Politecnico di Torino – Italy
Energy Department

ENERGY EFFICIENCY IN THE INDUSTRIAL SECTOR: STATE OF THE ART AND RELEVANT SOLUTIONS

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Enhancing energy efficiency solutions in the Mediterranean Region

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RES4MED

Summary

- Introduction
- Energy consumption
    - Industrial energy consumption by regions
    - Most energy-intensive industries in the industrial sector
    - Importance of energy efficiency in industry
- Energy management
    - Objectives
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    - EN ISO 50001:2011 - Energy Management Systems
- Energy saving technologies
    - Variable Speed Drive
    - High Efficiency Motors
    - High efficiency air compressors
    - High efficiency lighting systems
    - Waste heat recovery
    - Cogeneration

Introduction

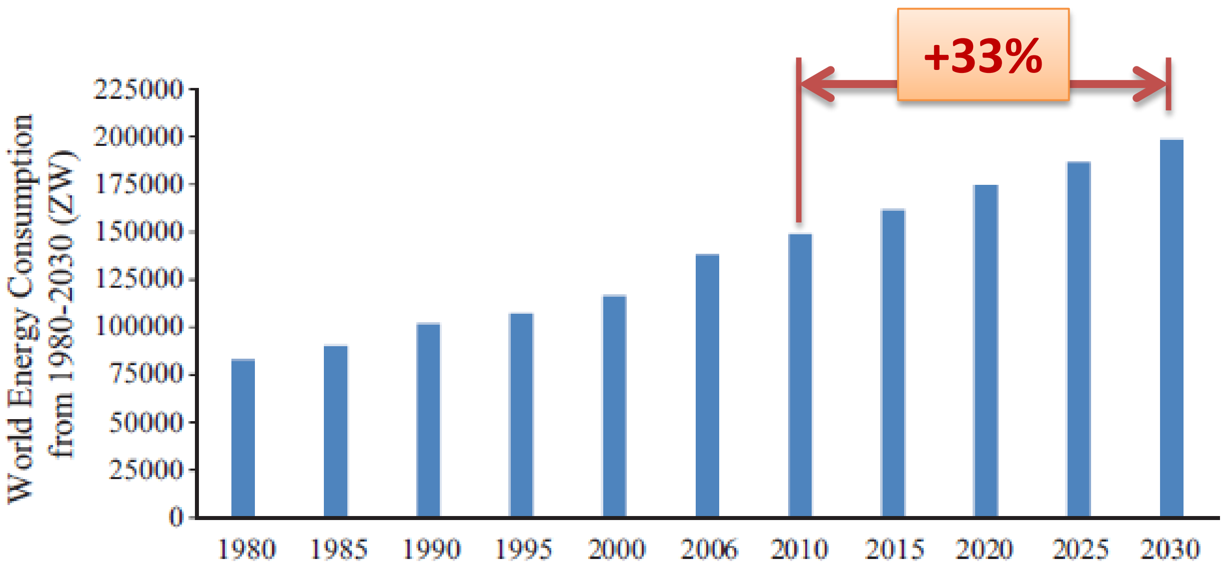
- The industrial sector uses more energy than any other end-use sectors and currently **this sector is consuming about 37% of the world's total delivered energy** [0].
- Energy is consumed in the industrial sector by a diverse group of industries including manufacturing, agriculture, mining, and construction and for a wide range of activities, such as processing and assembly, space conditioning, and lighting.
- Based on energy saving technologies results, it has been found that in the industrial sectors, **a noticeable amount of electric energy, emissions and utility bill can be still saved**
- Payback periods for different energy savings actions have been identified and found to be **economically viable in most cases**.
- This lecture presents a review about industrial energy saving by **management and by technologies:**
  - Energy saving by **management** includes energy audits, training programs, energy management systems (EMS), energy monitoring systems (SCADA)
  - Energy saving **technologies** are, for example, high efficiency motors (HEMs), variable speed drives (VSDs), economizers, systems for leak prevention and for reducing pressure drop, thermal recovery heat exchangers, highly efficient lamps, etc…

[0] E.A. Abdelaziz, R. Saidur, S. Mekhilef – A review on energy saving strategies in industrial sector. Renewable and Sustainable Energy Reviews 15 (2011) 150–168.

Summary

Energy consumption

- Energy is a basic need for different purposes in industrial facilities around the world. Huge amount of energy needed for countries with faster economic growth. Energy is thus a crucial factor for economic competitiveness and employment.
- World energy consumption is projected to **increase by 33% from 2010 to 2030**.
- **Total world energy use has continuously been increasing from the 80's** as shown in Fig. 1 [1].



1 ZW = 10^{21} W

Fig. 1. World marketed energy consumption from 1980 to 2030 (ZW) [1].

[1] U.S Energy Information Administration. International Energy Outlook 2009: World Energy and economic Outlook; 2009, Available Online at: http://www.eia.doe.gov/oiaf/ieo/world.html , http://www.eia.doe.gov/oiaf/ieo/highlights.html , http://www.eia.doe.gov/oiaf/ieo/industrial.html , http://www.eia.doe.gov/emeu/aer/eh/total.html

Energy consumption

- The most rapid growth in energy demand from 2006 to 2030 is projected for nations outside the Organization for Economic Cooperation and Development (non-OECD nations).
- This is because, in recent decades, OECD countries have been undergoing a transition from manufacturing economies to service economies. Total non-OECD energy consumption was increased by 73% compared to a 15% increase in energy use among the OECD countries [1].
- Over the next 25 years, the worldwide industrial energy consumption is projected to grow from 51,275 ZW in 2006 to 71,961 ZW in 2030 by an average of 1.4% per year (Fig. 2) [1,2].

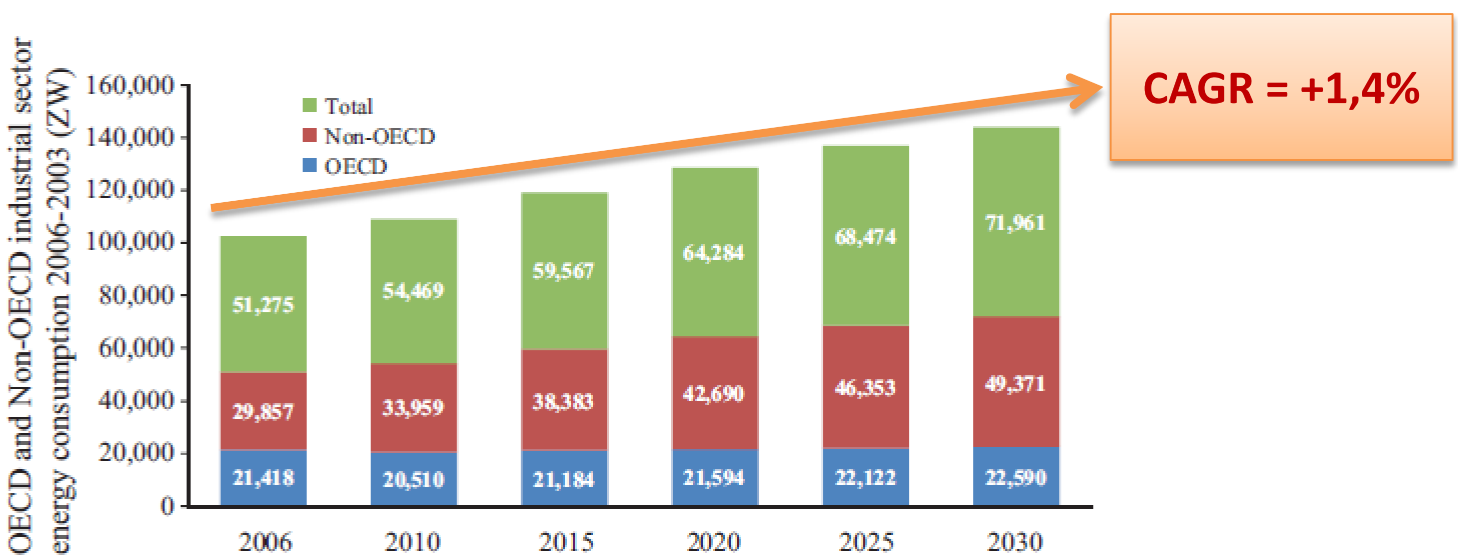


Fig. 2. OECD and non-OECD industrial sector energy consumption from 2006 to 2003 (ZW) [1].

Energy consumption ::: *Industrial energy consumption by Regions*

- Currently, **non-OECD economies consume 62% of global delivered energy in the industrial sector**. By the year 2030, industrial energy use in the non-OECD is expected to grow at an average annual rate of 2.7%.
- **Brazil, Russia, India, and China account for more than two-thirds of the growth in non-OECD industrial energy use** (Fig. 6).

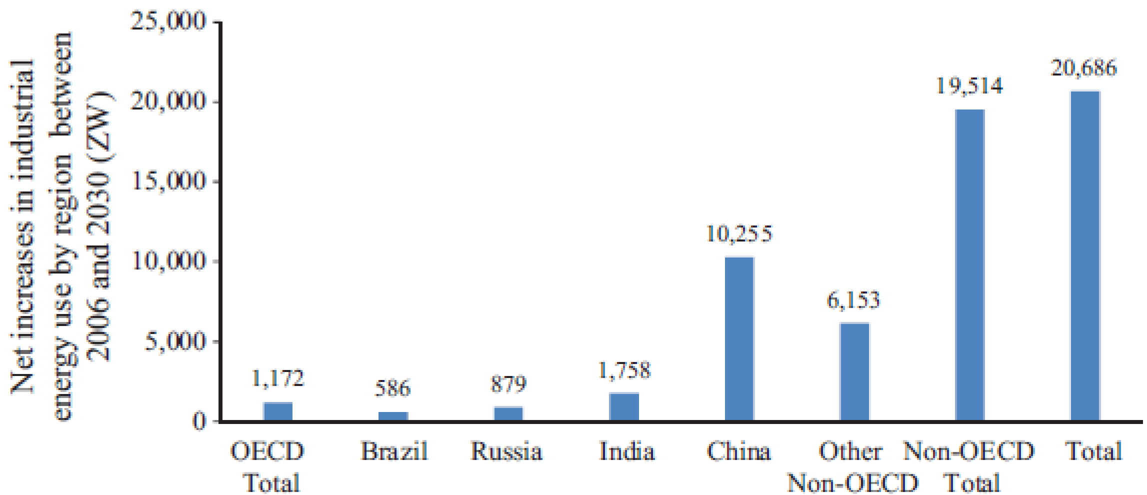


Fig. 6. Net increases in industrial energy use by region between 2006 and2030 (ZW) [1].

Energy consumption ::: *Industrial energy consumption by Regions*

- The **United States** is the largest energy consumer in terms of total use. In 2004, industrial used about 33% of the total energy use (Fig. 8)

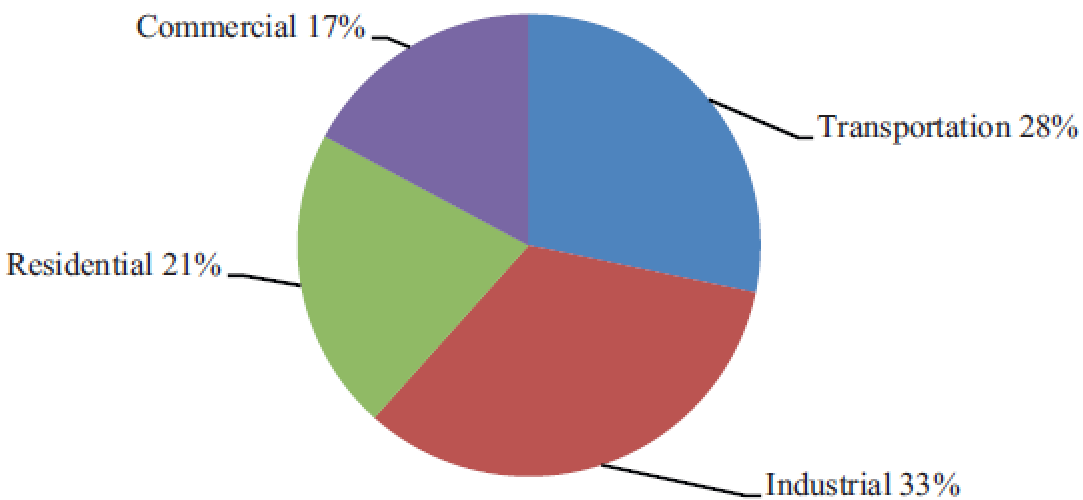


Fig. 8. Percentage of energy consumption by sector in USA in 2004 [1].

- **Most of the energy consumed in the industrial sector in USA is used for manufacturing** (mining, construction, agriculture, fisheries and forestry)

Energy consumption ::: *Industrial energy consumption by Regions*

- **China alone accounts for about 23% of world's industrial energy use**.
- **China's industrial sector is extremely energy-intensive** and accounted for 60% of the country's total energy use in 2000 and **70% in 2003**.
- **Industrial energy use in China grew at an average rate of 5% per year**. This growth is five times faster than the average growth that took place in the industrial sector worldwide during the same time period.
- Energy end use consumptions by sector in China from 1985 to 1997 and 2003 are shown in Figs. 10 and 11 respectively.

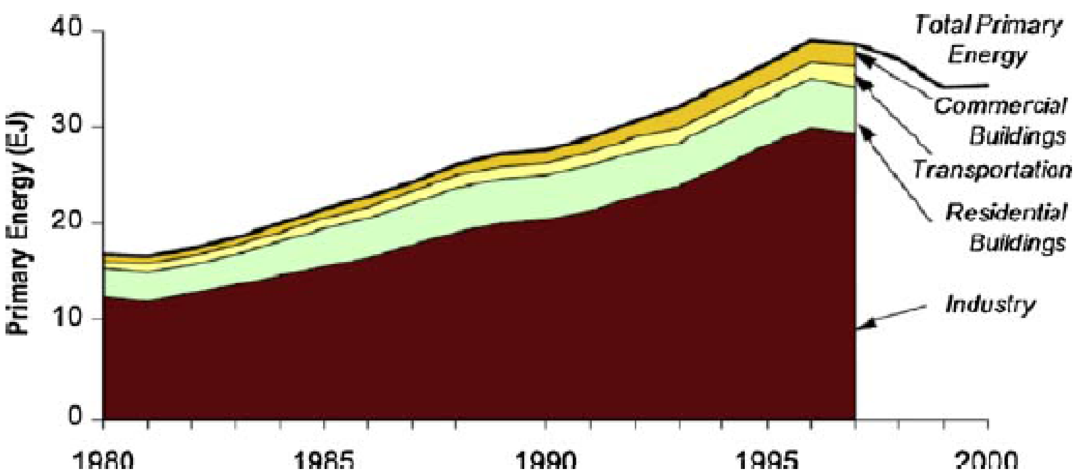


Fig. 10. Total energy consumption by sector in China from 1985 and 199 [4,5,7].

