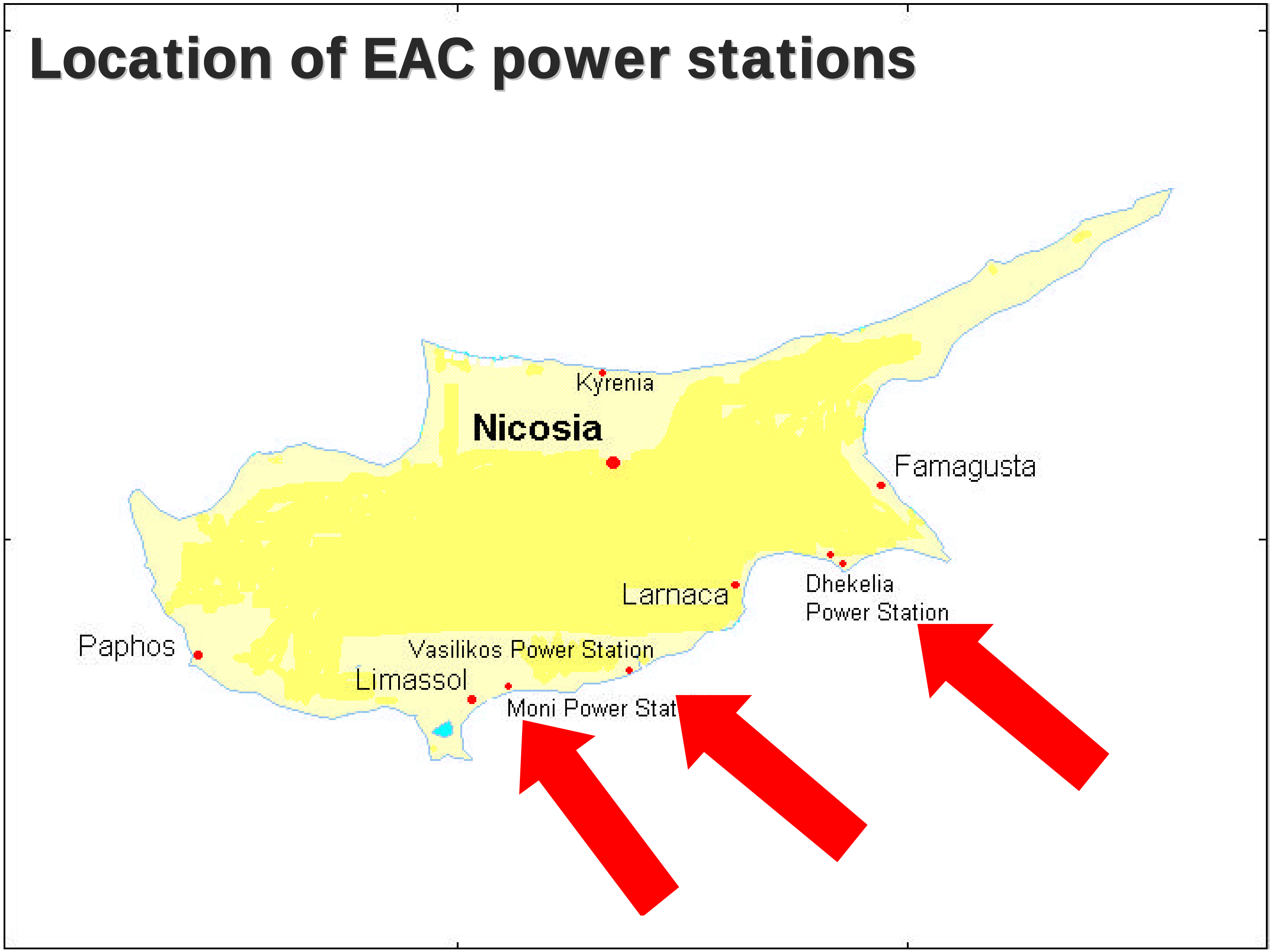
2. Depend on fossil fuels

3. Installed capacity 988MWe

4. Generation 3.785 million kWh (in 2002)

5. Peak load 775MWe (in 2002)

The electricity sector in Cyprus



Existing generation system

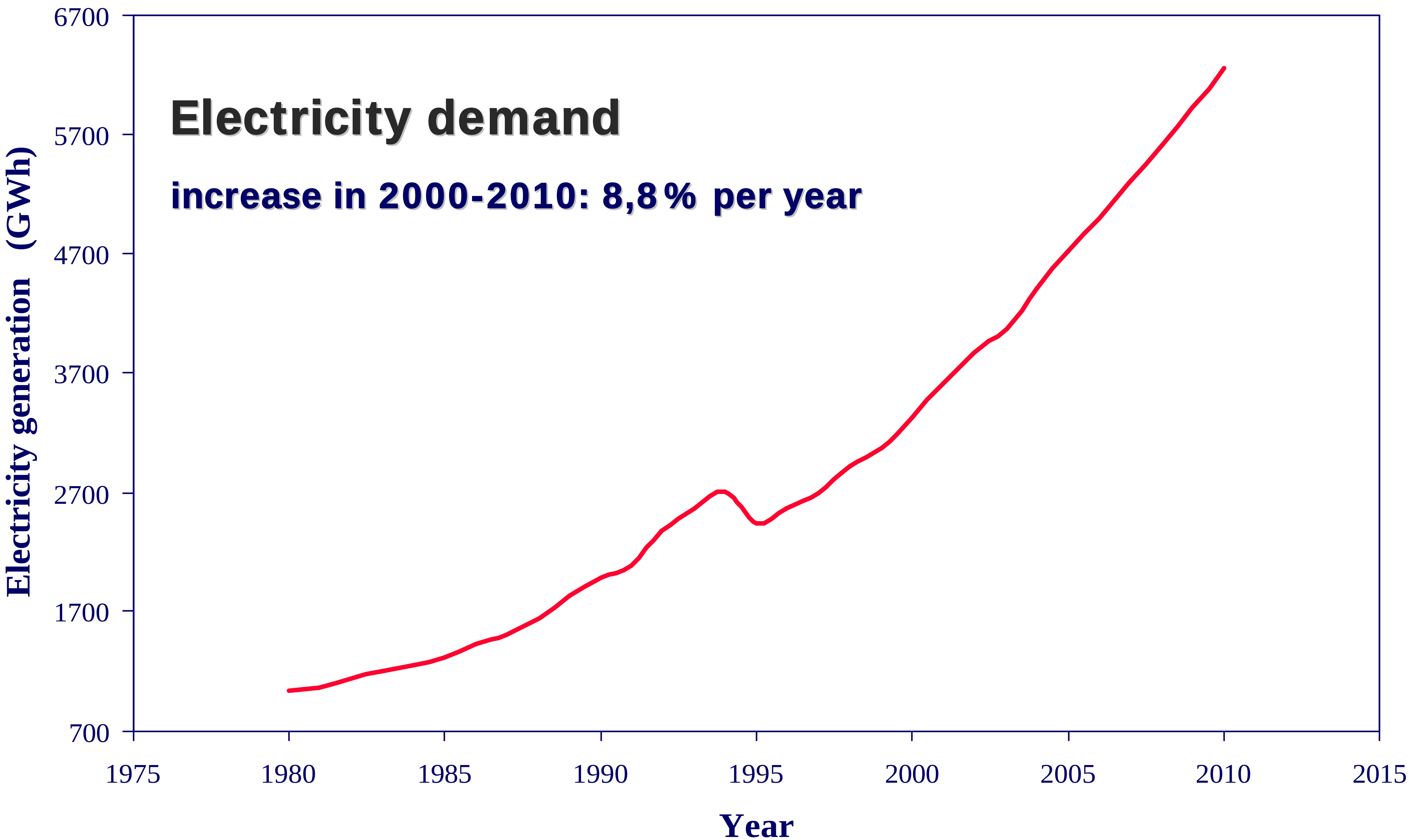
Steam turbine units (HFO)

1. Moni power station 6x30MWe
2. Dhekelia power station 6x60MWe
3. Vasilikos power station 2x130MWe

Gas turbine units (Diesel)

1. Moni power station 4x37,5MWe
2. Vasilikos power station 1x38MWe

The electricity sector in Cyprus



Future plans

1. **1x120MWe steam turbine by 2005** (HFO)
2. **1x180MWe combined cycle by 2006** (diesel or natural gas)
3. **RES:**

    Wind energy (in progress 6MWe wind park)

    R & D

EAC scientific background

1. **Approximately 200 scientists and engineers**
2. **Operation, maintenance and development of the power system**
3. **Special interests:**

RES, alternative ways of energy, energy systems, energy economics, emissions inventories, load forecasting, numerical methods, nuclear safety, ...

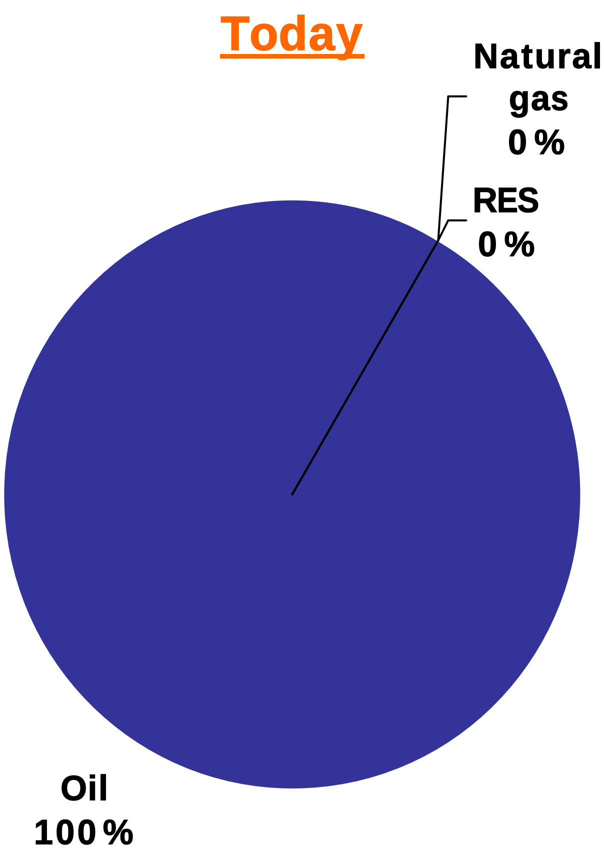
2. Fuel share (world and Cyprus)

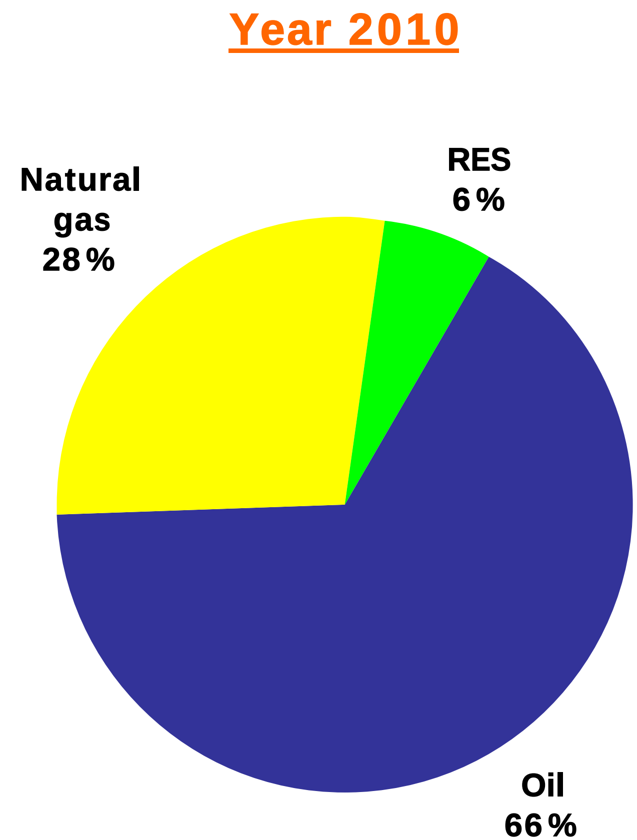
World and Cyprus fuel share for electricity generation

Technology	World*					Cyprus				
	1975	1980	1990	2000	2010	1975	1980	1990	2000	2010
	%									
Coal	36,7	38,1	38,2	37,8	38,2	0,0	0,0	0,0	0,0	0,0
Oil	22,1	19,7	11,3	9,6	8,0	100,0	100,0	100,0	100,0	65,8
Natural gas	2,5	12,0	13,7	14,8	24,3	0,0	0,0	0,0	0,0	28,2
Nuclear	5,9	8,6	17,0	17,6	12,3	0,0	0,0	0,0	0,0	0,0
Renewables	23,0	21,6	19,8	20,2	17,2	0,0	0,0	0,0	0,0	6,0
Total	90,2	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

*IEA (International Energy Agency), World Energy Outlook, Paris 2000.

Cyprus fuel share for electricity generation





3. Research and Development within EAC

Research and Development within EAC

1. Seven research projects on power generation

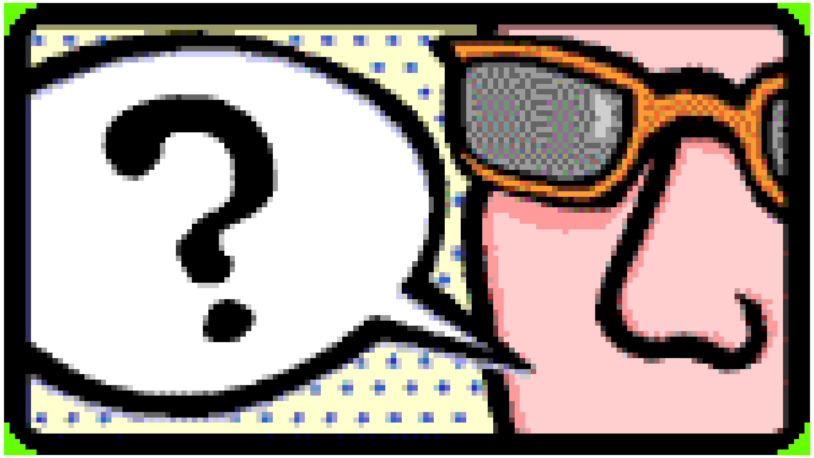
Advance GT and CC technologies	(2 projects)
RES - Hydrogen production	(2 projects)
DG	(2 projects)
Emissions abatement technologies	(1 project)

2. EAC input - coordination, WP leader, technical, economic and enviromental studies (software development)

3. Total funding ~ ½ million € - EC and RPF

4. No R & D section yet

Why R & D at EAC ?



EU targets for power generation

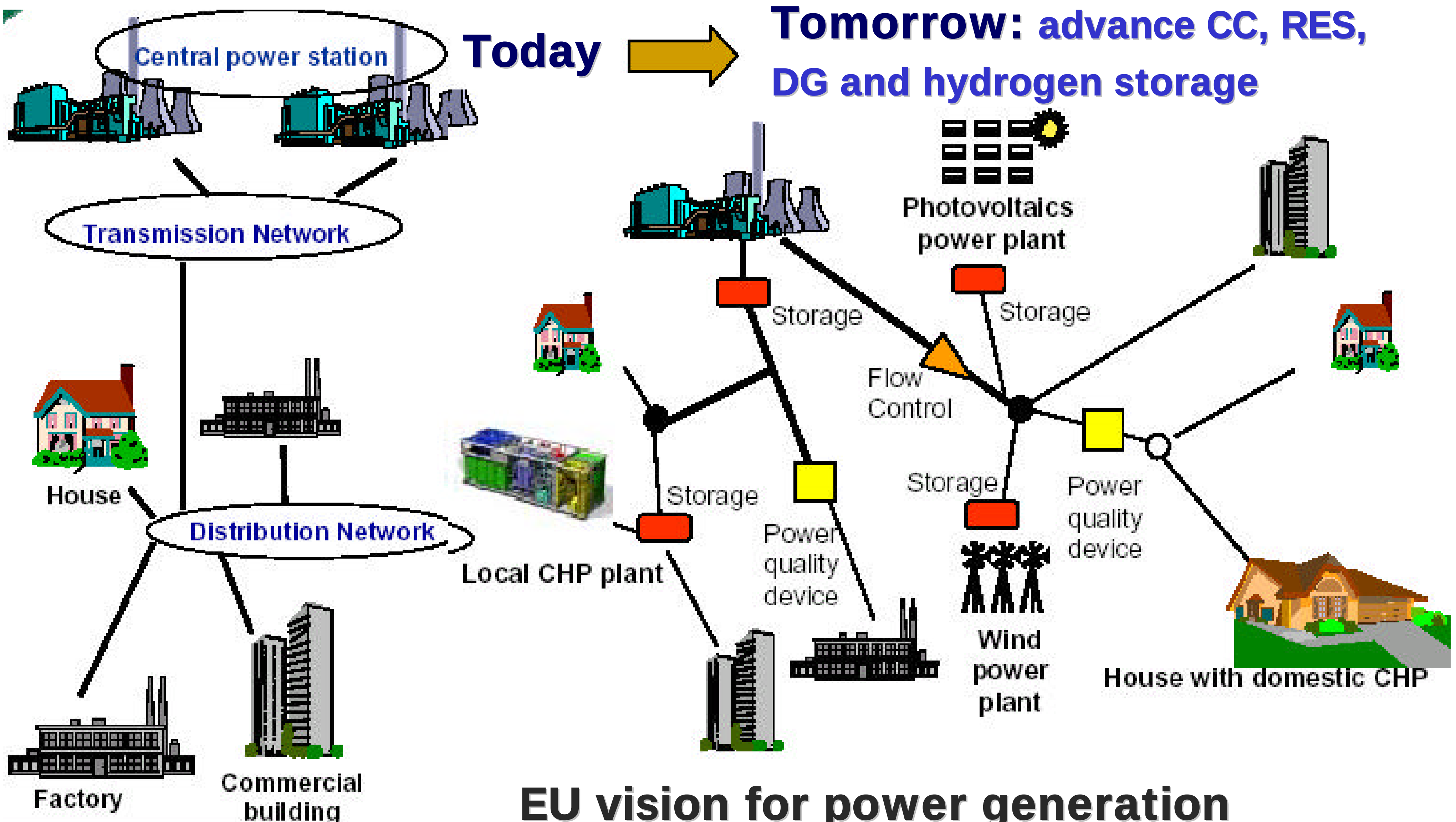
1. **Kyoto objectives:** reduction of EU greenhouse gases and other emissions

2. **Improving energy efficiency:** use of advance CC technologies

3. **Increase the share of renewable energy**

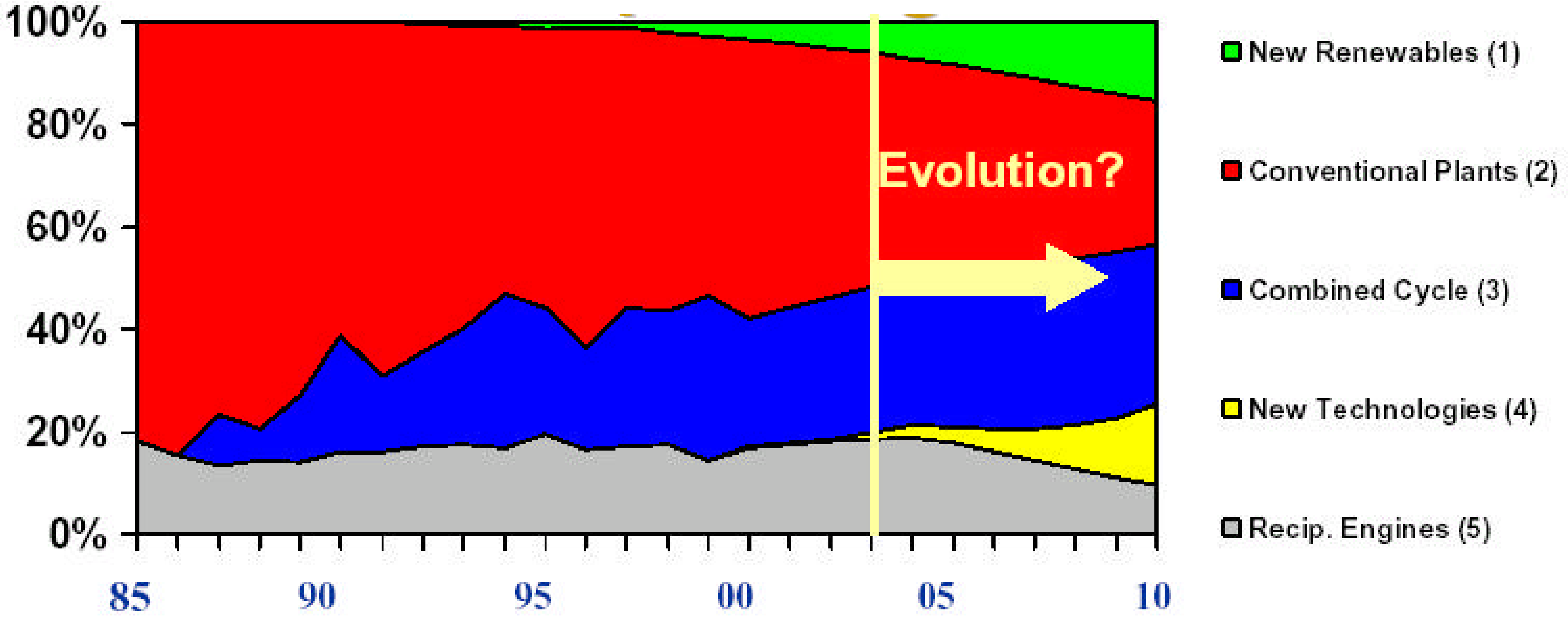
4. **Towards the hydrogen energy economy**

Research and Development within EAC



EU vision for power generation

Technological portofolio for power generation within EU



Notes: (1) Wind, Solar, Biomass and hydro, (2) Conventional ST, GT and Nuclear, (3) CC, (4) Small On-site CHP (mini/micro-turbines, fuel cells, …), (5) Diesel Engines (unit size > 0.5 MW)

4. Research on advance GT and CC technologies

Mixed Air Steam Turbines Fired by Liquid Fuels (MAST-B-LIQUID)

Contract No: ENK5-CT2002-00668

Objectives

1. Design guidelines for combustion chambers of mixed air-steam turbine (MAST) technologies - steam mass flow rate, intercooling, recuperation and mixture inhomogeneity

2. Technical, economic and environmental prospects of MAST technologies - capital outlay, water economy, base or peak load operation

Gas turbine manufacturers - products, specs

EXAMPLE

Results

(a) 239 different models

(b) 0,2MWe - 268MWe range

(c) Identification of MAST technologies

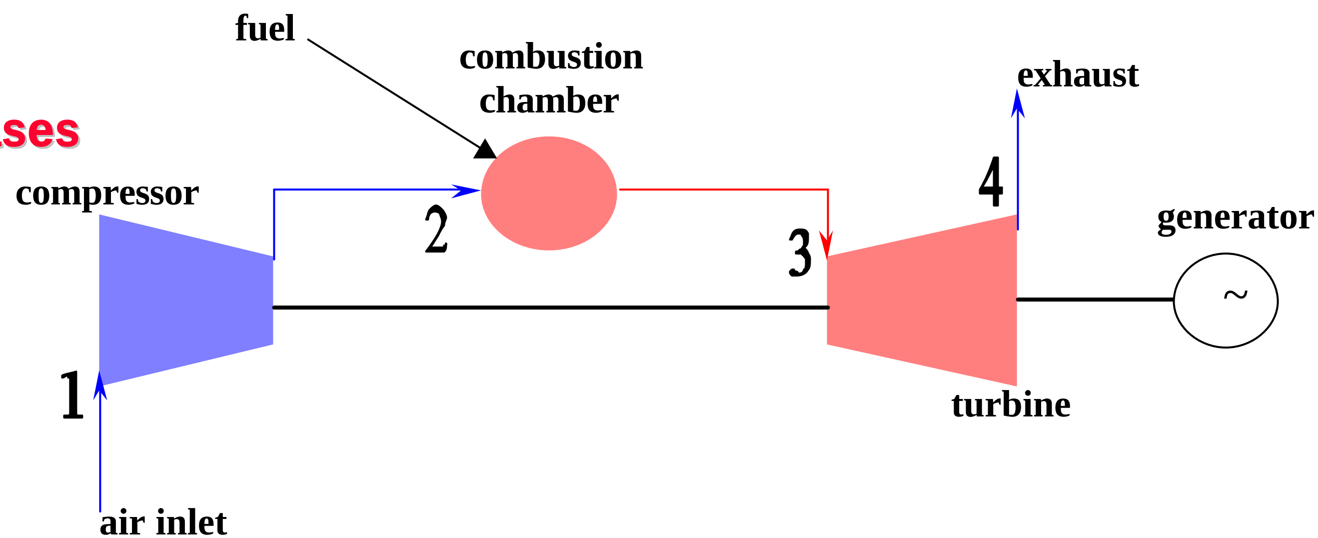
Turbine	Manufacturer	Power (MWe)	Efficiency (%)
LM5000PC	General Electric	34,5	37,2
RLM5000	European Gas Turbines	35,1	37,8
MW-251	MITSUBISHI Heavy Industries	36,8	28,9
PG 6541B	European Gas Turbines	38,3	31,4
PG6541B	Greenwich Turbine, Inc.	38,3	31,4
PG6541	John Brown Engineering	38,3	31,4
PG6541B	KVAERNER ENERGY AS	38,3	31,4
MS6001	Nuovo Pignone	38,3	31,4
PG6541	Thomassen International	38,3	31,4
TG20	FIAT TTG	38,4	30,7
TG20B7/8U	Fiat Avio Power Division	39,4	29,9
LM6000PA	KVAERNER ENERGY AS	39,6	39,7
LM6000	Greenwich Turbine, Inc.	39,9	38,8
LM6000	John Brown Engineering	40,0	38,8
LM6000	Nuovo Pignone	40,0	38,9
LM6000	Fiat Avio Power Division	40,5	39,1
RLM6000	European Gas Turbines	40,6	39,5
DR-63G	Dresser-Rand	40,7	39,2