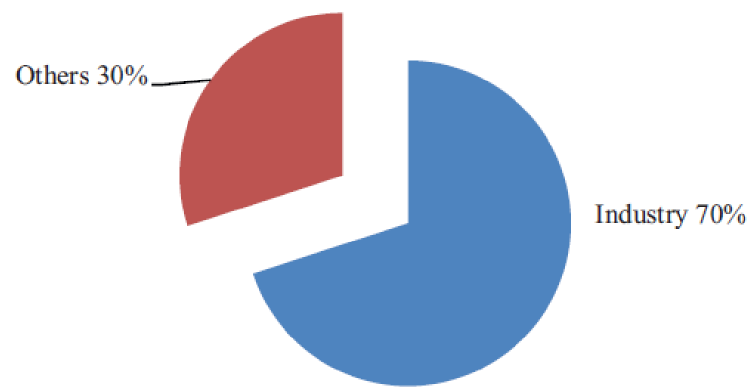


Fig. 11. Share of industry in 2003.

Energy consumption ::: *Most energy-intensive industries in the industrial sector*

- If we consider the 2006 situation, **five industries account for 68% of all energy used in the industrial sector** (Fig. 13): chemicals (29%), iron and steel (20%), nonmetallic minerals (10%), pulp and paper (6%), and nonferrous metals (3%).

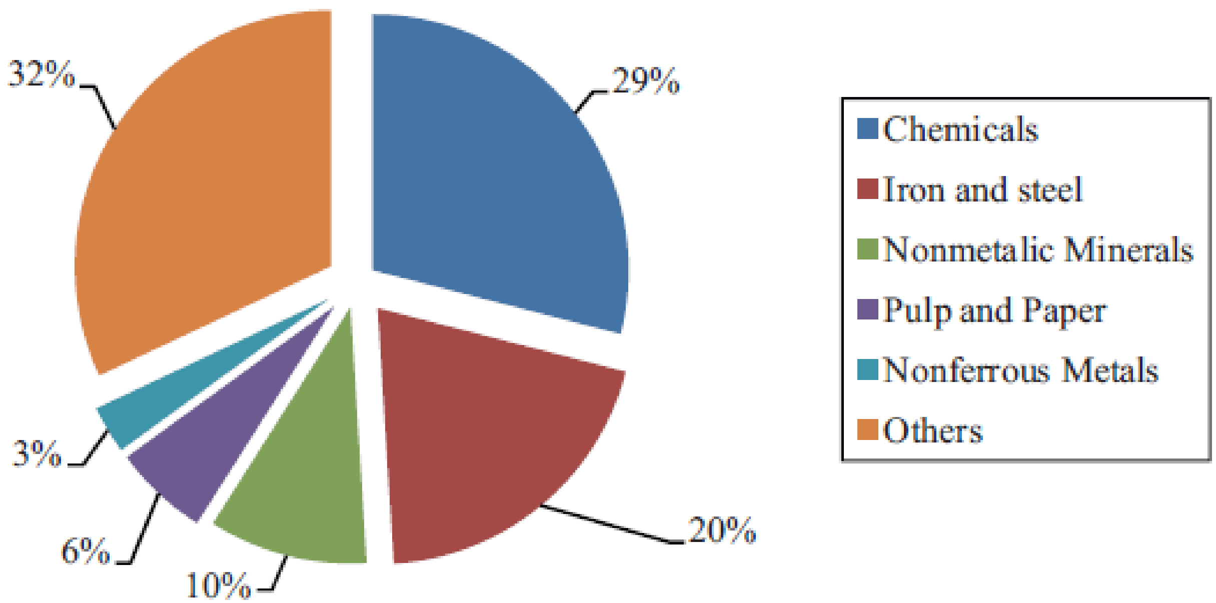


Fig. 13. World industrial sector energy consumption by major energy-intensive industry shares in 2006 [1].

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Energy consumption ::: *Importance of energy efficiency in industry*

- Industrial development across the world will result in more energy use and **will lead to more concentration of greenhouse gases** such as carbon dioxide (CO2) **and other emissions** such as sulfur dioxide (SO2), nitrogen oxide (NOx) and carbon monoxide (CO)
- The Intergovernmental Panel on Climate Change **(IPCC) reported that continued emissions will lead to a temperature increase of between 1.4 and 5.8 °C over the period from 1990 to 2100**
- Furthermore, The Department of Energy (The United States of America) highlighted that, global carbon emissions are rising by more than 2% per year and by 2015 may be more than 50% above the 1997 level, **all of which is because of the increasing energy demand and the inefficient energy use** [9].
- In industry, energy efficiency can be improved by two different approaches as follows:
    - 1. Energy savings **by management**
    - 2. Energy saving **by technologies**

[9] Mahmoud A, Shuhaimi M, Abdel Samed M. A combined process integration and fuel switching strategy for emissions reduction in chemical process plants. Energy 2009;34:190–5

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Summary

Energy management ::: *Objectives*

- Energy management is the **strategy of meeting energy demand when and where it is needed**
- This can be achieved by adjusting and optimizing energy using systems and procedures so as to **reduce energy requirements per unit of output while keeping constant or reducing the total costs of producing the same output**
- Nowadays, the role of energy management has greatly expanded in industries. **Top management of the company participates in planning various energy management projects** on a regular basis.
- The annual reports of the many companies **should mention the details of energy conservation activities** and various achievements by the company regarding energy conservation projects.
- A good energy management should be based on the following aspects:

1. Energy Audits
2. Energy Management System such as EN 50001
3. Energy efficiency courses and training programs
4. Energy Monitoring Systems (SCADA - *Supervisory Control And Data Acquisition*)

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Energy management ::: *EN 16247-1:2012 - Energy Audits*

- Energy audit is an **inspection, survey and analysis** of energy flows for energy conservation **to reduce the amount of energy input into the system without negatively affecting the output**.

- Energy audit is a systematic approach in the industrial sector. It helps any organization to:

  1. analyze its energy use and **discover areas where energy use can be reduced** and waste can occur
  2. **plan and practice feasible energy conservation methods** that will enhance their energy efficiency
  3. **identify all the energy streams in a facility**, quantify energy usage, in an attempt to balance the total energy input with its use

- The main benefits that can be achieved through an accurate Energy Audit are:

  1. **Reduction in specific energy consumption** and environmental pollution.
  2. **Reduction in operating costs** (approximately 20–30%) by systematic analysis.
  3. **Improvement in the overall performance of the total system** and its productivity.
  4. To avert **equipment failure**.

Energy management ::: *EN 16247-1:2012 - Energy Audits*

Typical energy audit program

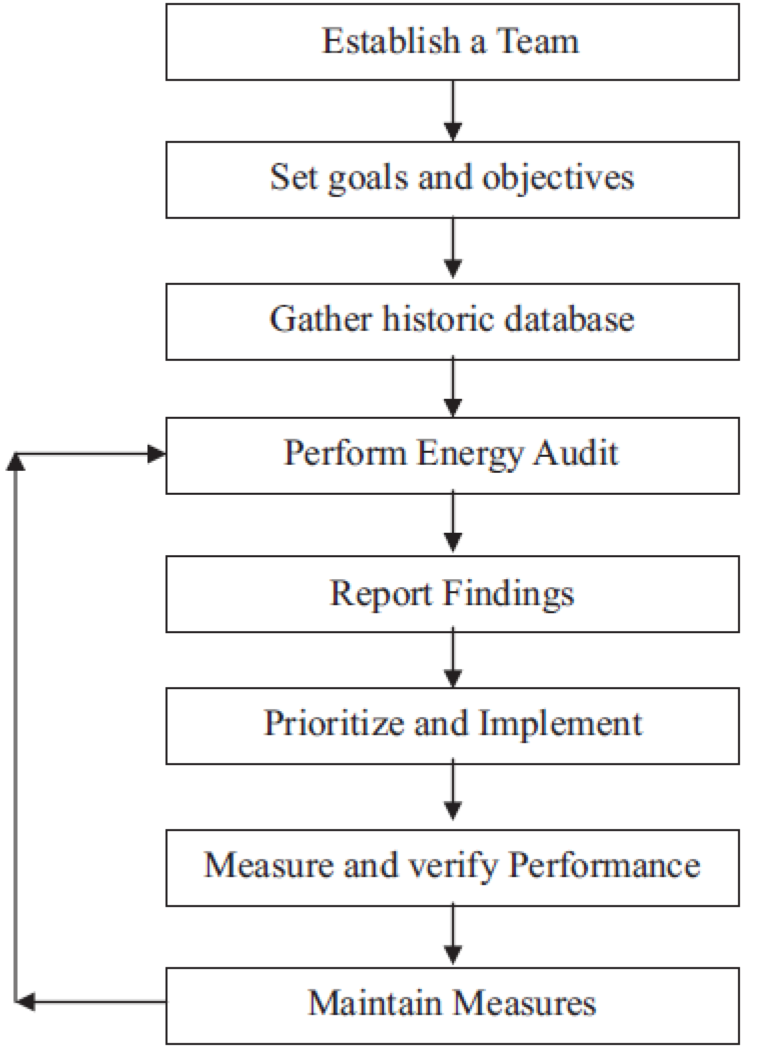


Fig. 15. Typical energy audit program [15].

Energy management ::: *EN 16247-1:2012 - Energy Audits*

- At European level, the **Standard EN 16247:2012 is the reference for the realization of Energy Audits**
- The definition of the Audit given in the Standard is "*a systematic inspection and analysis of energy use and energy consumption of a site, building, system or organization with the objective of identifying energy flows and the potential for energy efficiency improvements*"
- The energy audit process should be:

  a) **appropriate**: suitable for the agreed scope, aims and thoroughness;

  b) **complete**: in order to define the audited object and the organization;

  c) **representative**: in order to collect reliable and relevant data;

  d) **traceable**: in order to trace the origin and processing of data;

  e) **useful**: in order to include a cost effectiveness analysis of the energy saving opportunities identified;

  f) **verifiable**: in order to allow the organization to monitor the achievement of the targets of implemented energy efficiency improvement opportunities.

Energy management ::: *EN 16247-1:2012 - Energy Audits*

- The energy auditor should, in cooperation with the organization, collect the following (where available):

  a) **list of energy using systems, processes and equipment**;

  b) detailed characteristics of the audited object(s) including known **adjustment factors** and how the organization believes they influence energy consumption;

  c) **historical data**:

    1. energy consumption;
    2. adjustment factors;
    3. relevant related measurements.

  d) operational history and past events that could have affected energy consumption in the period covered by the data collected;

  e) design, **operation and maintenance documents**;

  f) energy audits or previous studies related to energy and energy efficiency;

  g) current and projected tariff, or a reference tariff to be used for the protection of commercial confidence;

  h) other relevant economic data;

  i) the status of the energy management system.

Energy management ::: *EN 16247-1:2012 - Energy Audits*

- **The Analysis phase**: the energy auditor should establish the **existing energy performance situation** of the audited object (**baseline**).
- **The existing energy performance situation becomes a reference against which improvements can be measured**. It should include:
    a) a **breakdown of the energy consumption by use and source**;
    b) **energy flows and an energy balance** of the audited object;
    c) **pattern of energy demand in time**;
    d) relationships between **energy consumption and adjustment factors**;
    e) one or more **Energy Performance Indicators (EnPis)** suitable to evaluate the audited object.
- Based on the existing energy performance situation of the audited object, the energy auditor should **identify energy efficiency improvement opportunities**.

Energy management ::: *EN 16247-1:2012 - Energy Audits*

- The energy auditor should evaluate the impact of each energy efficiency improvement opportunity on the existing energy performance situation based on:

  a) the **financial savings** enabled by the energy efficiency improvement measures;

  b) the **necessary investments**;

  c) the **return on investment** or any other economical criteria agreed with the organization;

  d) The **other possible non-energy gains** (such as productivity or maintenance)

  e) A comparison in terms of both cost and energy consumption between alternative energy efficiency improvement measures

- Energy saving actions should be **ranked considering the agreed upon criteria (e.g: SPB, NPV, etc…)**.

Energy management ::: *EN 16247-1:2012 - Energy Audits*

PLANNING INPUTS

- Past and actual energy consumptions
- Variables that mainly affect energy consumptions (adjustment factors)
- Process efficiency

ENERGY REVIEW

A. Energy consumption analysis

B. Identification of the most energy intensive areas

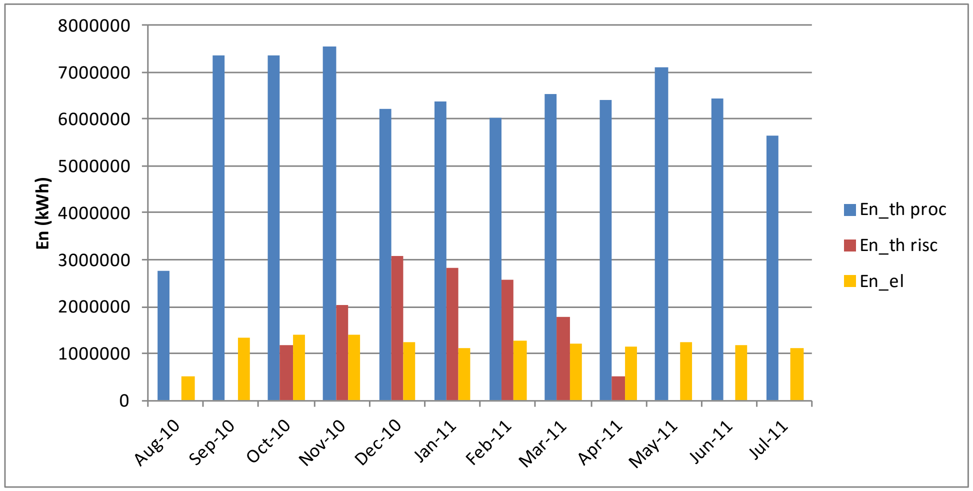
C. Assessment of energy saving actions

PLANNING OUTPUTS

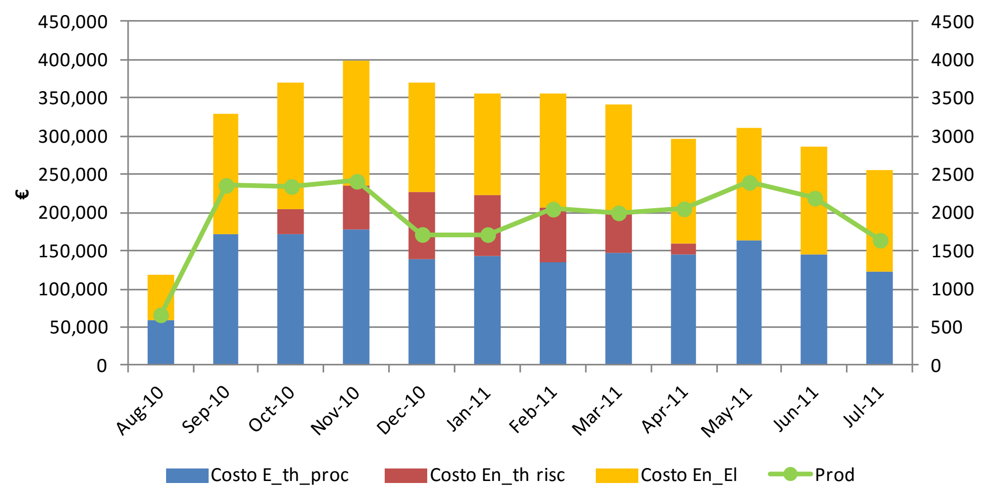
- Existing energy performance situation (baseline)
- Electrical and thermal balance of the plan
- Energy Performance Indicators (EnPIs)
- Energy saving actions
- Energy policy