Simple gas turbine cycle

(Brayton or Joule cycle)

Energy loss from exhaust gases

(T=400^{o}C - 600^{o}C)



Max power ~ 270MWe

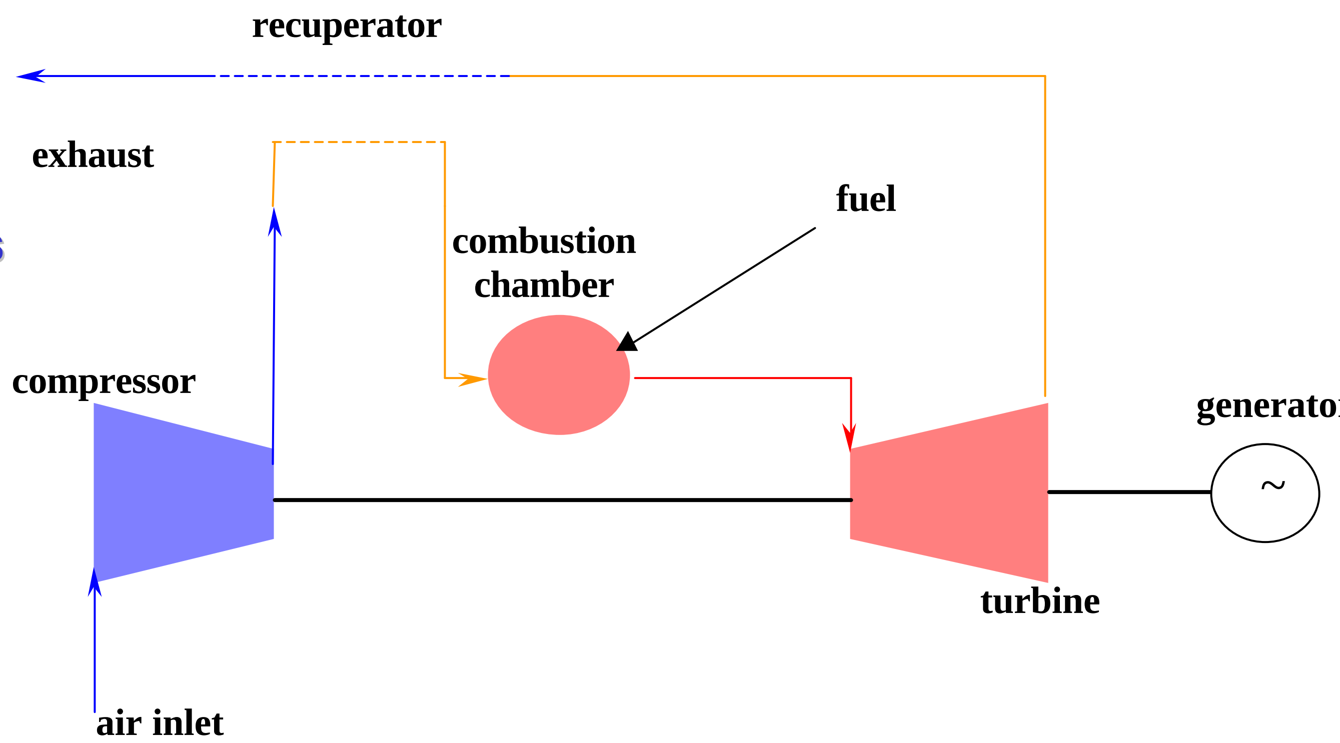
Max efficiency ~ 40 %

Non-MAST technologies

Gas to gas recuperation

Max efficiency 43%

Use for more than 50 years

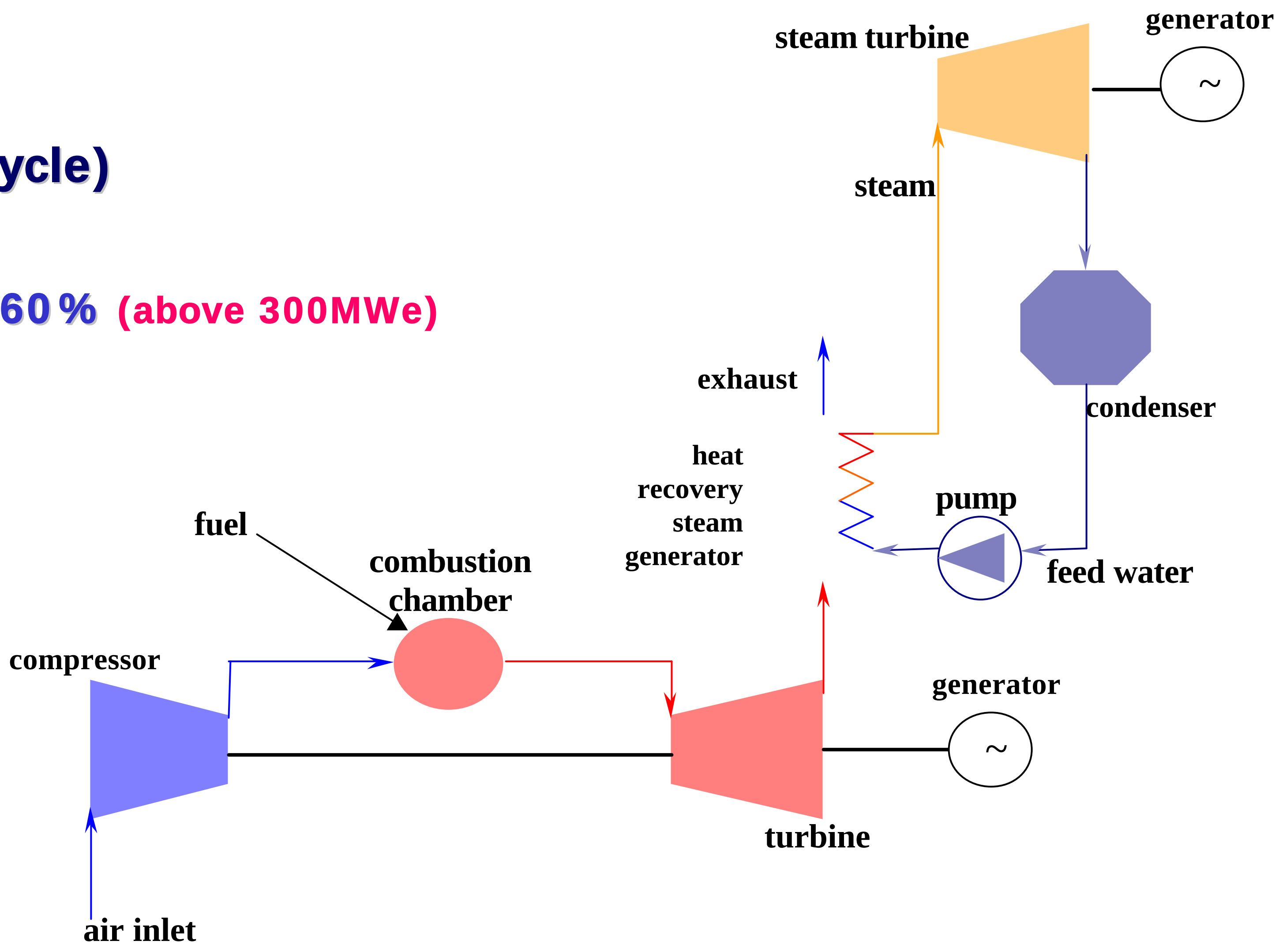


Combined cycle

(Brayton - Rankine cycle)

Max efficiency ~ 58%-60% (above 300MWe)

Widely used

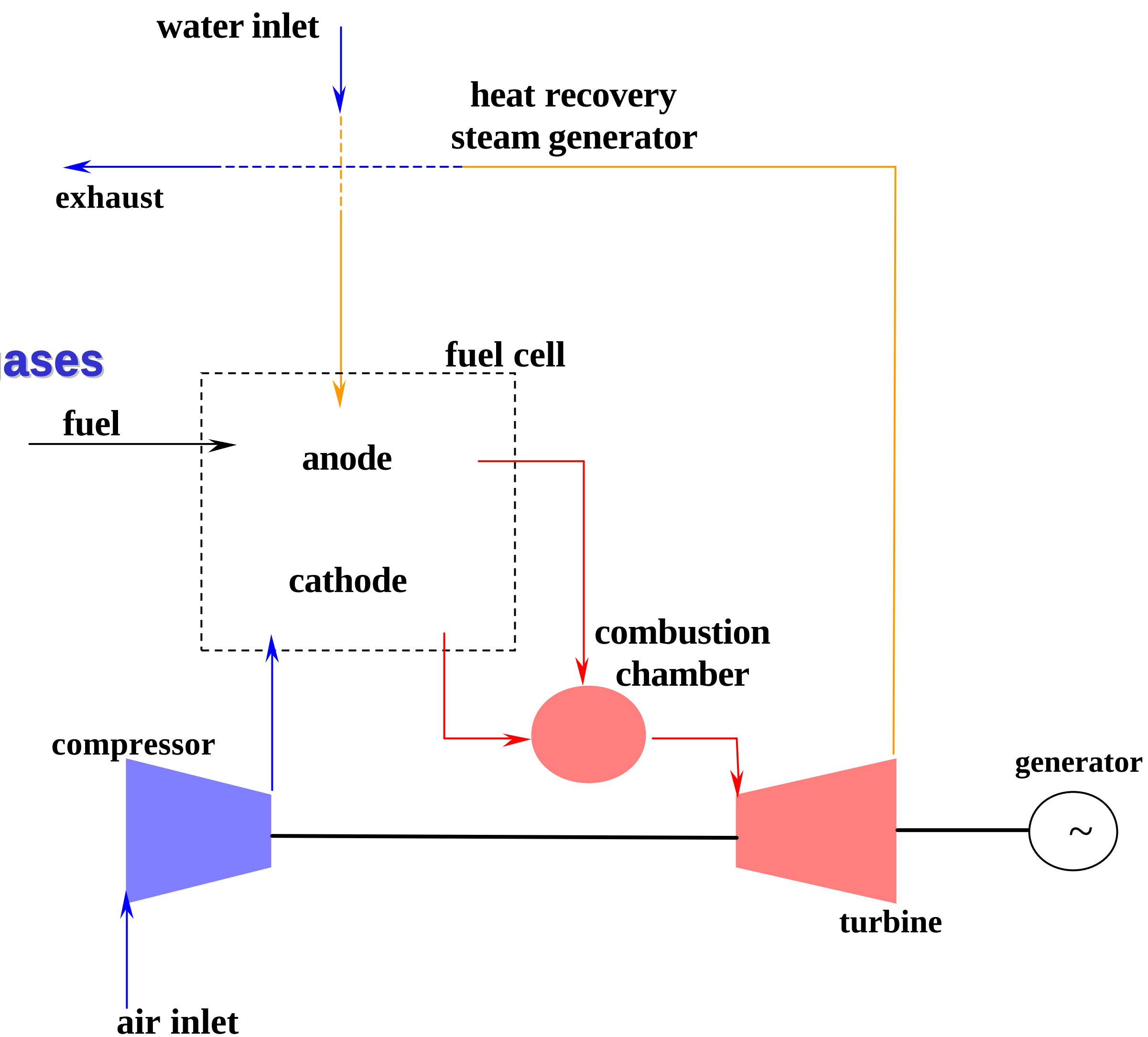


Brayton - fuel cell cycle

Choice for future power plants

High pressure and temperature gases from fuel cell

Expected efficiency ~ 70 %



Non-MAST technologies

Other non-MAST technologies

Brayton - Diesel cycle

Brayton - Stirling cycle

Brayton - Brayton cycle

Brayton - Kalina cycle

Chemical recuperation cycle with steam reforming

Chemical recuperation cycle with gas recycling

Gas turbine turbocharged by the steam turbine (GTTST)

Coal fire air turbine cycle (CAT)

Gratz cycle

Chemical looping combustion cycle (CLC)

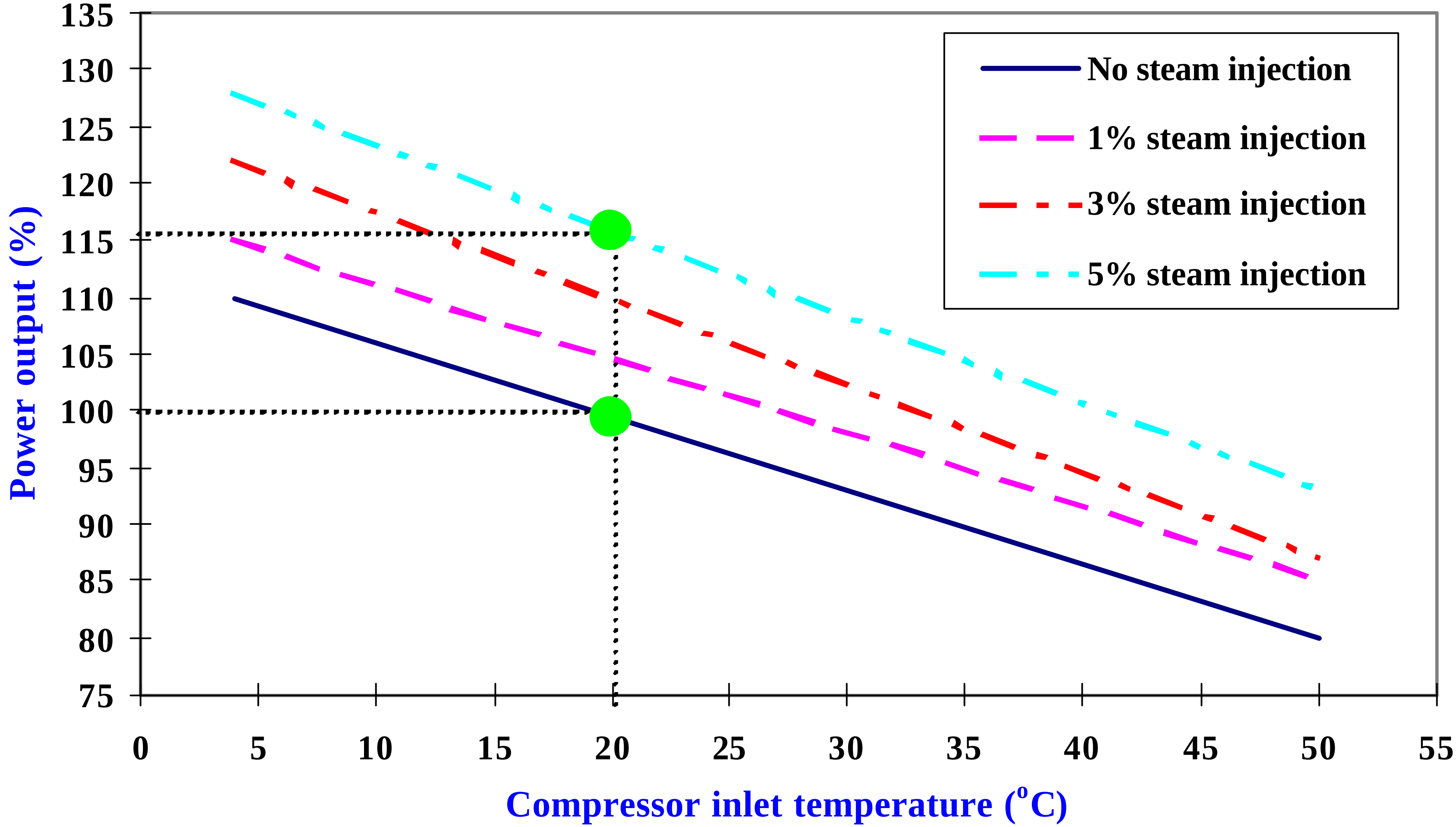
Hydrogen combustion turbine

Mixed Air Steam Turbine (MAST) technologies*

- Water or steam injection
- Before or in the combustion chamber
- Increase in mass flow, thus, power
- NO_X reduction
- Water consumption

* Also, referred as mixed gas turbine or as wet gas turbine technologies

Effect of steam injection on power output



Power output of commercial available MAST gas turbines

Turbine	Manufacturer	Power (MWe)	
		without steam injection	with steam injection
M1A-13CC	KAWASAKI Heavy Industries	1,3	2,4
501-KH	Allison Engine Company	4,9	6,8
LM1600 STIG*	General Electric	13,0	17,0
LM2500 STIG*	General Electric	22,8	28,1
LM5000 STIG*	General Electric	34,5	51,6

* STIG™ = STeam Injected Gas turbine

Efficiency of commercial available MAST gas turbines

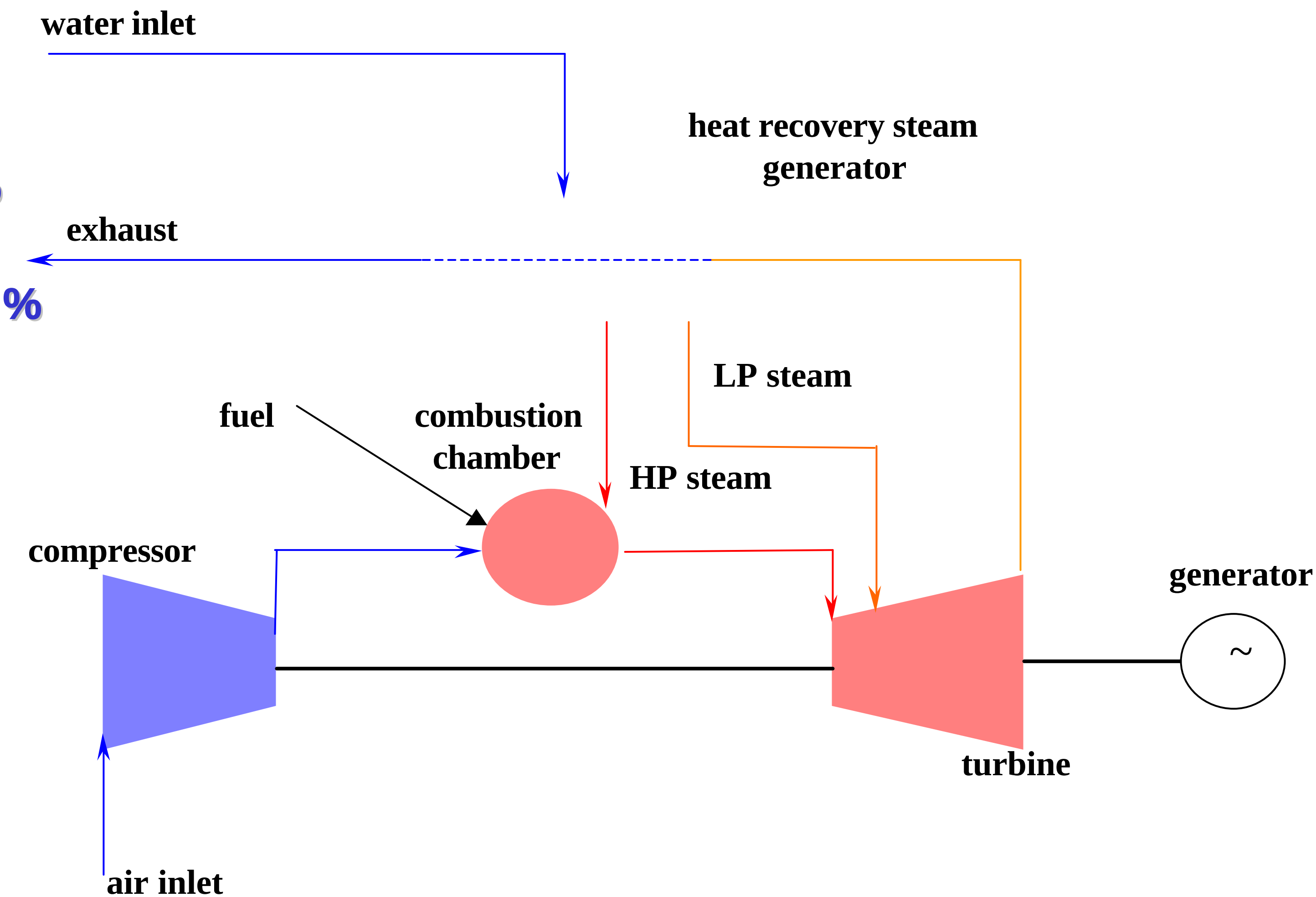
Turbine	Manufacturer	Efficiency (%)	
		without steam injection	with steam injection
M1A-13CC	KAWASAKI Heavy Industries	22,3	33,7
501-KH	Allison Engine Company	31,5	39,9
LM1600 STIG*	General Electric	35,5	39,5
LM2500 STIG*	General Electric	36,8	41,0
LM5000 STIG*	General Electric	37,2	43,8