Energy Audit boundary

Energy management ::: *EN 16247-1:2012 - Energy Audits*



Monthly energy consumptions



Monthly energy costs

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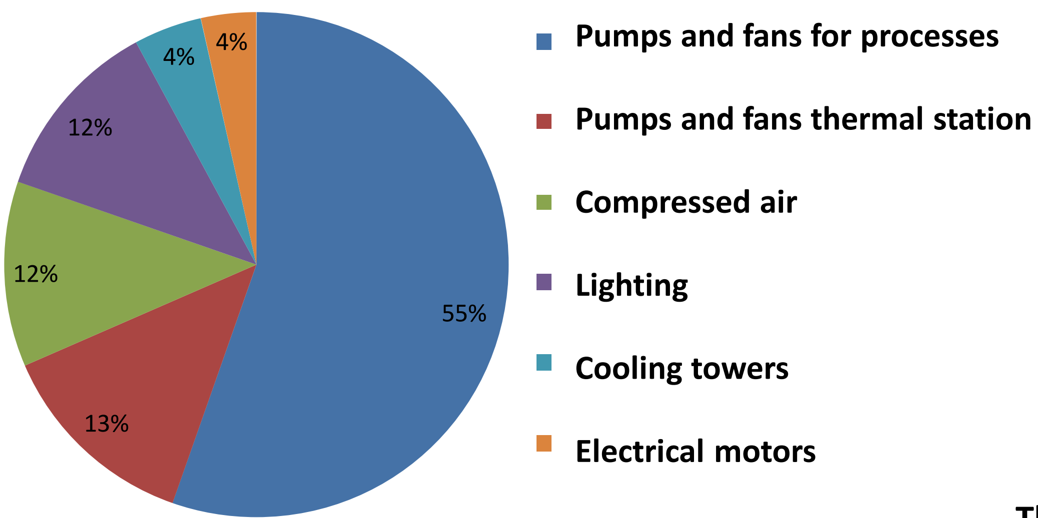
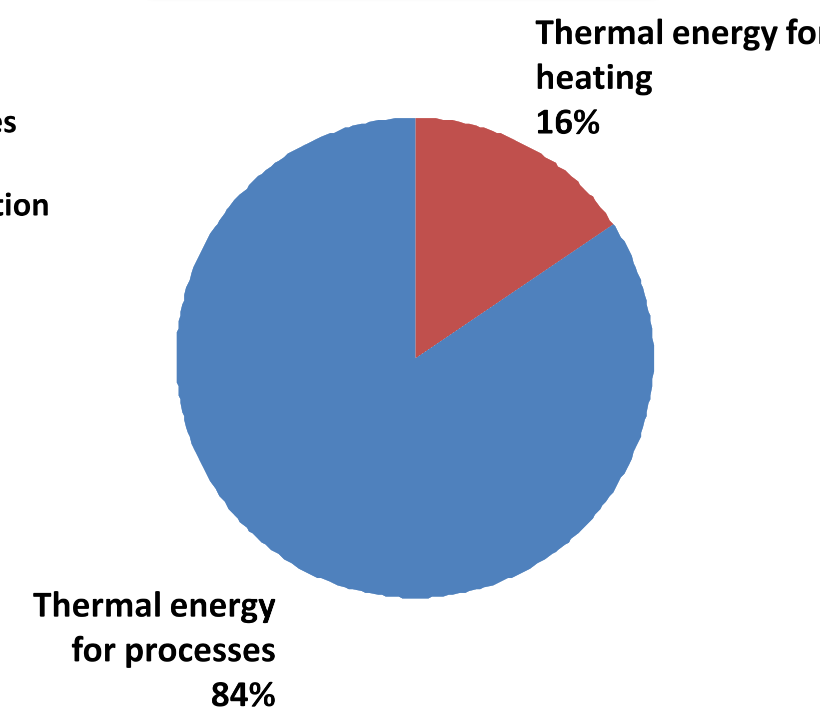
Energy management ::: *EN 16247-1:2012 - Energy Audits*

Electrical consumptions share

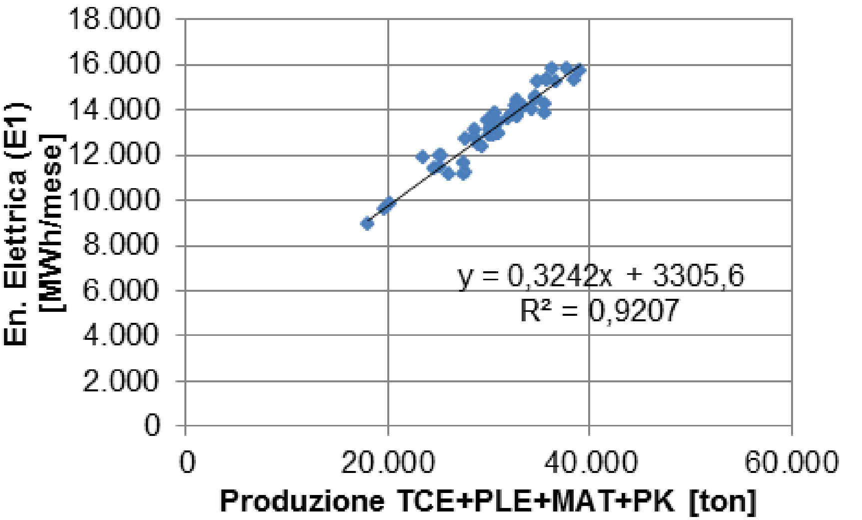


Thermal consumptions share

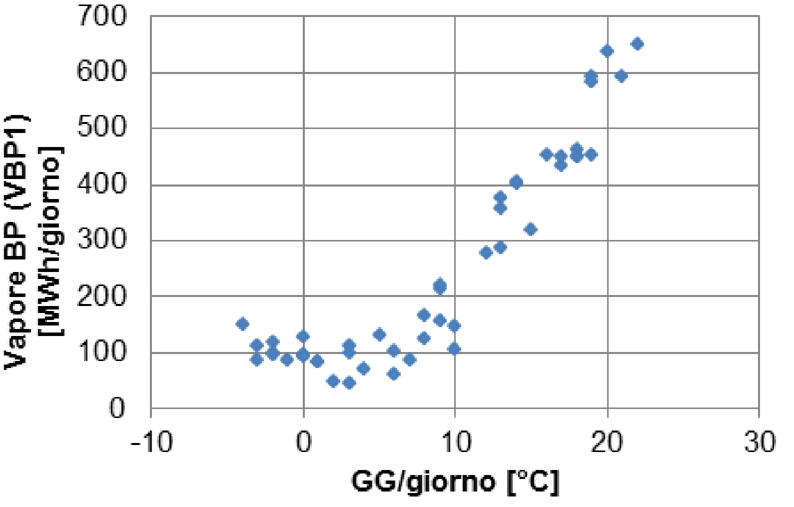


Energy management ::: *EN 16247-1:2012 - Energy Audits*

Regression analysis between electrical energy consumption and monthly production



Regression analysis between thermal energy consumption and degree days



Energy management ::: *EN 16247-1:2012 - Energy Audits*

- Some example of independent variables that can be used in the EnPIs evaluation:
  - Turnover
  - Number of employees
  - Production (t, m2, n° items)
  - Surfaces, volumes

- Why should we use EnPIs?
  1. Benchmark between energy performance of different companies in the same industry sector
  2. To check whether the implemented energy savings actions returned to the expected results in time

Energy management ::: *Energy Audit*

- Some example of EnPIs:

$$EnPI_{El} = \frac{EnEl[kWh]}{Production[t]}$$

Specific consumption of Electricity

$$EnPI_{AC} = \frac{EnEl[kWh]}{AC[m^3]} \times \frac{AC[m^3]}{Production[t]}$$

Specific consumption of Compressed air

$$EnPI_{Th\_p} = \frac{EnTh\_p[kWh]}{Production[t]}$$

Specific consumption of thermal energy for process

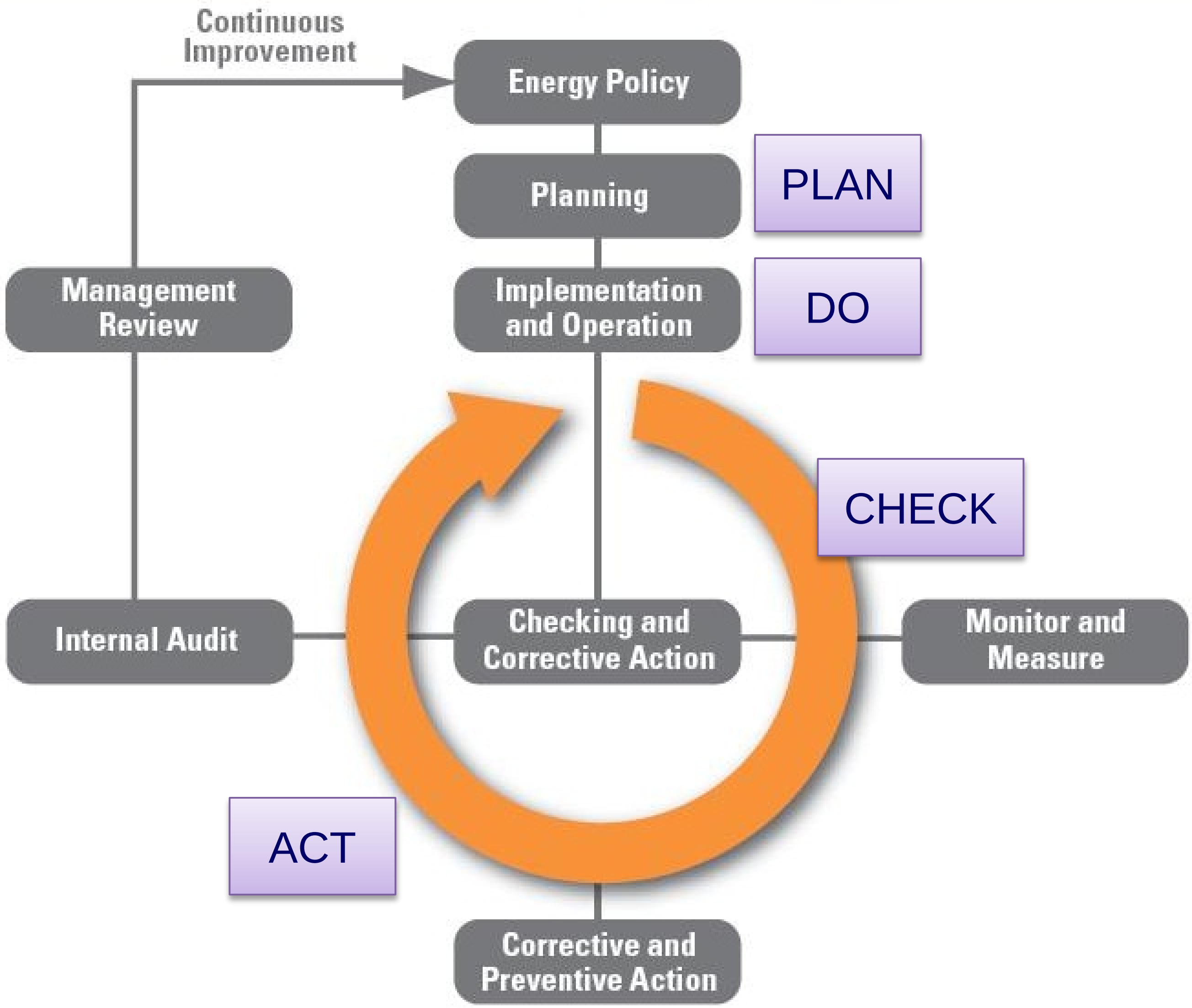
$$EnPI_{Th\_h} = \frac{EnTh\_h[kWh]}{V[m^3] * DD[°C]}$$

Specific consumption of thermal energy for heating

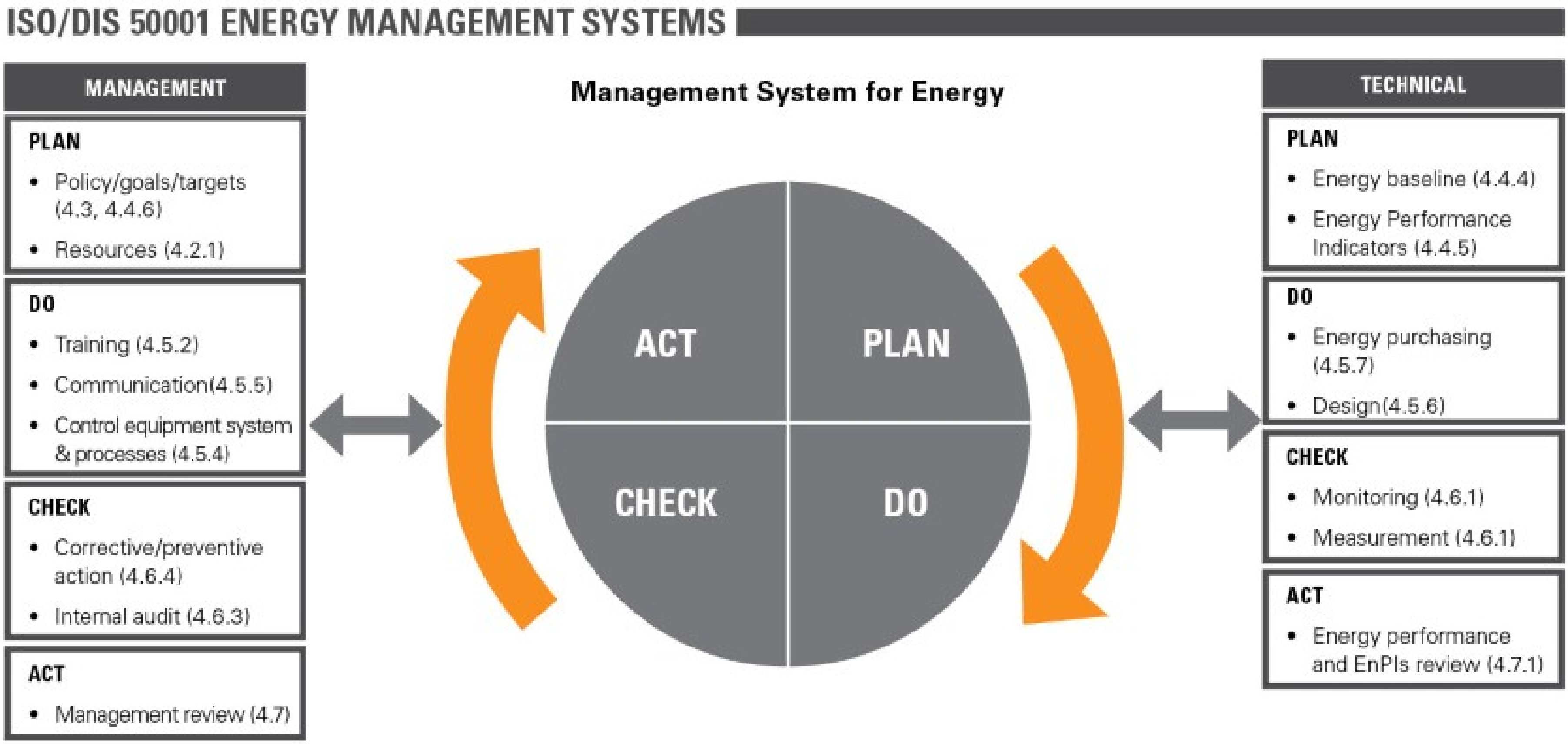
Energy management ::: *EN 50001:2011 - Energy management systems*