* STIG™ = STeam Injected Gas turbine

Cheng cycle

Power increase ~ 60 %

Gain in efficiency ~ 10 %

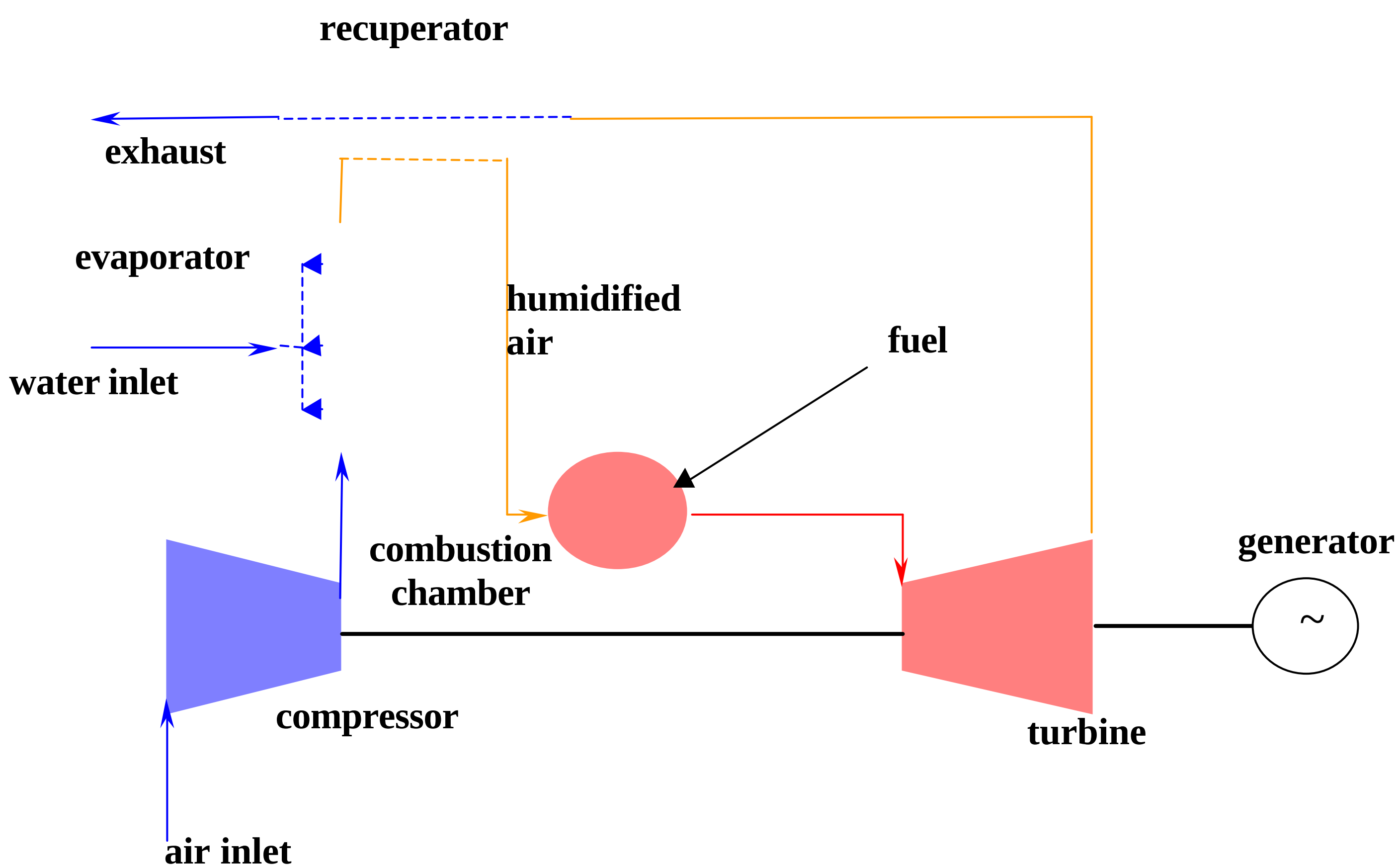


Evaporation cycle

Injection of liquid water before combustion chamber

Power increase ~ 60 %

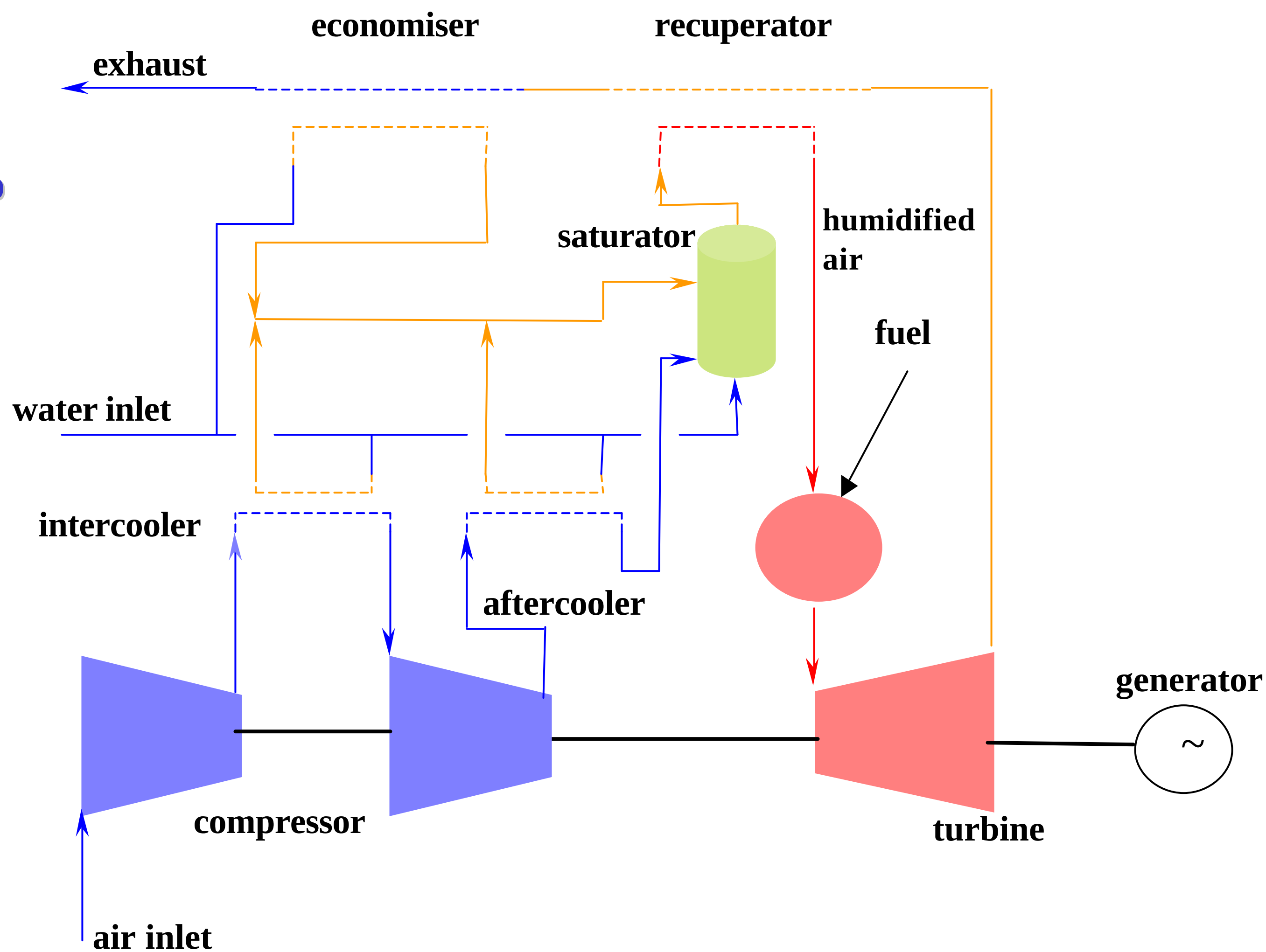
Gain in efficiency ~ 60 %



HAT cycle
(Humit Air Turbine)

Expected efficiency ~ 57 %

Pilot plant 600kW - Lund University

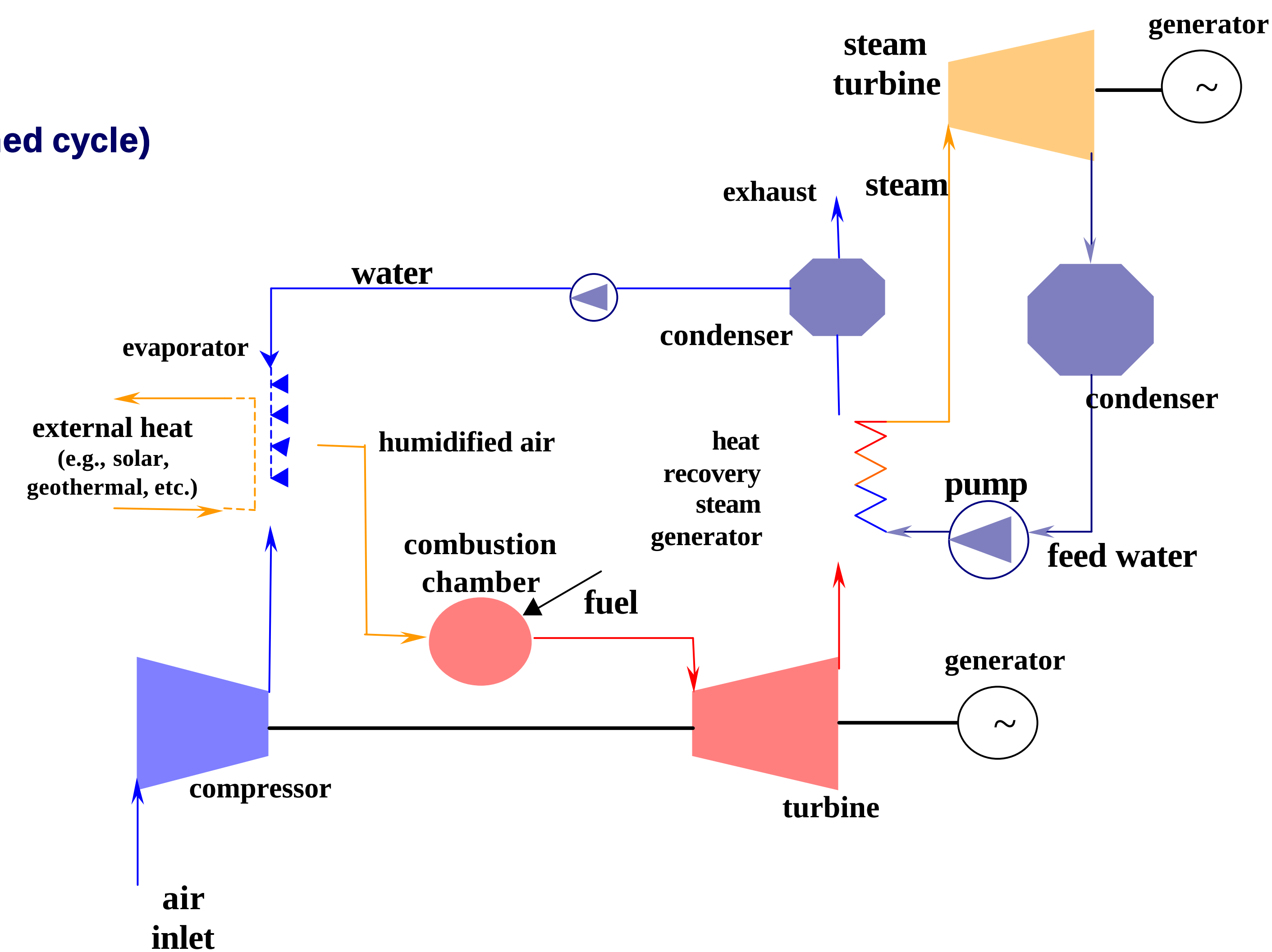


LOTHECO cycle
(Low Temperature HEat COmbined cycle)

Bottoming Rankine cycle

Water recycling

Expected efficiency 60 %



MAST technologies

Other MAST technologies

The steam injected cycle with topping steam turbine

The turbo-charged steam injected cycle

The Dual-Recuperated Inter-cooled-After-cooled Steam Injected cycle (DRIASI)

The wet compression cycle

Advance GT and CC technologies - Synopsis

Combined cycle - non-MAST technology
(Brayton - Rankine cycle)

- well established technology
- widely used
- efficiency ~ 58% - 60%
- medium and large scale applications - above 300MWe

HAT cycle - MAST technology

- pilot plant (600kWe)
- expected efficiency ~ 57%
- small scale applications - less than 50MWe

Advance GT and CC technologies - Synopsis (continue)

LOTHECO - MAST technology

- under investigation
- expected efficiency ~ 60 %
- small, medium and large scale applications
- choice for future power plants

Brayton - fuel cell cycle - non-MAST technology

- under investigation
- expected efficiency ~ 70 %
- small, medium and large scale applications
- choice for future power plants

5. Parametric analysis of CC technology in Cyprus*

Mixed Air Steam Turbines Fired by Liquid Fuels (MAST-B-LIQUID)

Contract No: ENK5-CT2002-00668

*** Poullikkas A., "Parametric study for the penetration of combined cycle technologies into Cyprus power system", *Applied Thermal Engineering*, to appear, 2004.**

Objective

Technical, economic and enviromental analysis for the penetration of CC technologies into Cyprus power system

Optimisation algorithm

IPP technology selection algorithm*

1. Economic model

2. Evaluation of candidate power technologies:

- Capital cost
- Fuel consumption and cost
- Operation and maintenance cost
- Plant load factor
- Life expectancy etc.

3. Least cost power generation configuration

*Poullikkas A., "A technology selection algorithm for independent power producers", *The Electricity Journal*, 2001.

Cost function*

$$\textbf{least cost solution} = \min\left[c_k\right] = \min\left[\frac{C_o + \sum_{j=1}^{n} \frac{C_j}{(1+i)^j}}{P_o + \sum_{j=1}^{n} \frac{P_j}{(1+i)^j}}\right]_k$$

c	:	electricity unit cost for candidate generation technology k in €/kWh
C_o	:	production cost of the reference year in €
C	:	production cost of year j in €
P_o	:	electricity production of the reference year in kWh
P	:	electricity production of year j in kWh
i	:	discount rate in %

*Poullikkas A., "A technology selection algorithm for independent power producers", *The Electricity Journal*, 2001.

Eligible conventional plants

1. **HFO steam turbine** **(business as usual scenario)**

2. **Gasoil open cycle gas turbine**

3. **Natural gas (LNG) open cycle gas turbine**

Parametric study data

Combined cycle technology - variations

1. Fuel type

2. Capital cost

3. Efficiency

Parametric study data

Combined cycle technology - advantages

1. **High thermal efficiency** - LOTHECO, HAT
2. **Low emissions**
3. **Low capital costs**
4. **Short construction times**
5. **Less space requirements**
6. **Flexibility in plant size**
7. **Fast start-up**

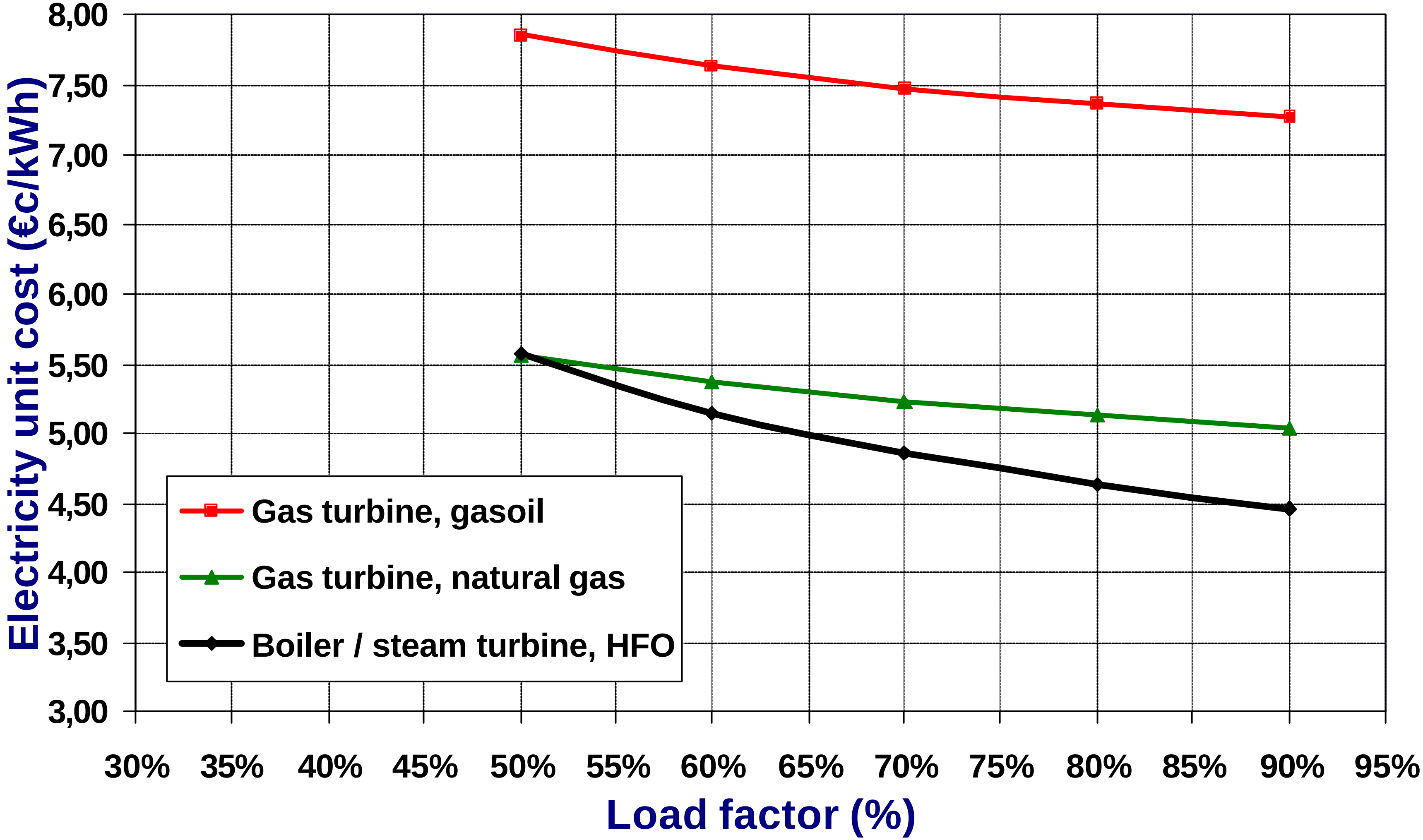
Parametric study data

Technical and economic parameters of candidate technologies

Option No	Technology	Fuel type	Capacity	Capital Cost	Efficiency	Fuel net calorific value	Fuel cost		Fixed O&M	Variable O&M
			MWe	€/kW	%	GJ/t	€/t	€/GJ	€/kW-month	€/MWh
1	Boiler / steam turbine	HFO	120	1258	37,26	41,3	125	3,03	1,4	1,50
2	Gas turbine	Gasoil	81	550	27,14	42,5	190	4,47	1,25	6,00
3	Gas turbine	Natural gas	81	532	28,38	45,0	141	3,13	0,83	4,00
4	Combined cycle	Gasoil	180	700-900	40-70	42,5	190	4,47	1,57	3,20
5	Combined cycle	Natural gas	180	700-900	40-70	45,0	141	3,13	1,25	2,50

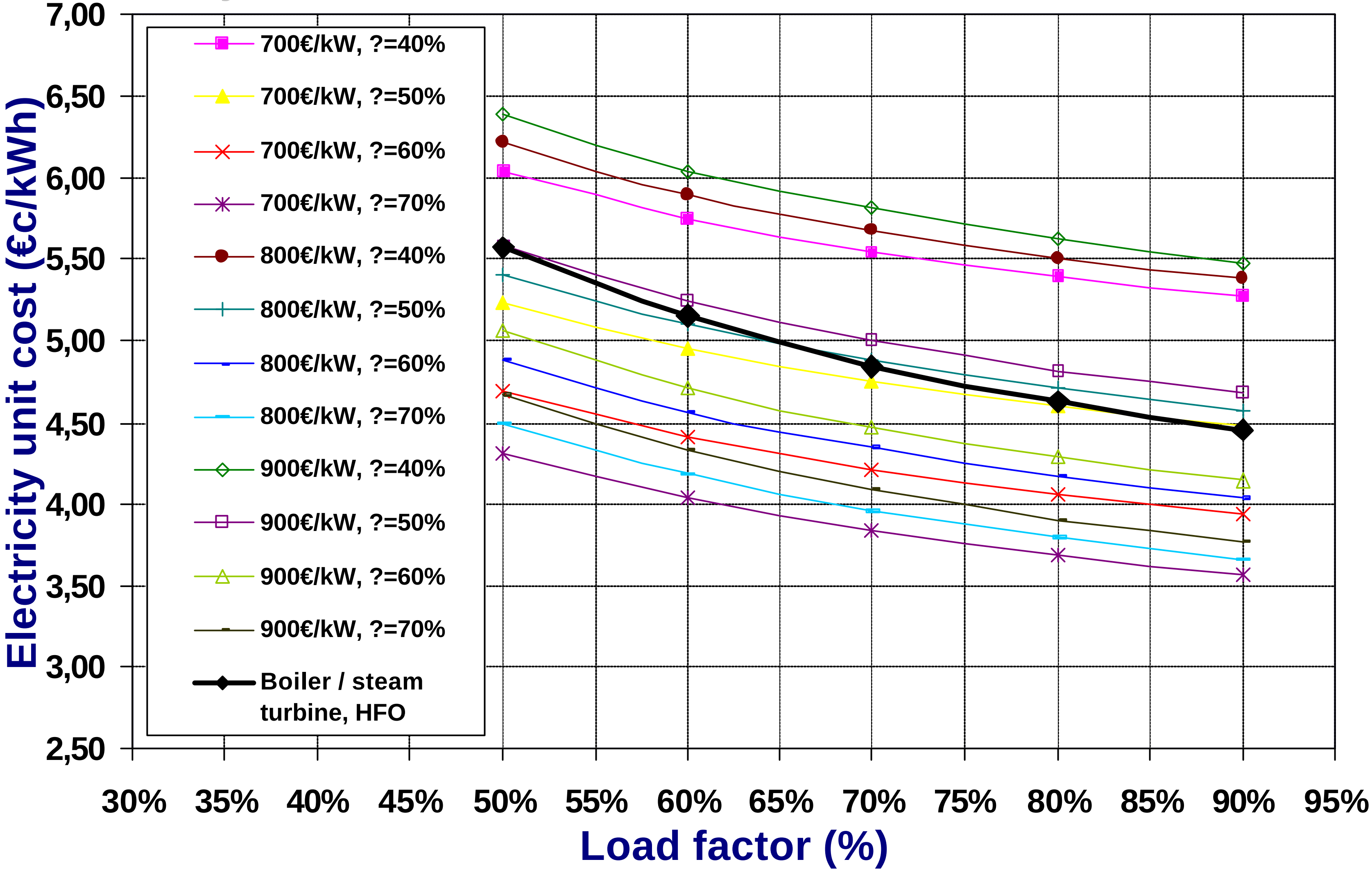
Cost-benefit analysis

Conventional technologies

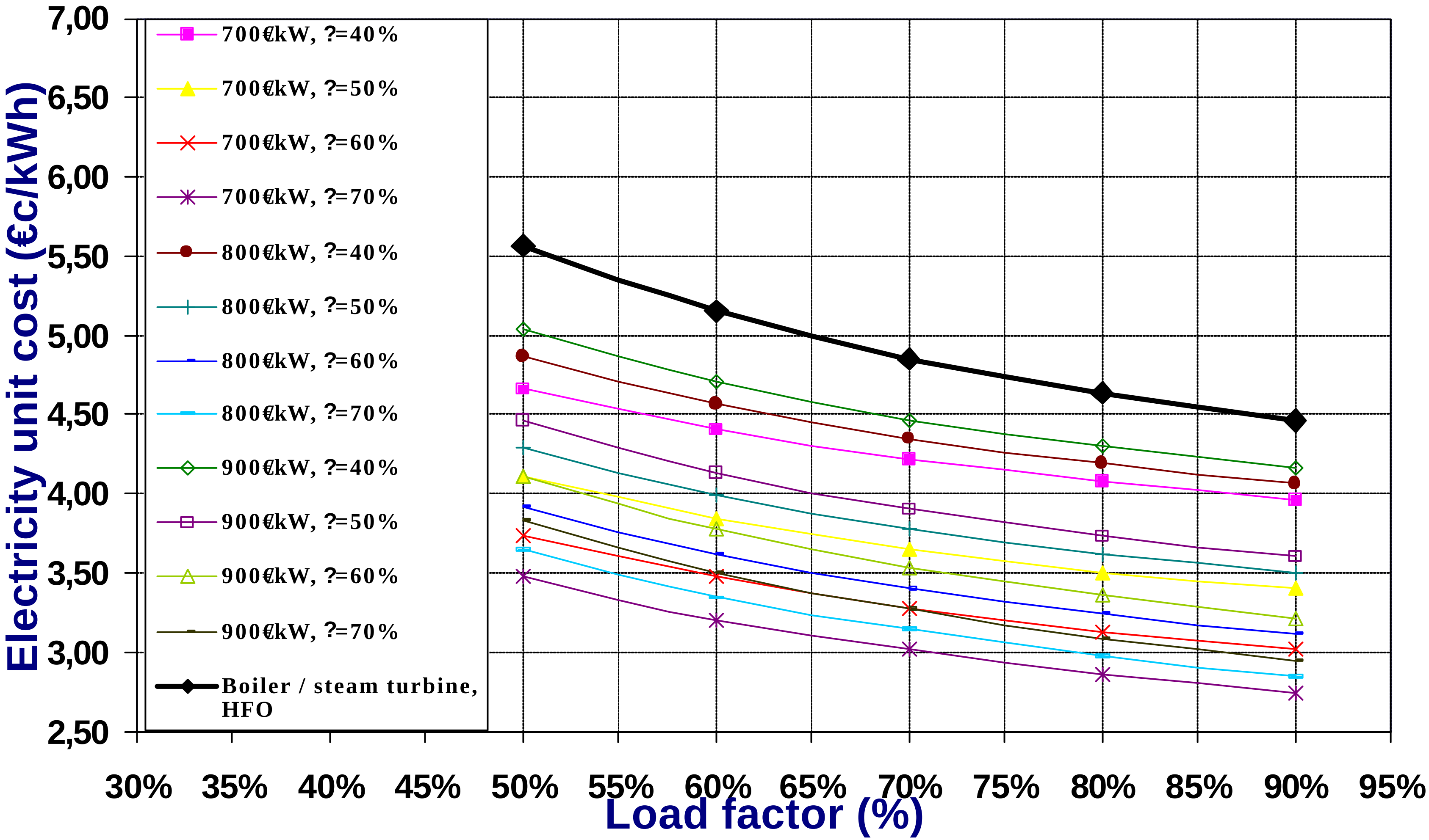


Cost-benefit analysis

Diesel combined cycle

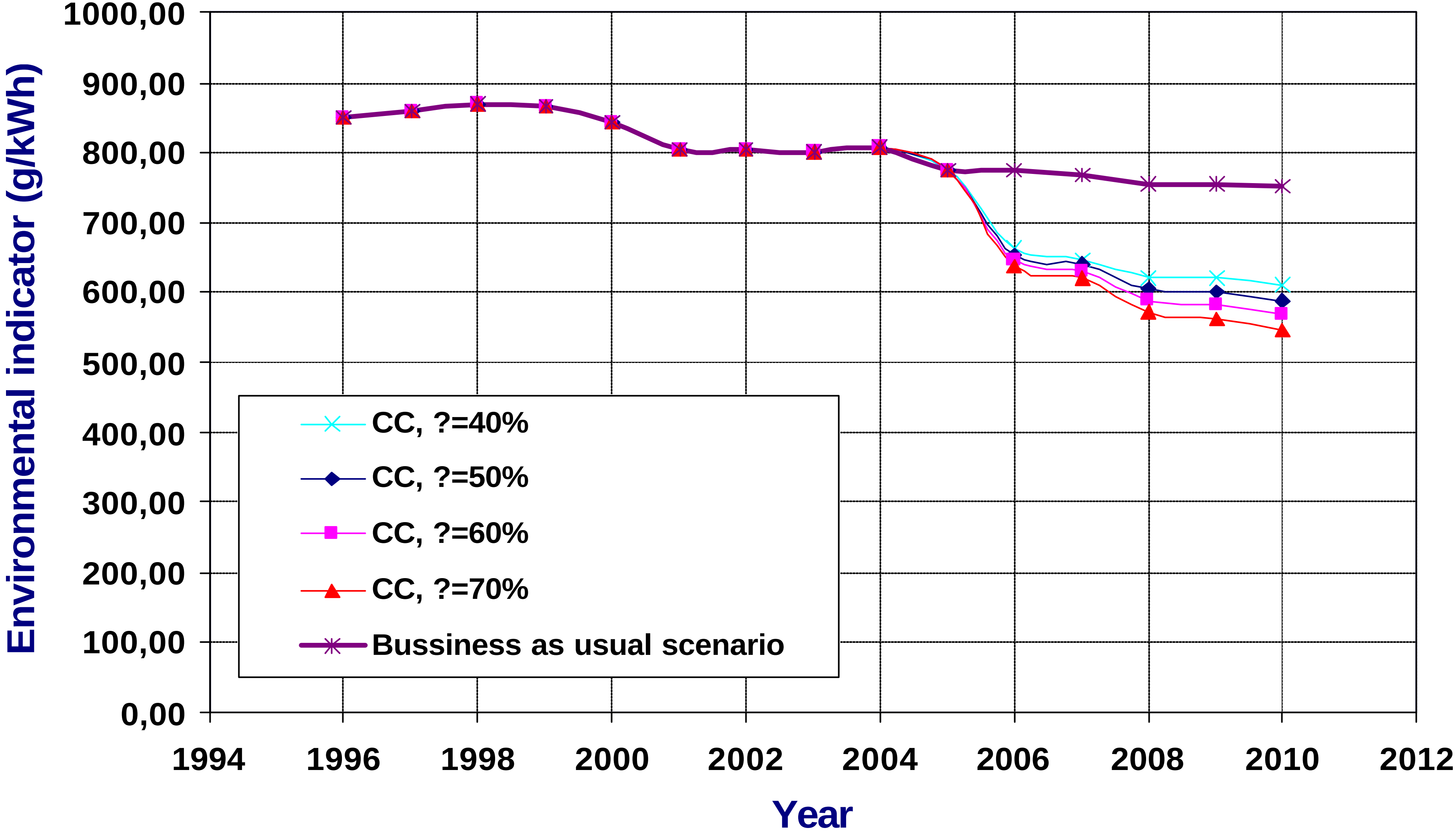


Natural gas combined cycle



CO_2 emissions

CO_2 emissions environmental indicator for natural gas combined cycle



▲ Cost-benefit analysis:

Conventional technologies	**least cost solution**	**HFO steam turbine plant**
Gasoil combined cycle	**least cost solution**	**?> 60%, capital cost 700€/kW - 900€/kW**
Natural gas combined cycle	**least cost technology**	

▲ Reduction of CO_2 emissions by -18 % (year 2010)

5. Case study of LOTHECO cycle*

Combined cycle power plant with integrated low temperature heat (LOTHECO)

Contract No: ENK5-CT2000-00063

*** Poullikkas A., Kellas A.,"The use of sustainable combined cycle technologies in Cyprus: A case study for the use of LOTHECO cycle", *Renewable and Sustainable Energy Reviews,* to appear, 2004.**

Case study of LOTHECO cycle

Objectives

1. Installation of LOTHECO cycle in Cyprus - ?

2. Use of IPP optimization algorithm

3. Foreseen main emissions

Case study of LOTHECO cycle

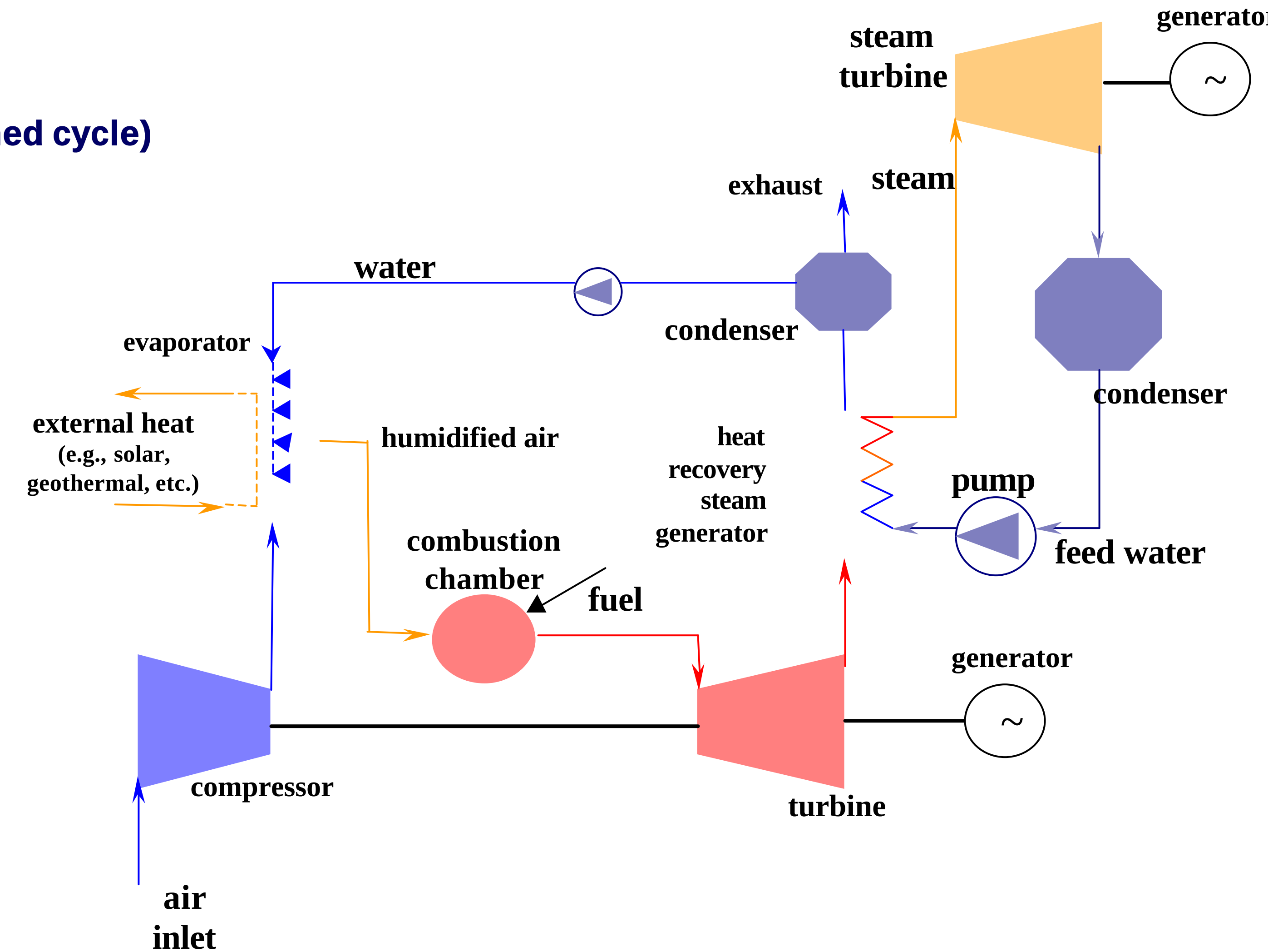
LOTHECO cycle

(Low Temperature HEat COmbined cycle)

Bottoming Rankine cycle

Water recycling

Expected efficiency 60 %



Cost function*

$$\textbf{least cost solution} = \min\left[c_k\right] = \min\left[\frac{C_o + \sum_{j=1}^{n} \frac{C_j}{(1+i)^j}}{P_o + \sum_{j=1}^{n} \frac{P_j}{(1+i)^j}}\right]_k$$

c	:	electricity unit cost for candidate generation technology *k* in €/kWh
C_o	:	production cost of the reference year in €
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P	:	electricity production of year *j* in kWh
i	:	discount rate in %

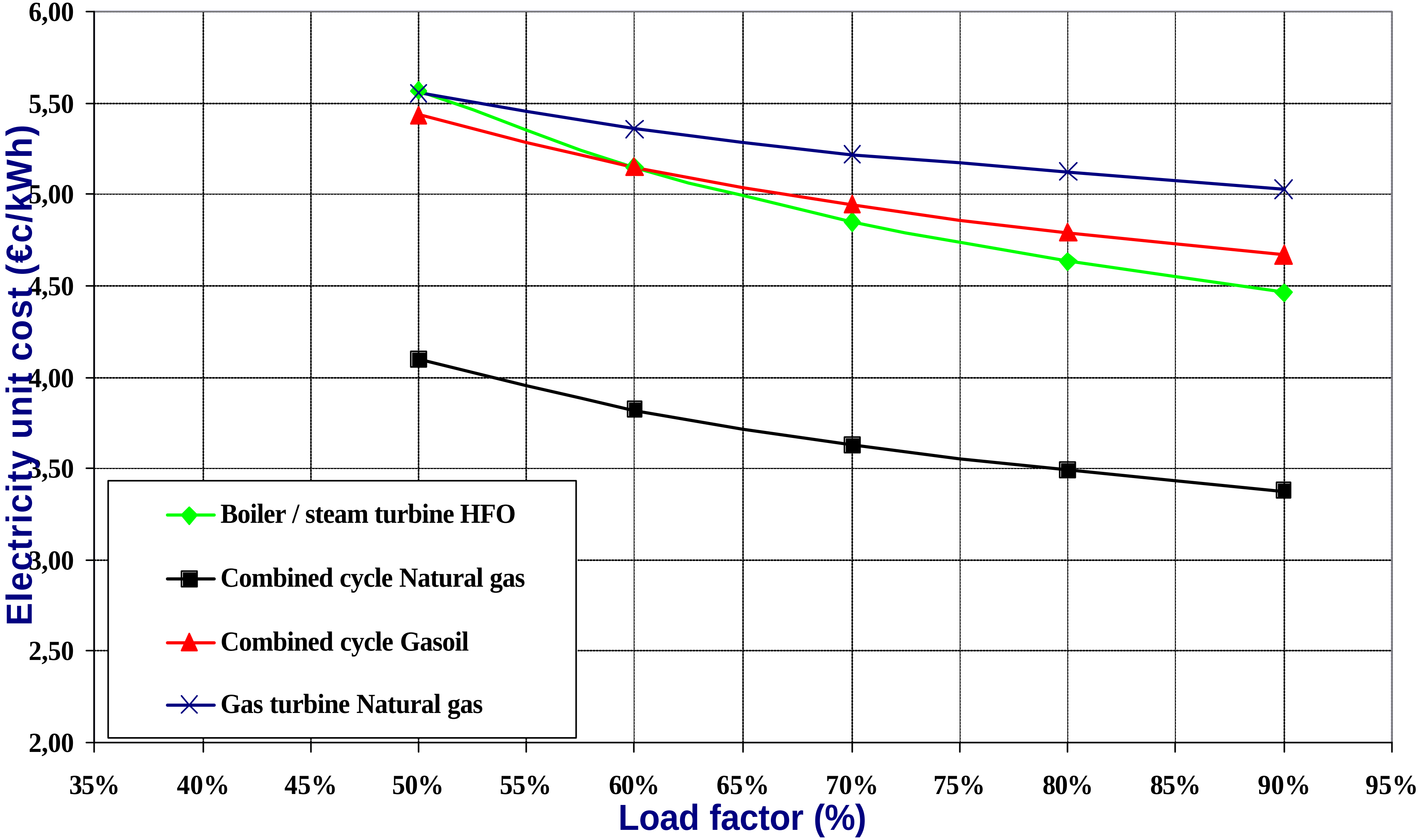
*Poullikkas A., "A technology selection algorithm for independent power producers", *The Electricity Journal*, 2001.