- **European Standard for Energy Management Systems (EnMS)**
- The purpose of this International Standard is **to enable organizations to establish the systems and processes necessary to improve energy performance**
- This International Standard is **applicable to all types and sizes of organizations**, irrespective of geographical, cultural or social conditions.
- An EnMS enables an organization to achieve its policy commitments, to improve its energy performance and demonstrate the conformity of the system to the this International Standard.
- EN 50001 is based on the **Plan - Do - Check - Act (PDCA) continual improvement framework:**
    - **Plan**: conduct the Energy Audit and establish the baseline, energy performance indicators (EnPIs), objectives, targets and action plans necessary to deliver results that will improve energy performance in accordance with the organization’s energy policy;
    - **Do**: implement the energy management action plans;
    - **Check**: monitor and measure the achieved energy performance against the energy policy and targets, and report the results;
    - **Act**: take actions to continually improve energy performance and the EnMS

Energy management ::: *EN ISO 50001:2011 - Energy management systems*



Energy management ::: *EN ISO 50001:2011 - Energy management systems*



Summary

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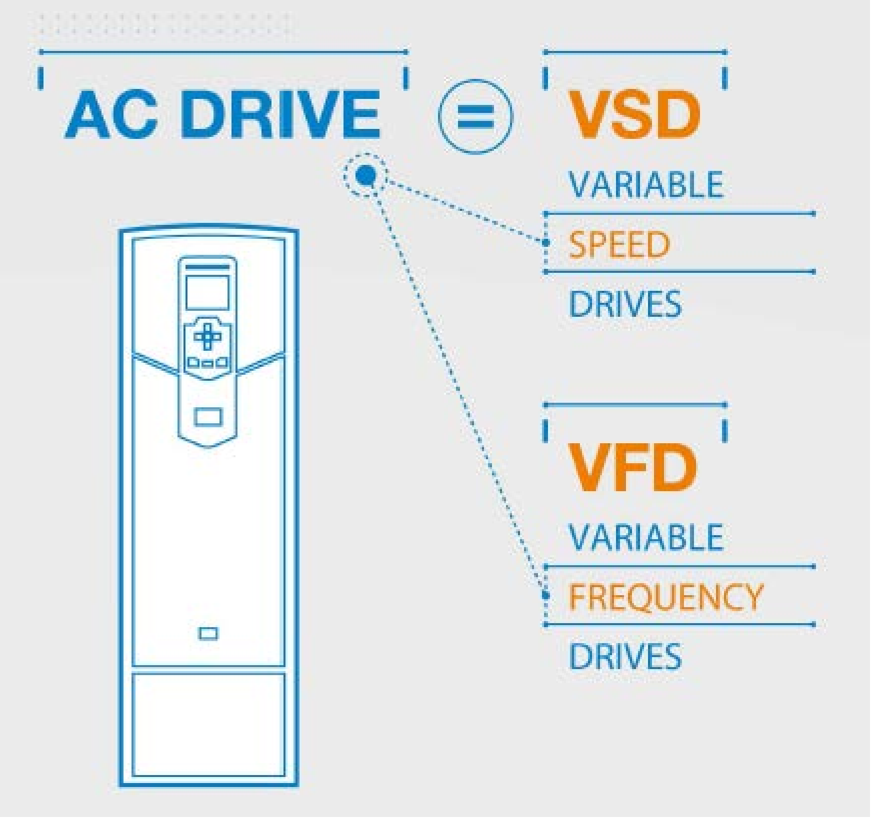
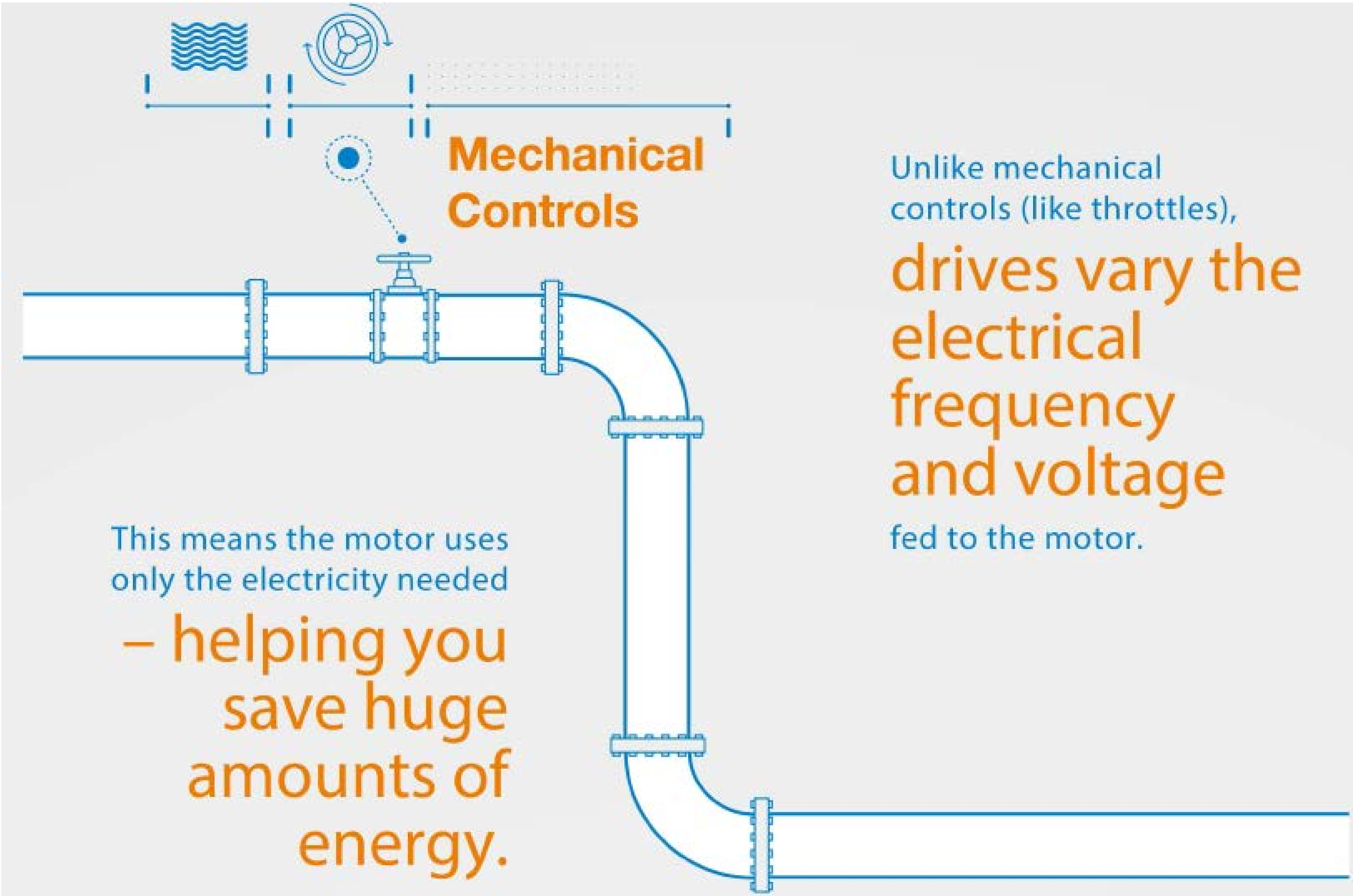
- Energy saving technologies
  - Variable Speed Drives
  - High Efficiency Motors
  - High efficiency air compressors
  - High efficiency lighting systems
  - Waste heat recovery
  - Cogeneration

Energy saving technologies ::: *Variable speed drives*

- A variable speed drive is an electronic power converter that generates a variable frequency output that can be **used to modulate and control the motor's speed**, torque and mechanical **power output**.
- This application offers a **significant energy saving** if applied in many industrial applications



Energy saving technologies ::: *Variable speed drives*



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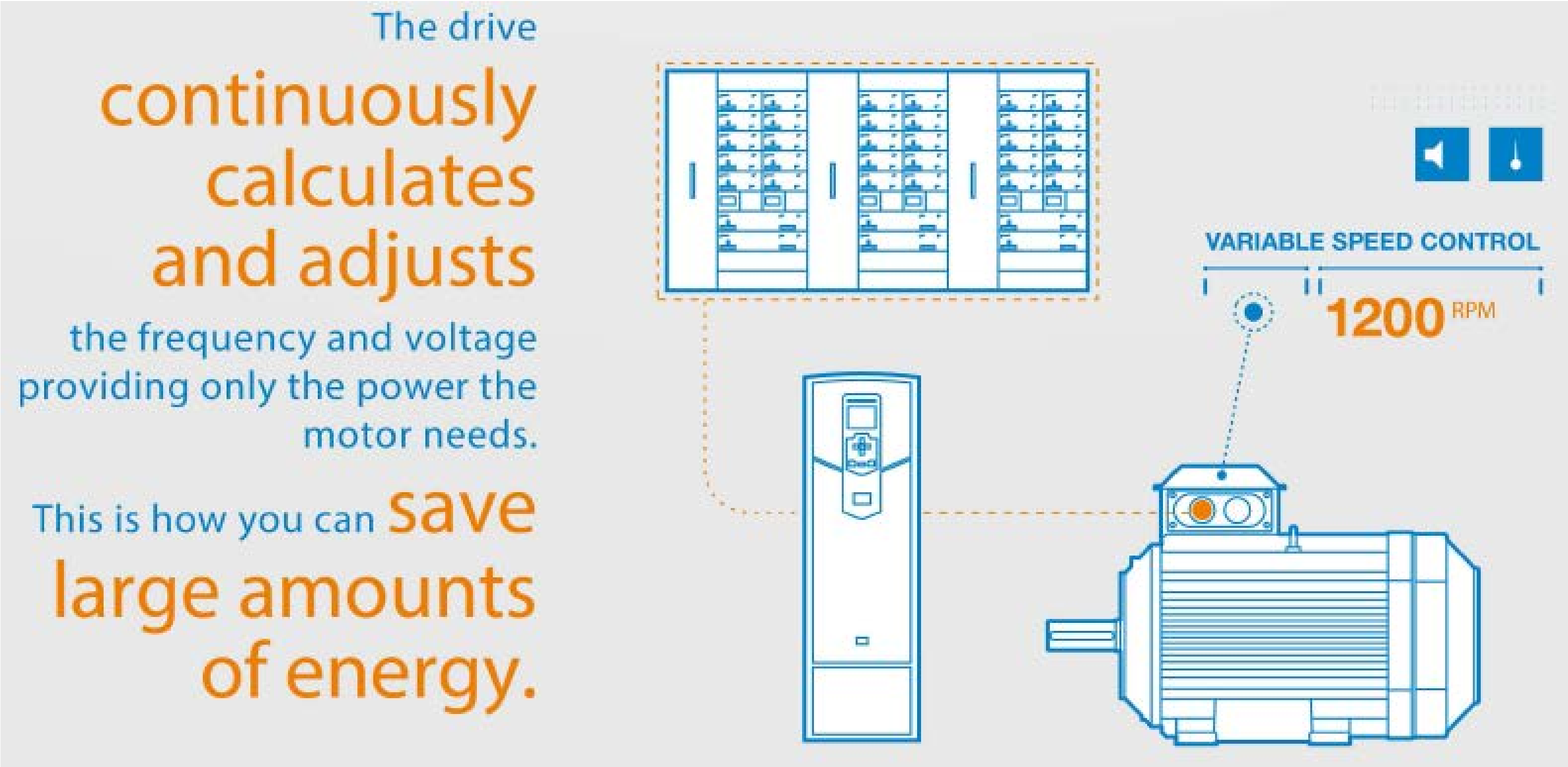
Energy saving technologies ::: *Variable speed drives*



Energy saving technologies ::: *Variable speed drives*

Fans driven by VSD

Inverter to modulate the motor's speed

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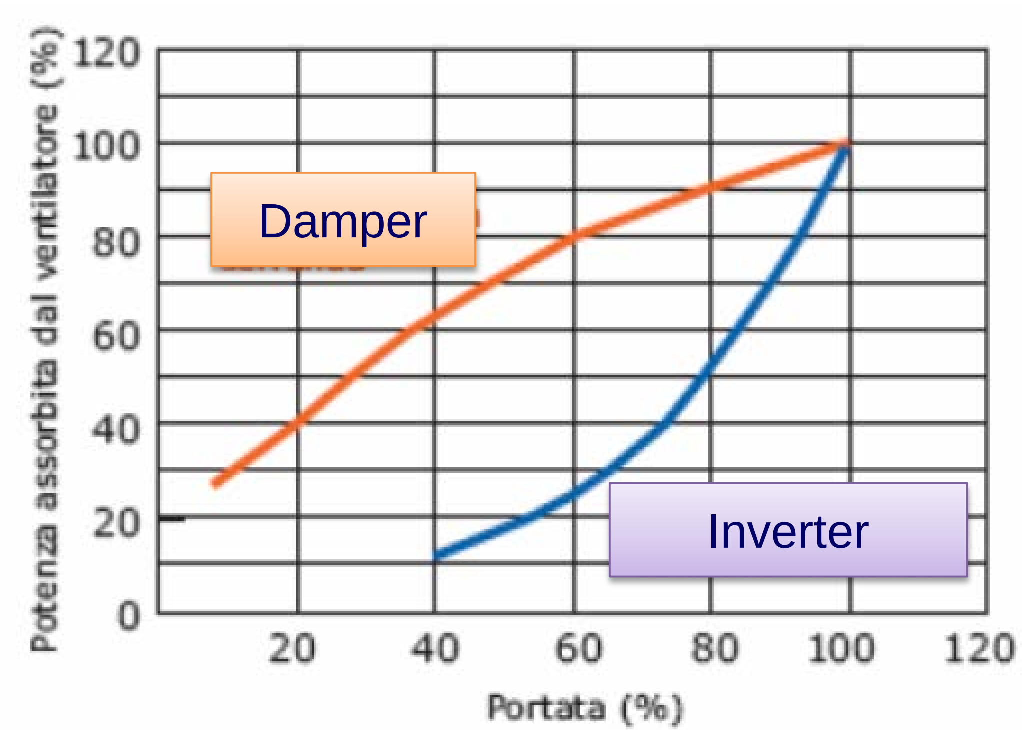
Energy saving technologies ::: *Variable speed drives*

- Two different techniques for regulating a fan flow are shown:
    - A damper
    - A Variable Speed Drive



A reduction of fan power from 80% to 25% is obtained at 60% of nominal fan load!!