IPP technology selection algorithm

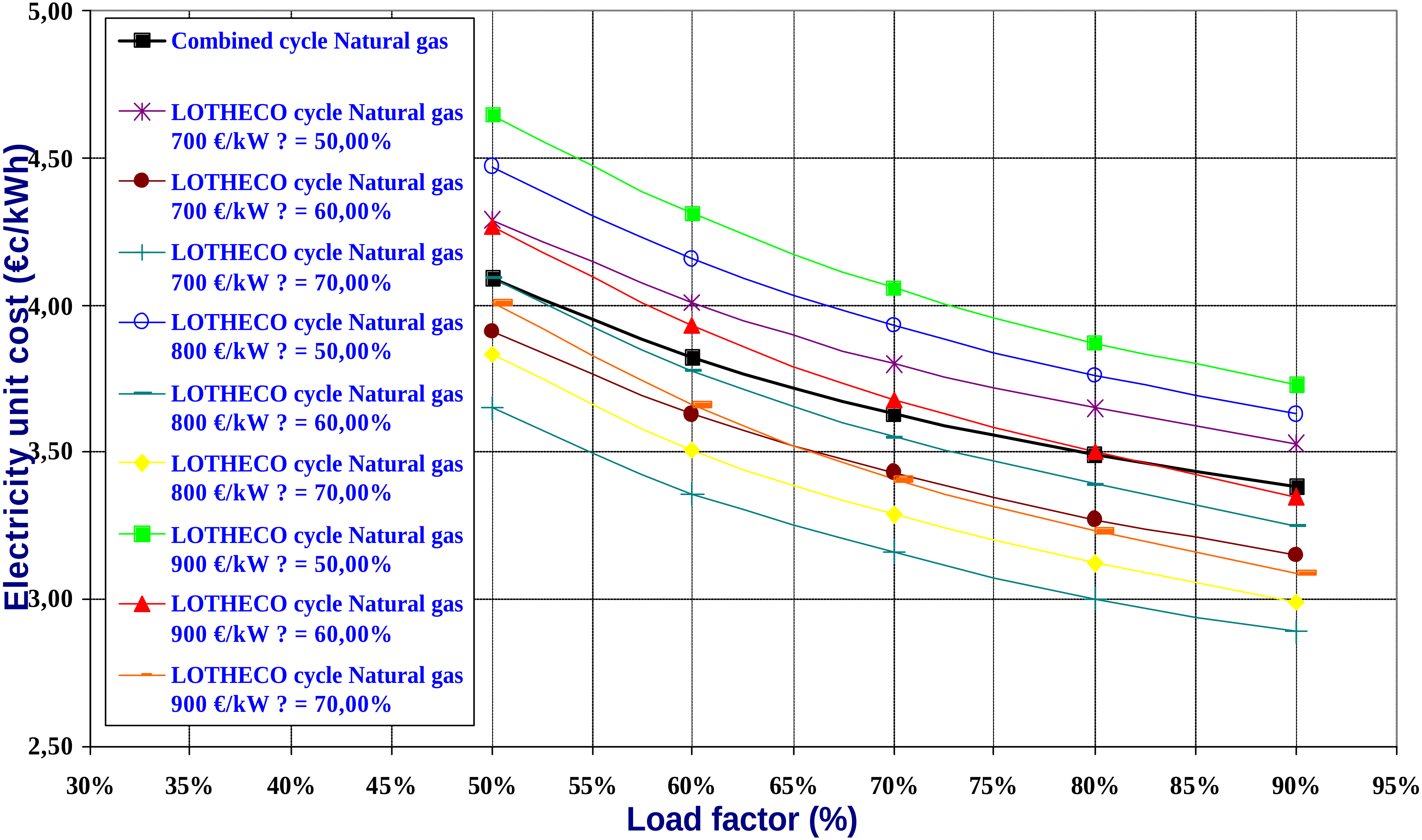
Input Data

Option No	Technology	Fuel type	Capacity	Capital Cost	Efficiency	Fuel net calorific value	Fuel cost		Fixed O&M	Variable O&M
			MWe	€/kW	%	GJ/t	€/t	€/GJ	€/kW-month	€/MWh
1	Boiler / steam turbine	HFO (1% S)	120	1258	37,26	41,3	125	3,03	1,40	1,50
2	Combined cycle	Natural gas	180	686	50,00	45,0	141	3,13	1,25	2,50
3	Combined cycle	Gasoil	180	707	47,27	42,5	190	4,47	1,57	3,20
4	Gas turbine	Natural gas	81	532	28,38	45,0	141	3,13	0,83	4,00
5	LOTHECO cycle	Natural gas	180	700	50,00	45,0	141	3,13	1,63	3,25
6	LOTHECO cycle	Natural gas	180	700	60,00	45,0	141	3,13	1,63	3,25
7	LOTHECO cycle	Natural gas	180	700	70,00	45,0	141	3,13	1,63	3,25
8	LOTHECO cycle	Natural gas	180	800	50,00	45,0	141	3,13	1,63	3,25
9	LOTHECO cycle	Natural gas	180	800	60,00	45,0	141	3,13	1,63	3,25
10	LOTHECO cycle	Natural gas	180	800	70,00	45,0	141	3,13	1,63	3,25
11	LOTHECO cycle	Natural gas	180	900	50,00	45,0	141	3,13	1,63	3,25
12	LOTHECO cycle	Natural gas	180	900	60,00	45,0	141	3,13	1,63	3,25
13	LOTHECO cycle	Natural gas	180	900	70,00	45,0	141	3,13	1,63	3,25

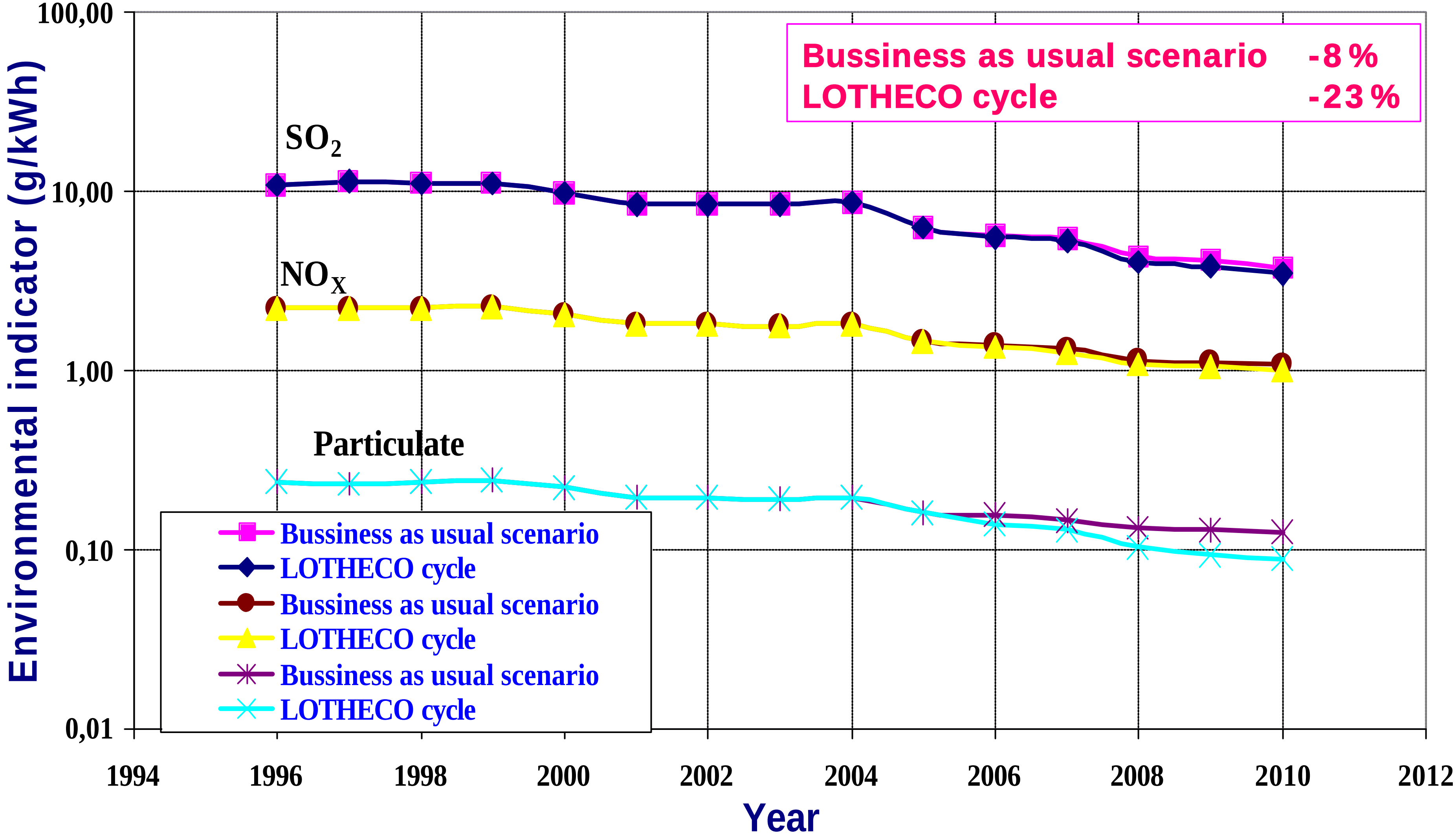
IPP technology selection algorithm



IPP technology selection algorithm

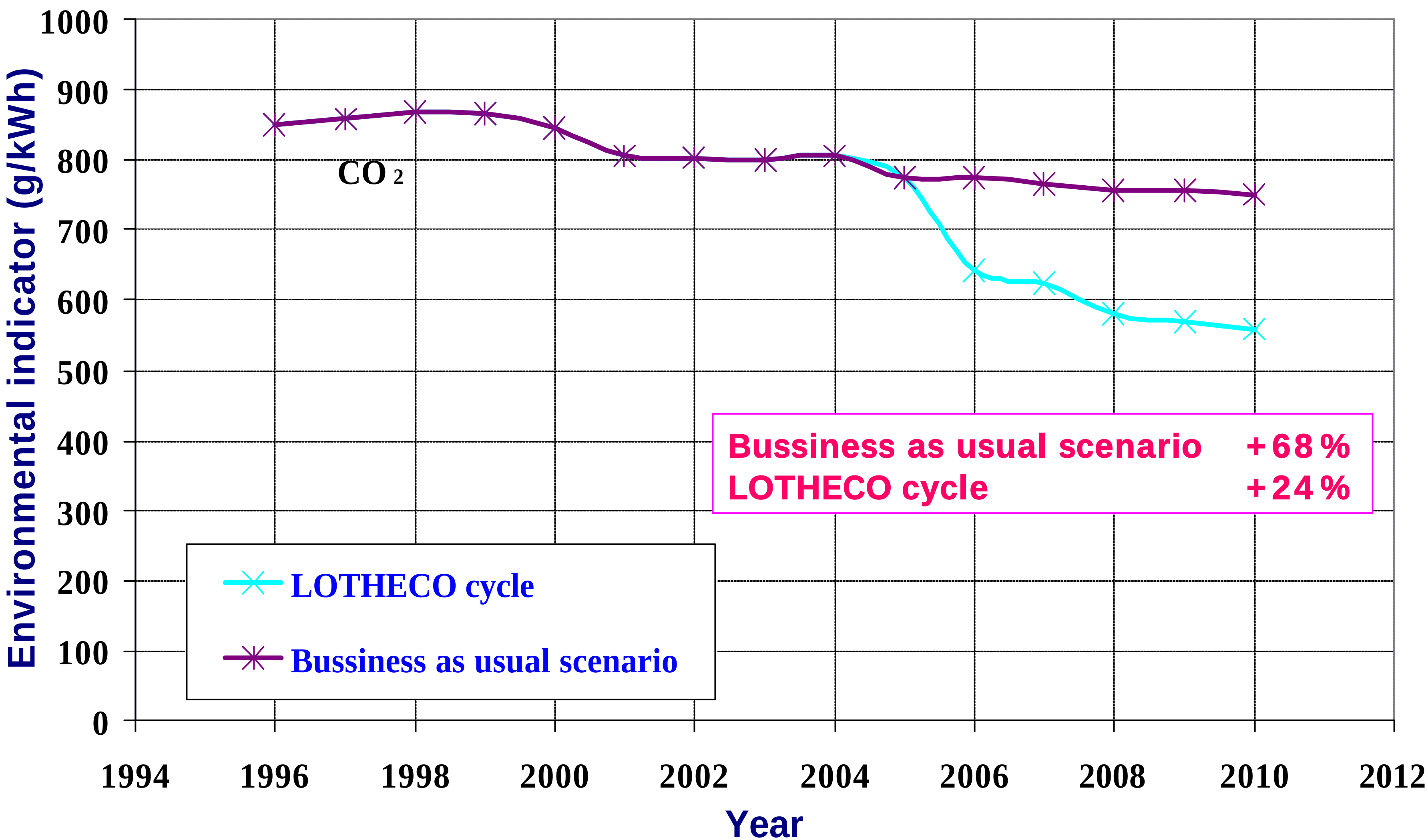


Emissions



Bussiness as usual scenario -8 %
LOTHECO cycle -23 %
SO2
NOX
Particulate
Bussiness as usual scenario
LOTHECO cycle
Bussiness as usual scenario
LOTHECO cycle
Bussiness as usual scenario
LOTHECO cycle
Environmental indicator (g/kWh)
100,00
10,00
1,00
0,10
0,01
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Year

Emissions



1000
900
800
700
600
500
400
300
200
100
0
Environmental indicator (g/kWh)
CO 2
Bussiness as usual scenario +68 %
LOTHECO cycle +24 %
LOTHECO cycle
Bussiness as usual scenario
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Year

- **LOTHECO cycle:**

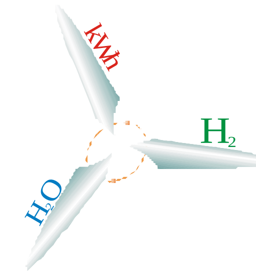
  least cost option when ? > 60 % and capital cost 700-900€ / kW

  reduction in primary emissions by 2010: -23 % (i.o. -8 %)

  reduction in CO_2 emissions by 2010: +24 % (i.o. +68 %)

5. Research on RES, DG and Hydrogen

1. Research projects



- RES - Hydrogen production (2 projects)
- DG (2 projects)

2. EC policy towards hydrogen economy

3. EC vision for power generation

Conclusions

1. The electricity sector in Cyprus

2. Fuel share **(world and Cyprus)**

3. Research and Development within EAC

- **Research on advance GT and CC technologies**
- **Parametric analysis of CC technology in Cyprus**
- **Case study of LOTHECO cycle**
- **Research on RES, DG and Hydrogen**