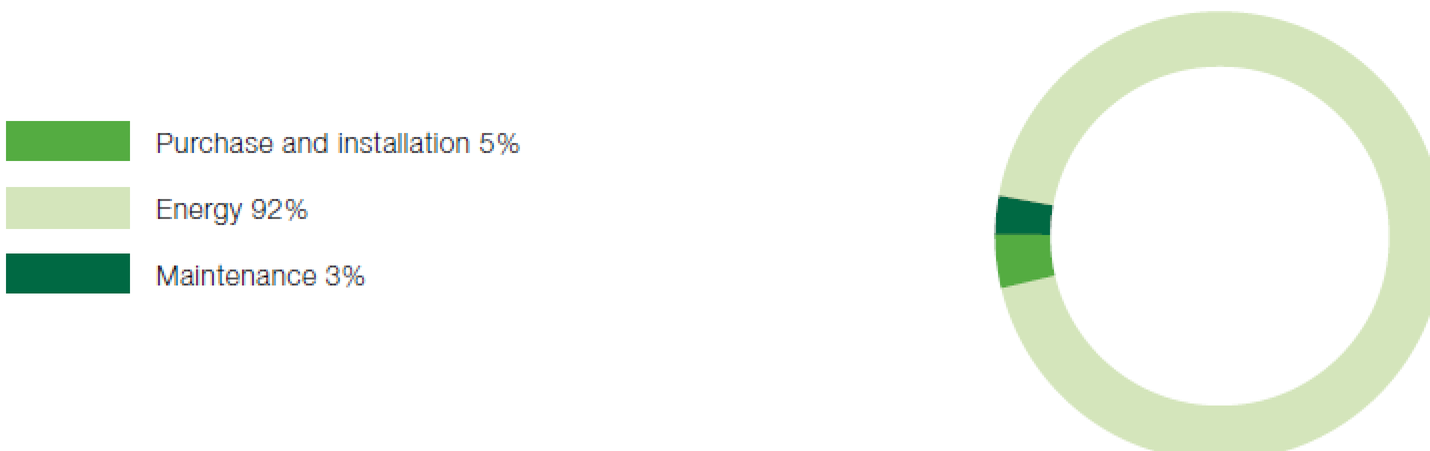
Energy saving technologies ::: *Variable speed drives*

- Typical applications that benefit from variable-speed drives:
    - Pumps
    - Fans
    - Air handling units (AHUs)
    - Compressors
    - Chillers
    - Cooling tower fans
    - Control valves
    - …

Energy saving technologies ::: *High Efficiency Motors*

- **Life Cycle Cost Analysis**: involves the analysis of the costs of a system or a component over its entire life span. Typical costs for a system may include:
  - Purchase and installation
  - Energy consumption
  - Maintenance
- **The purchase price of a motor is only 5% of its life-cycle cost. The greatest part is its energy consumption over the whole life**

Main elements of life cycle costs for a motor and drive *



* Typical life cycle cost when retrofitting a new motor and drive to an existing system

Energy saving technologies ::: *High Efficiency Motors*

- It has been estimated that **electric motors account for about 65% of the electricity consumed in industrial applications**, so the energy saving potential among industries is enormous.
- Energy consumption is dependent on the kW rating of the motor, loading, and the hours run.

$$\mathbf{E} = \frac{\mathbf{P} * \mathbf{h} * \mathbf{f}}{\eta}$$

- The International Electrotechnical Commission (IEC) has introduced standards relating to energy efficient motors.
- IEC 60034-2-1 specifies rules concerning efficiency testing methods and **IEC 60034-30 defines efficiency classes for a wide range of electric motors**

2.1.1 IEC efficiency classes

IEC 60034-30-1 defines four IE (International Efficiency) classes for all electric motors that are rated for sinusoidal voltage.

Standard efficiency	IE1
High efficiency	IE2
Premium efficiency	IE3
Super premium efficiency	IE4

Energy saving technologies ::: *High Efficiency Motors*

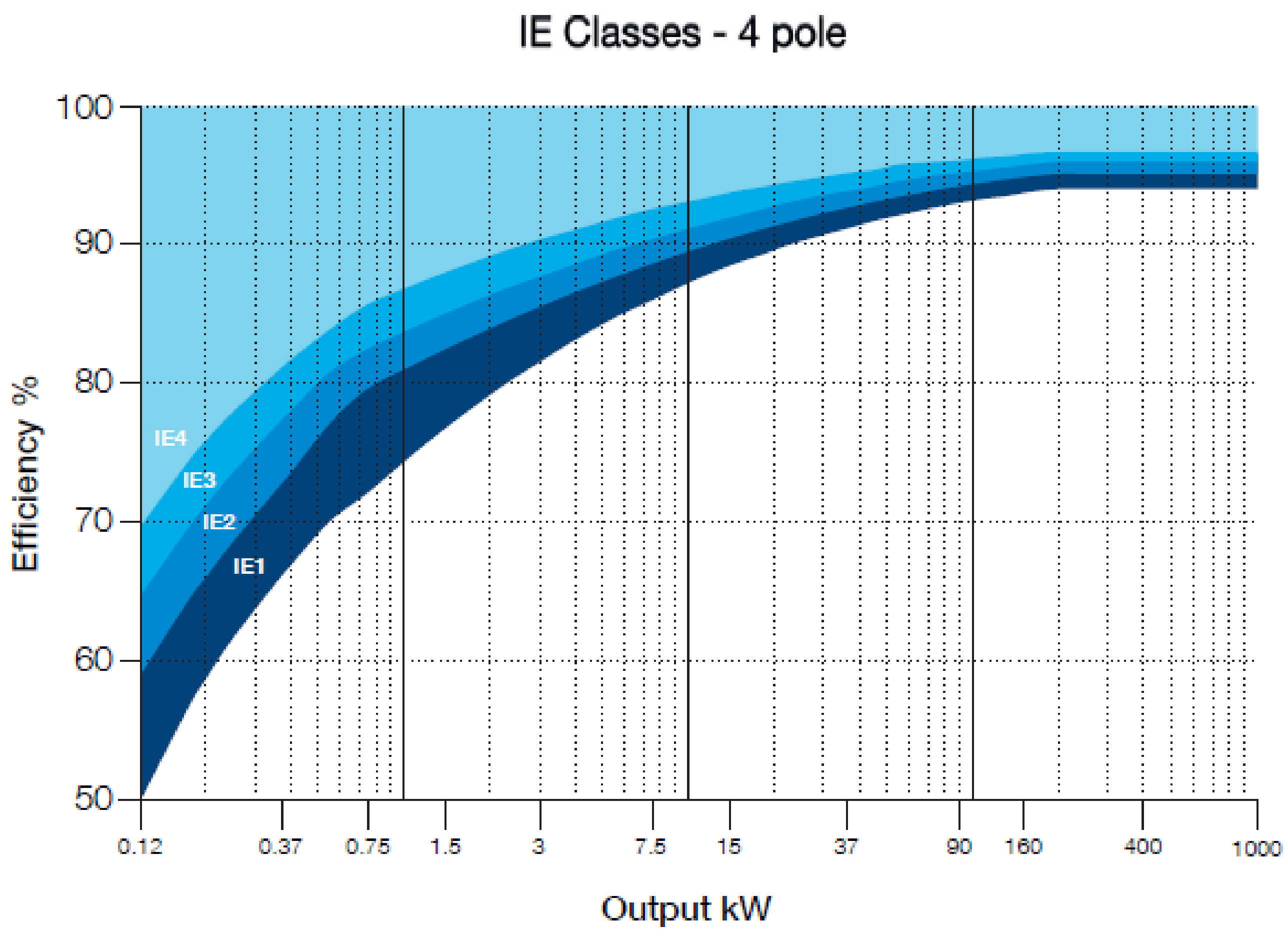


Figure 2.1 IE efficiency classes for 4-pole motors at 50 Hz

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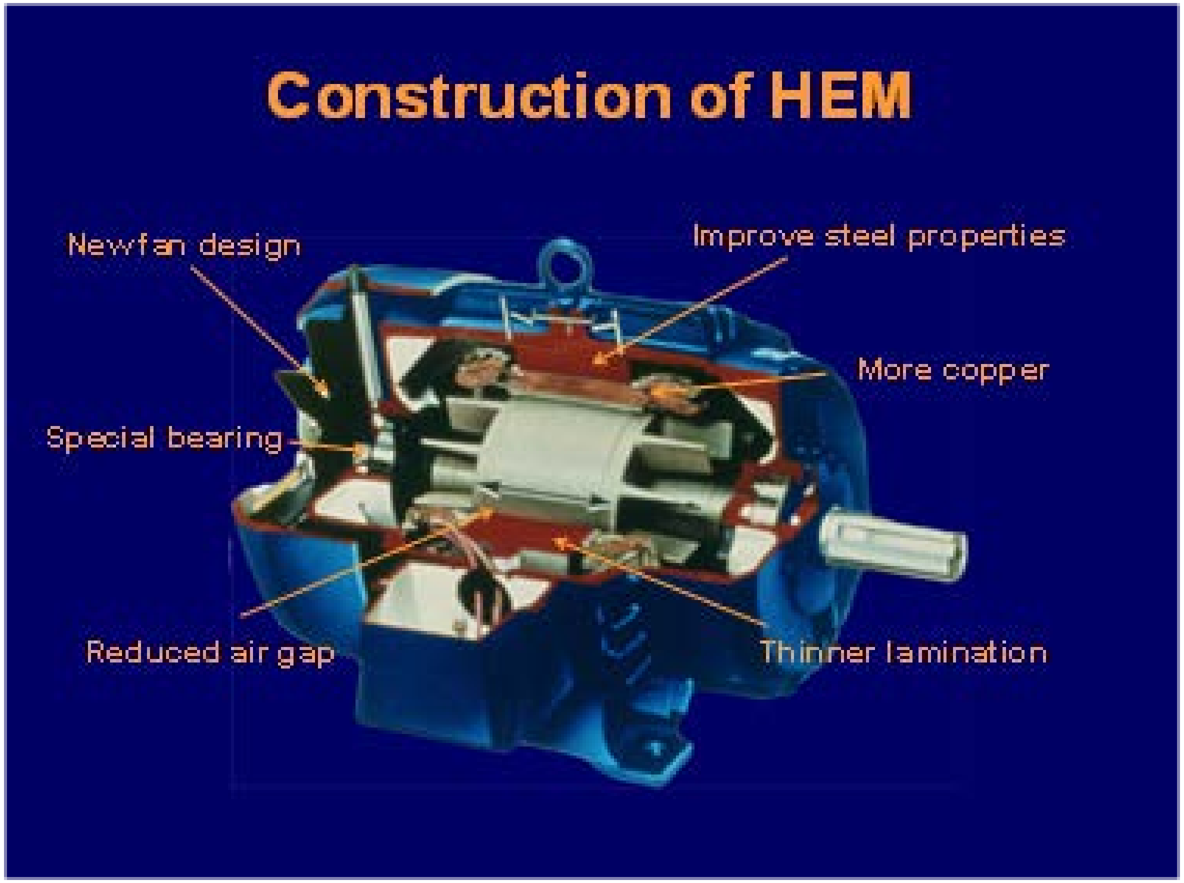
Energy saving technologies ::: *High Efficiency Motors*



Energy saving technologies ::: *High Efficiency Motors*

Payback period for high efficient motors

Table 7

Bill savings and payback period for high efficient motor [30].

Hp	Load (50%)		Load (75%)		Load (100%)	
	Bill savings (RM/year)	Payback (year)	Bill savings (RM/year)	Payback (year)	Bill savings (RM/year)	Payback (year)
0.25	43,469	7.89	65,203	5.26	86,937	3.95
0.5	21,734	5.1	32,601	3,4	43,469	2.55
0.75	37,259	3.48	55,888	2.32	74,518	1.74
1	149,035	2.9	223,553	1.94	298,070	1.45
1.5	18,629	1.94	27,944	1.29	37,259	0.97
2	124,196	1.71	186,294	1.14	248,392	0.86
3	335,329	1.06	502,994	0.7	670,658	0.53
4	2,036,814	1.67	3,055,222	1.12	4,073,629	0.84
5.5	68,308	2.08	102,462	1.39	136,616	1.04
7.5	186,294	1.98	279,441	1.32	372,588	0.99
15	93,147	1.77	139,721	1.18	186,294	0.88
20	2,483,920	1.45	3,725,880	0.97	4,967,840	0.73
25	931,470	1.62	1,397,205	1.08	1,862,940	0.81
30	372,588	1.47	558,882	0.98	745,176	0.74
40	993,568	1.32	1,490,352	0.88	1,987,136	0.66
50	620,980	1.11	931,470	0.74	1,241,960	0.56
60	1,862,940	1.17	2,794,410	0.78	3,725,880	0.59
75	465,735	1.18	698,603	0.78	931,470	0.59

[30] Saidur R, Rahim NA, Masjuki HH, Mekhilef S, Ping HW, Jamaluddin MF. Enduse energy analysis in the Malaysian industrial sector. Energy 2009;34: 153–8.

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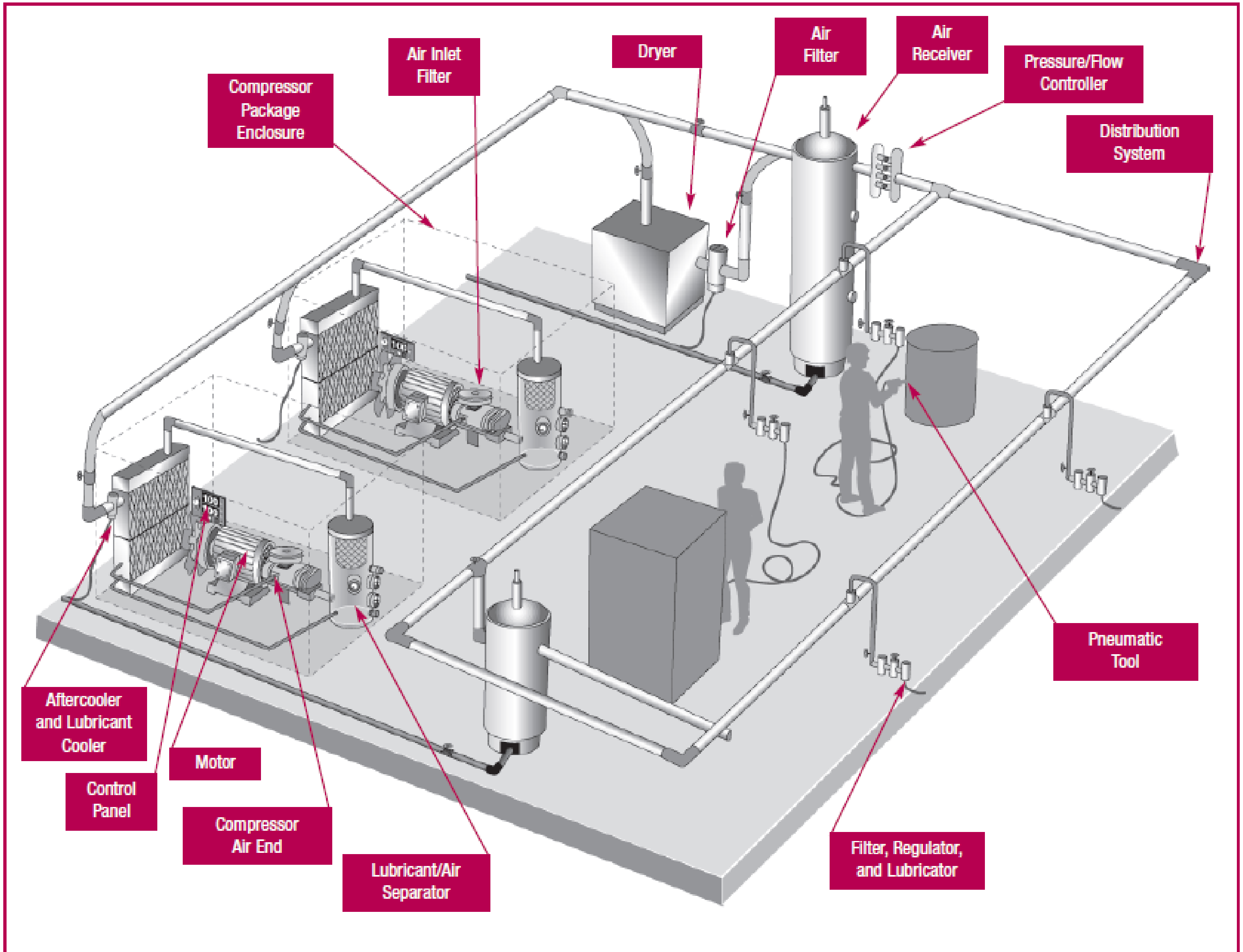
Energy saving technologies ::: *High efficiency air compressors*



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Energy saving technologies ::: *High efficiency air compressors*

➢ Compressed air is used in thousands of applications and is vital to the productivity of industries around the globe.

Application	Air Usage Description
Aluminum Smelting Plants	Compressed air used on lifting gantry cranes.
Spray Finishing Equipment	Compressed air is used to vaporize paint so it can be applied to components and products.
Air Operated Lifting Equipment	Small and compact air hoists can be used for a multitude of lifting operations.
Shot Blasting	Blasting and cleaning operations use compressed air to propel grit.
Cooling & Heating	Compressed air is used in a vortex tube to create high volumes of cool air for industrial cooling processes. Vortex tubes can also be reverse flowed to produce high temperature air used in heating processes.
Cleaning	Compressed air is used for cleaning processes in manufacturing facilities.
Welding Equipment	Compressed air is used for cooling.
Robotics	Compressed air is used for controlling robotic machines on assembly lines.
Paper Pressing	Compressed air is used via cylinders for a variety of pressing applications.
Printing	Compressed air used for operation of printing pumps and equipment.
Roller Adjustment	Compressed air is used to precisely control the roller thickness which determines the paper thickness.

Energy saving technologies ::: *High efficiency air compressors*

100 kW rotary-screw compressor

- pneumatic tools and drives
- process
- products movement

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Energy saving technologies ::: *High efficiency air compressors*

- Replace motors with HEM
- Replace compressors with high efficiency units
- Lower the demand air pressure of the system
- Lower inlet air temperature as possible
- Turn off the compressor if it is not used
- Install VSD
- High efficiency air filtering and drying systems
- Heat recovery from the compression process
- Leak prevention

Energy efficiency aspects

Energy saving technologies ::: *High efficiency air compressors*

- **Leaks** represent a significant source of wasted energy in the industrial compressed-air systems.
- **Leaks can waste 20–30% of a compressor's output**.
- Leaks occur most often at the joints, connections, elbows, sudden expansions, valve systems, hoses, tubes, filters, hoses, check valves, relief valves, extensions, and the equipment connected to the compressed-air lines.
- These **leaks can cause a drop in system pressure affecting production**.
- Leaks cause an **increase in compressor energy** and maintenance **costs**.
- Power losses increase exponentially as the diameter of hole increase as shown in Fig. 23

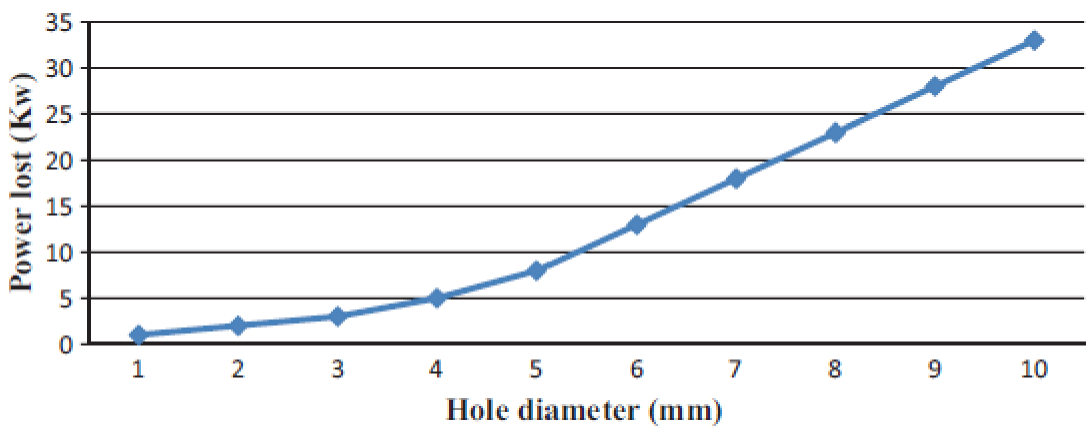

Fig. 23. Dependence of power loss on hole diameter at 600 kPa [31].

[31] Kaya D, Phelan P, Chau D, Sarac HI. Energy conservation in compressed-air systems. International Journal of Energy Research 2002;26:837–49.

Energy saving technologies ::: *High efficiency air compressors*

- The best way to detect leaks is to **use an ultrasonic acoustic detector**, which can recognize the high frequency hissing sounds associated with air leaks.
- This equipment facilitates identification of even the smallest leak regardless of the baseline ambient noise level in an industrial plant

Table 9
Cost of waste energy due to leak prevention [34].

Diameter of leak (in.)	Cost per year
1/64	$48.00
3/64	$424.00
1/16	$744.00
1/8	$2981.00
1/4	$11,904.00
5/16	$18,721.00
3/8	$27,036.00

[34] PS (Plant Support). Compressed air ultrasonic leak detection guide; 2010, Available online at: http://www.plantsupport.com/download/UCAGuide.pdf

Energy saving technologies ::: *High efficiency air compressors*

- Minimizing **pressure drops** requires a systems approach in design and maintenance. **Air treatment components should be selected with the lowest possible pressure drop** at specified maximum operating conditions and best performance.
- Manufacturers’ recommendations for maintenance should be followed, particularly in air filtering and drying equipment.
- **Operating compressed-air systems at the lowest functional pressure that meets production requirements will result in energy saving**. For example, reducing pressure settings by 13 kPa will reduce energy consumption by 1%.
- Another example is when reducing the pressure for about (70–84 kPa), 5–6% savings of compressed-air electrical demand could be saved [32,36].
- If possible, **use different compressed air circuits at different pressure levels**

[32] Galitsky C, Worrell E. Energy efficiency improvement and cost saving opportunities for the vehicle assembly industry. Lawrence Berkeley National Laboratory 2008 [LBNL-50939-Revision].

[36] D’Antonio M, Epstein G, Moray S, Schmidt C. Compressed air load reduction approaches and innovations. In: Proceedings of the twenty-seventh industrial energy technology conference; 2005

Energy saving technologies ::: *High efficiency lighting systems*

- There are several opportunities to optimize lighting system in (almost) any industrial facility.
- Seven practical energy-efficiency opportunities to reduce energy use cost-effectively are given below:
  - **Lighting controls**
  - **LED lamps** installation
  - Replace **mercury lights** with **Metal halide** or **High pressure sodium** lights
  - Replace **magnetic ballasts with electronic ballasts**
  - **Optimization of plant lighting** (Lux optimization) in production and non-production departments
  - Optimal use of **natural sunlight**

Energy saving technologies ::: *High efficiency lighting systems*

- **Lighting controls**: lights can be **shut off during non-working hours by automatic controls**, such as **occupancy sensors** which turn off lights when a space becomes unoccupied.
- Manual controls can also be used in addition to automatic controls to save additional energy in smaller areas.
- The **payback period for lighting control systems is generally less than 2 years**

Lighting control panel

Energy saving technologies ::: *High efficiency lighting systems*

- **Replace Mercury lights with Metal halide or High pressure sodium lights:** where color rendition is critical, metal halide lamps can replace mercury or fluorescent lamps **with an energy savings of 50%**.
- Where color rendition is not critical, high pressure sodium lamps offer **energy savings of 50 to 60%** compared to mercury lamps

Metal halide lamps

Energy saving technologies ::: *High efficiency lighting systems*

- **Replace magnetic ballasts with electronic ballasts:** A ballast is a mechanism that regulates the amount of electricity required to start a lighting and maintain a steady output of light.
- **Electronic ballasts save 12 – 20% of electricity use compared to magnetic ballast**
- High efficiency lamps have electronic ballasts

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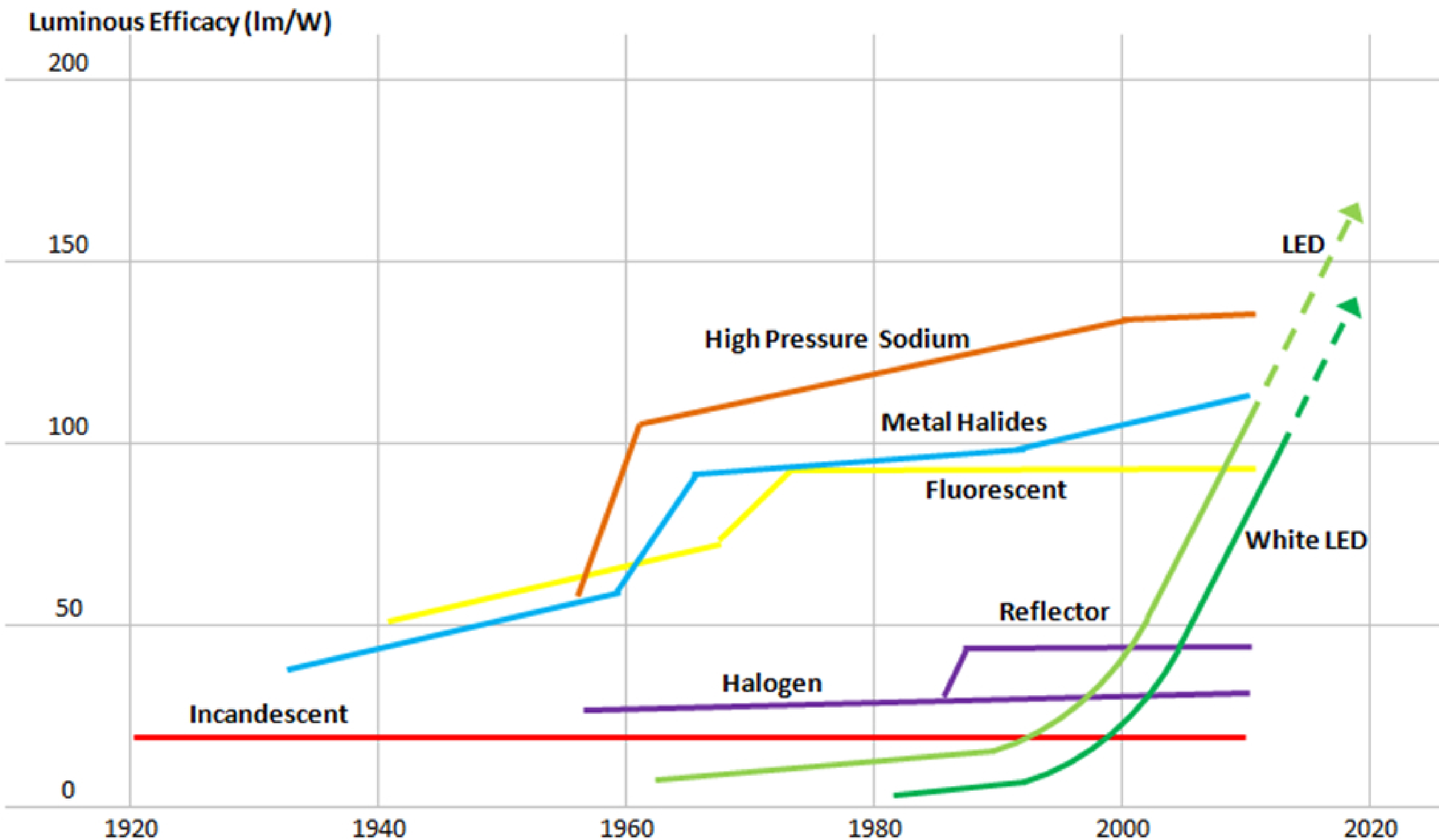
Energy saving technologies ::: *High efficiency lighting systems*

- **Optimization of plant lighting (Lux optimization):** In many plants the lighting system is not specifically designed for the process. **There are lux standards for each type of process**
- Therefore, the plant engineers should **optimize the lighting system based on the standard lux specific for each process step**
- **Optimal use of natural sunlight**: Many plants do not use natural sunlight to an optimum level. In addition to optimizing the size of the windows, transparent sheets can be installed at the roof in order to allow more sunlight to penetrate into the production area.
- **Daylight sensors** can be used to automatically reduce the luminous flux of the lamp

Energy saving technologies ::: *High efficiency lighting systems*

- **Luminous efficacy**: Unit of measurement: lumens per watt [lm/W].
- The **luminous efficacy of a source is a measure of the efficiency with which the source converts the electricity into visible light**



Energy saving technologies ::: *Waste heat recovery*

- **Waste heat** is **heat generated in a process and then "dumped" into the environment even if it could still be reused for useful and economic purpose**
- Sources of waste heat include **hot combustion gases discharged to the atmosphere**, **heated products exiting industrial processes**, and heat transfer from hot equipment surfaces.
- The exact quantity of industrial waste heat is poorly quantified, but various studies have estimated that as much as **20 to 50% of industrial energy consumption is currently discharged as waste heat** [37].
- While some waste heat losses from industrial processes are inevitable, facilities can reduce these losses by **improving equipment efficiency or installing waste heat recovery technologies**.
- The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved.

[37] Waste Heat Recovery: Technology and Opportunities in U.S. Industry. March 2008.
http://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/waste_heat_recovery.pdf

Energy saving technologies ::: *Waste heat recovery*

Table 1 – Examples of Waste Heat Sources and End-Uses

Waste Heat Sources	Uses for Waste Heat
• Combustion Exhausts: Glass melting furnace Cement kiln Fume incinerator Aluminum reverberatory furnace Boiler • Process off-gases: Steel electric arc furnace Aluminum reverberatory furnace • Cooling water from: Furnaces Air compressors Internal combustion engines • Conductive, convective, and radiative losses from equipment: Hall-Hèroult cells [a] • Conductive, convective, and radiative losses from heated products: Hot cokes Blast furnace slags [a]	• Combustion air preheating • Boiler feedwater preheating • Load preheating • Power generation • Steam generation for use in: power generation mechanical power process steam • Space heating • Water preheating • Transfer to liquid or gaseous process streams

a. Not currently recoverable with existing technology

[37] Waste Heat Recovery: Technology and Opportunities in U.S. Industry. March 2008. http://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/waste_heat_recovery.pdf

Energy saving technologies ::: *Waste heat recovery*

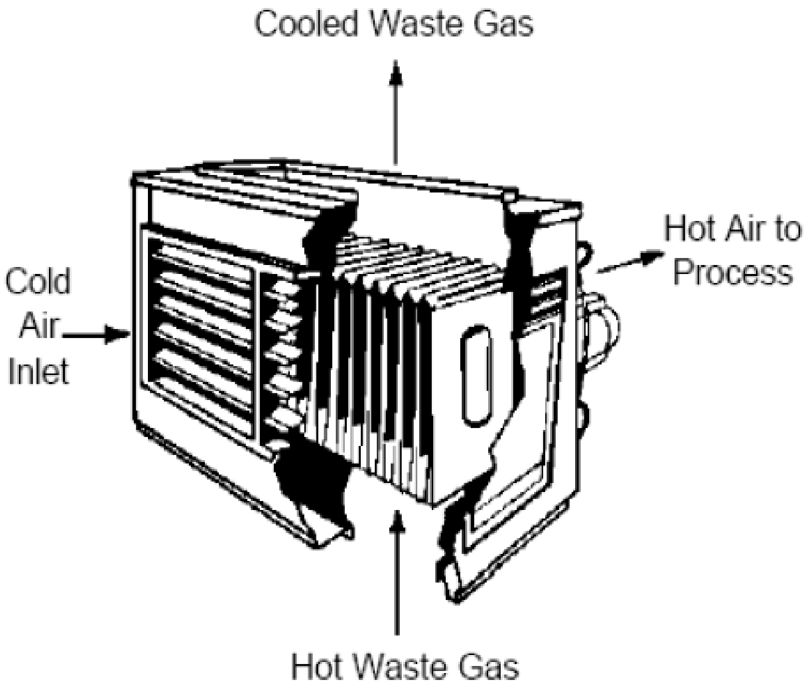


Figure 8 - Passive Gas to Gas Air Preheater
(Source, PG & E, 1997)

Insulated steam pipe

Economizer on flue gases
(+ 3-4% efficiency increase)

Energy saving technologies ::: *Waste heat recovery*

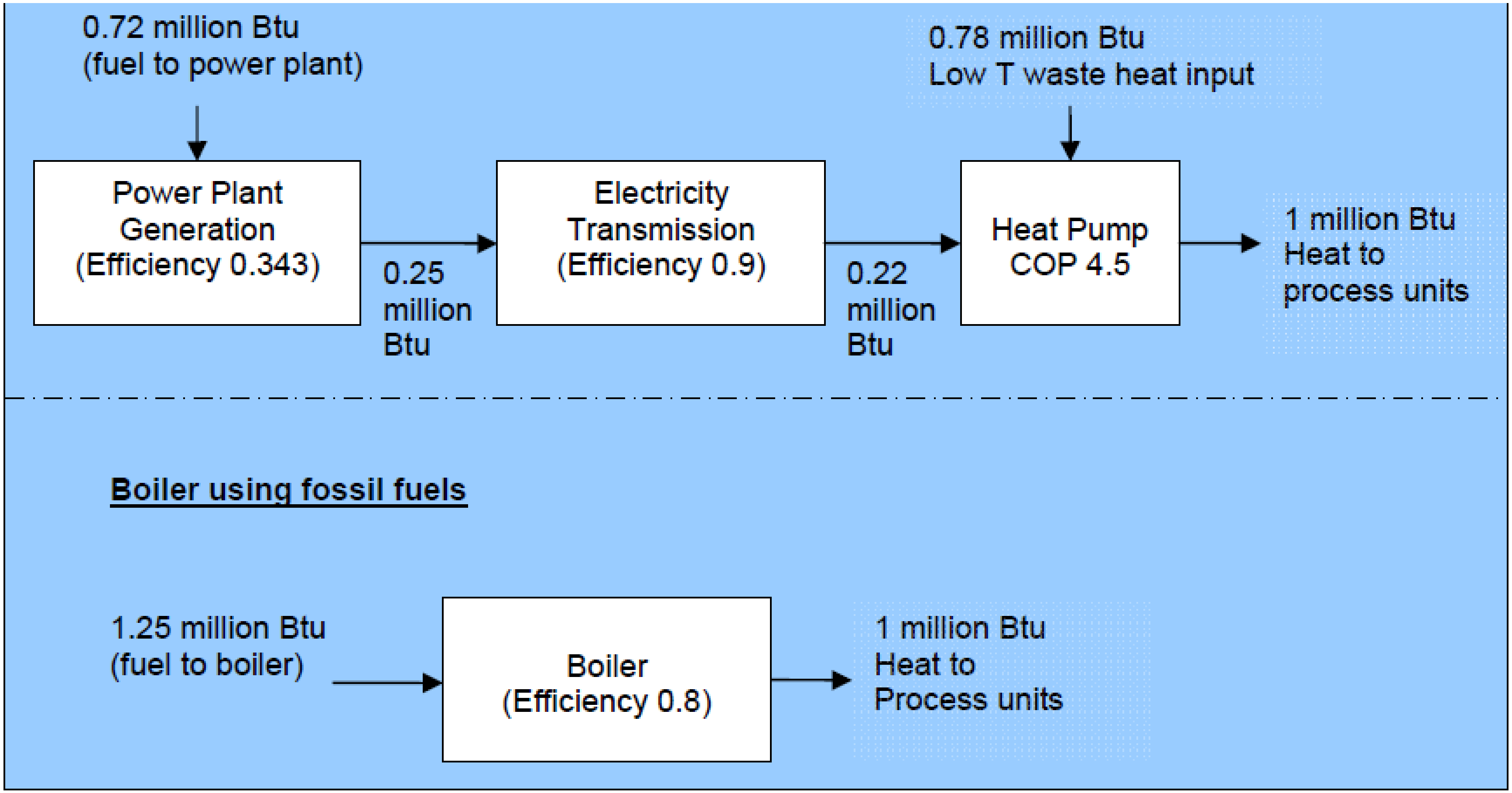


Figure 16 - Energy Losses from a Boiler versus a Heat Pump.

Note: *The heat pump receives heat from a low-temperature source and rejects it at a higher temperature. The heat pump uses waste heat plus an additional 0.22 million Btu of electrical energy to provide 1 million Btu of useful heat, while the boiler requires an input of 1.25 million Btu to provide 1 million Btu of steam heat.*

Energy saving technologies ::: *Waste heat recovery*

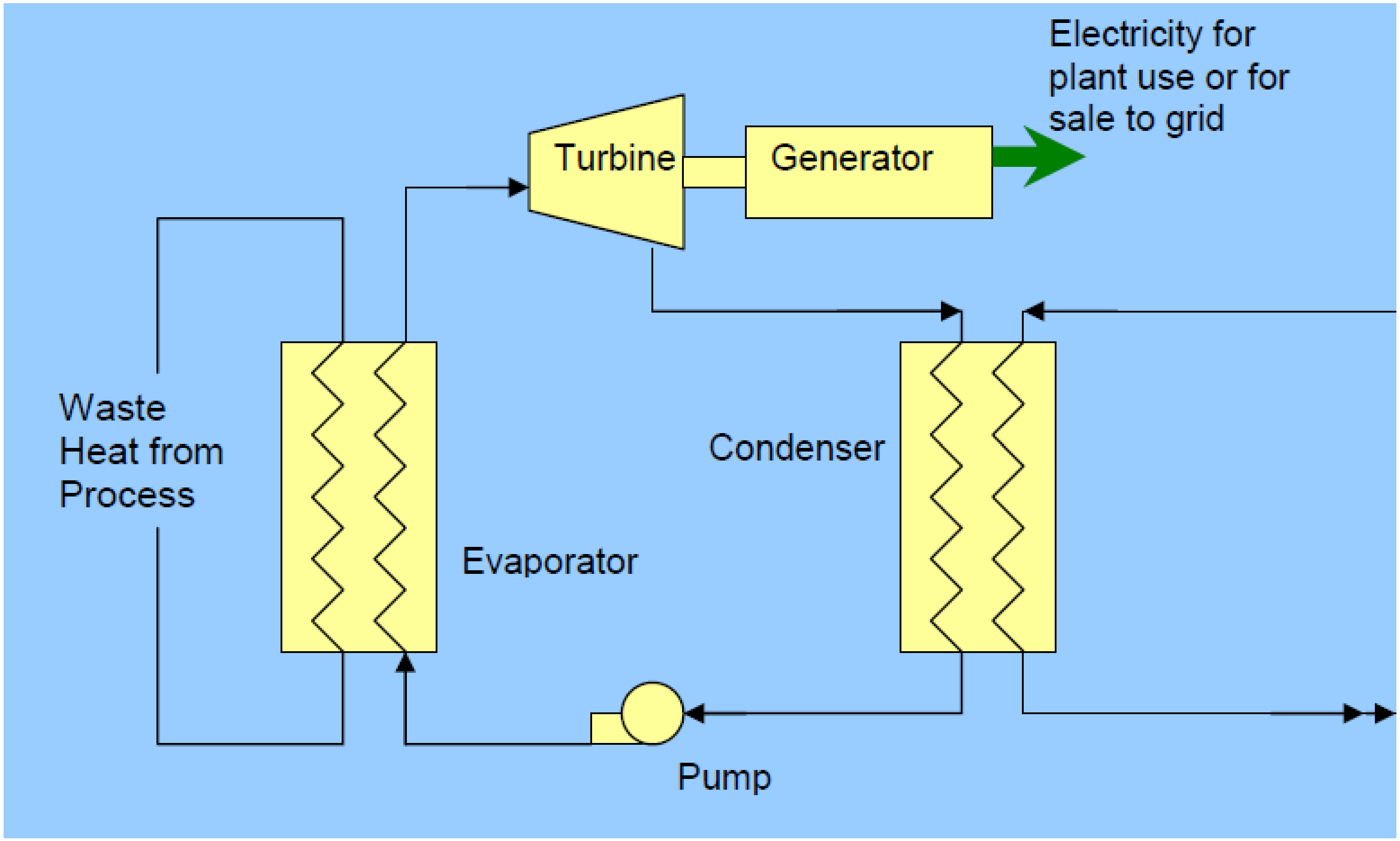
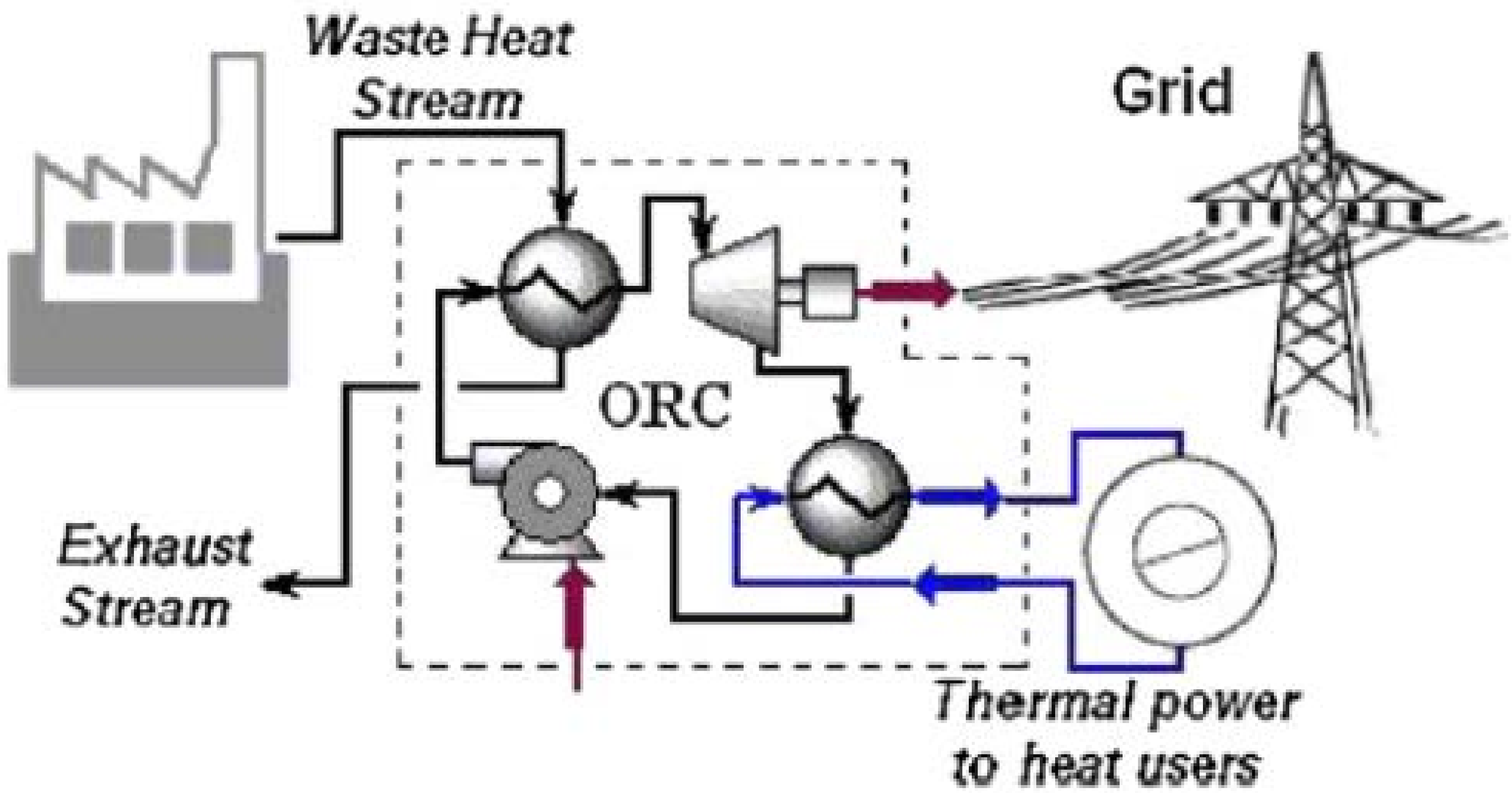


Figure 18 - Waste Heat Recovery with Rankine Cycle -

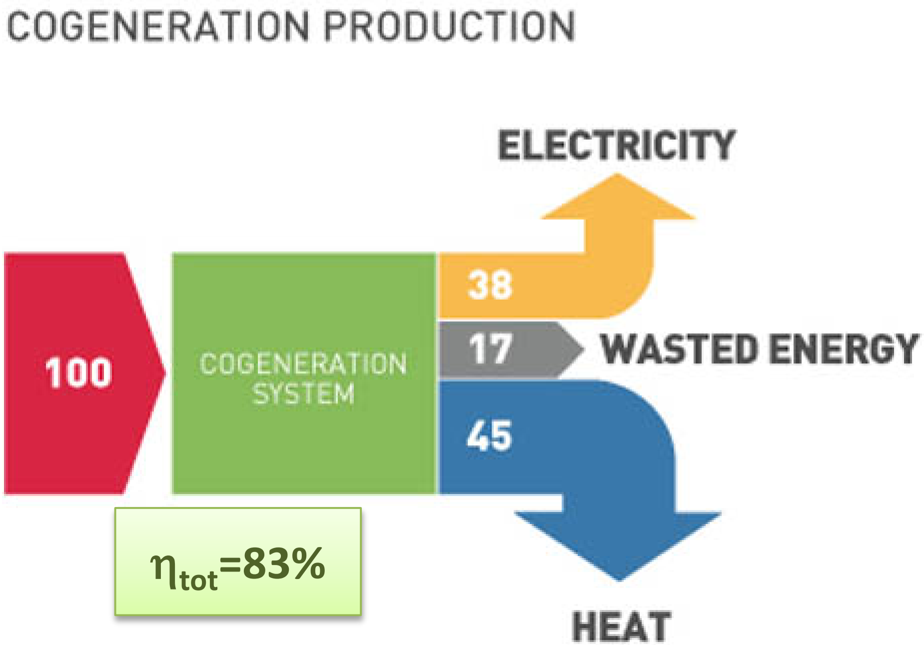
Energy saving technologies ::: *Waste heat recovery*

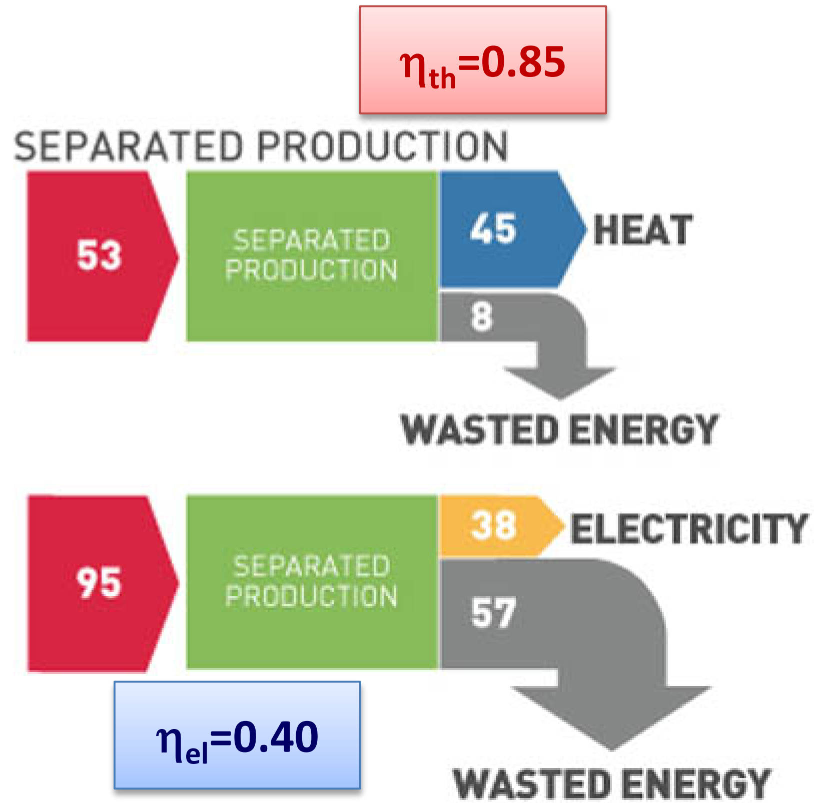


Energy saving technologies ::: *Cogeneration*

- Cogeneration (Combined Heat and Power or CHP) is **the simultaneous production of electricity and heat, both of which are used**
- In order to maximize the many benefits that arise from cogeneration, **this technology should be considered in applications characterized by simultaneous electrical and thermal loads**
- Moreover, an almost total **self-consumption of electricity and heat should be realized to be energetically efficient and economically viable**
- Through the utilization of the heat, **the efficiency of a cogeneration plant can reach 90% or more**

Energy saving technologies ::: *Cogeneration*





ENERGY INPUT
100

ENERGY INPUT
53+95=148

PES = 32% !!!

Energy saving technologies ::: *Cogeneration*

- Cogeneration benefits:
  - **Increased efficiency of energy conversion** and use respect to separate generation (*PES, Primary Energy Savings*)
  - **Lower CO2 emissions to the environment**
  - **Large cost savings**, providing additional competitiveness for industrial and commercial users, and offering affordable heat for domestic users
  - Improved local and general security of supply

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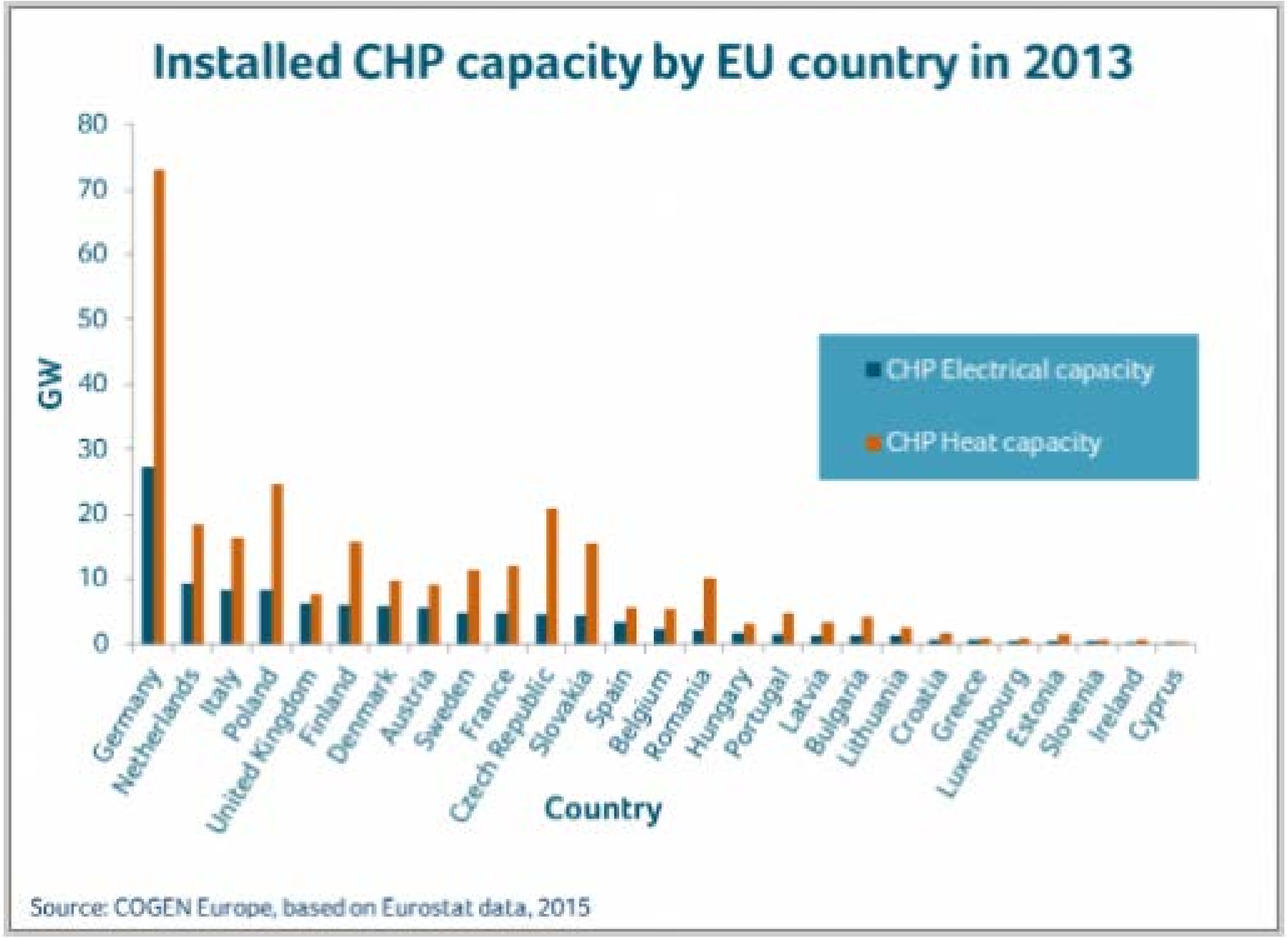
Energy saving technologies ::: *Cogeneration*



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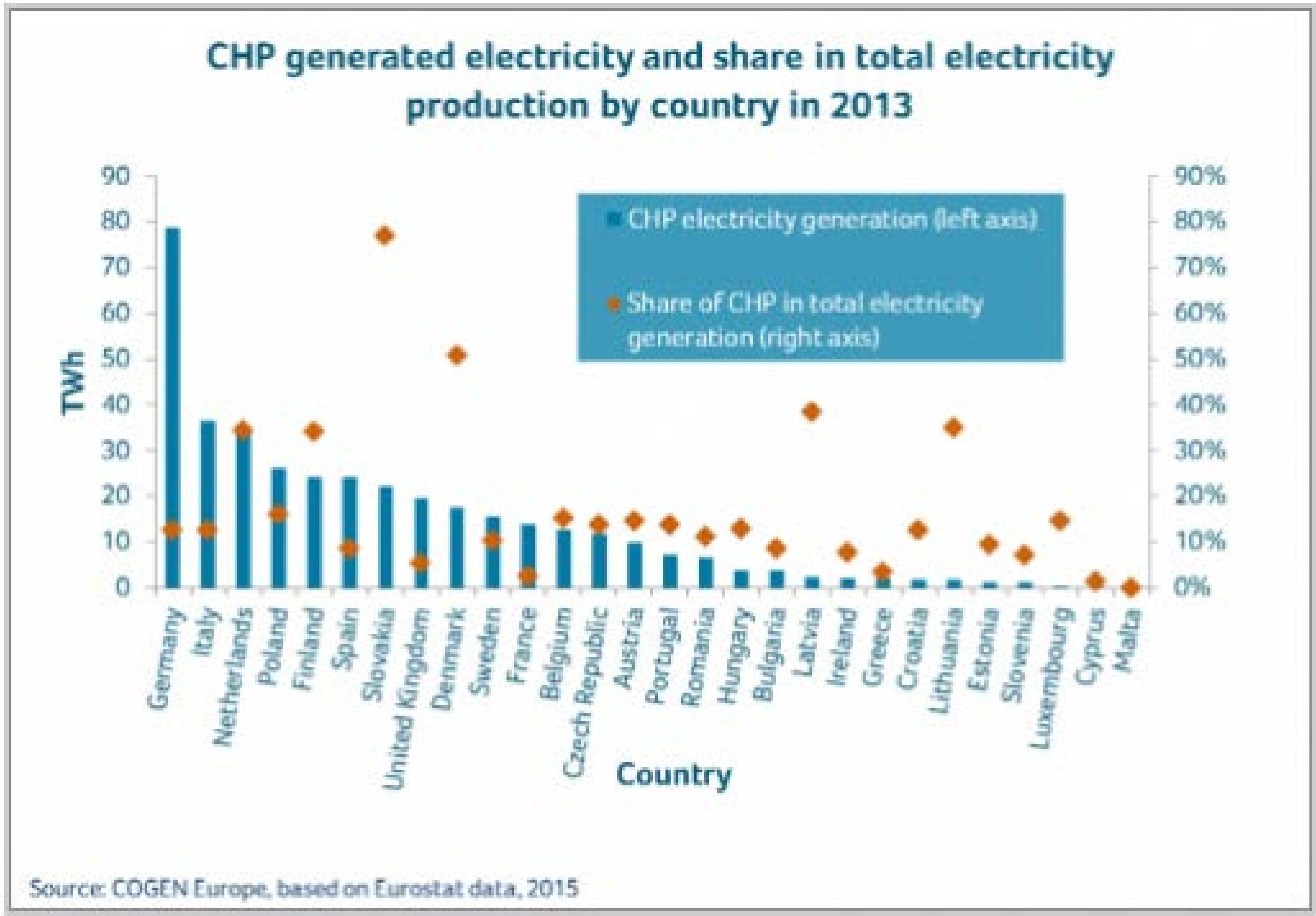
Energy saving technologies ::: *Cogeneration*



Energy saving technologies ::: *Cogeneration*

- Industrial Cogeneration: these are typically the largest type of CHP plant.
- Ranging in scale from a few MWe to the size of a conventional power station, the typical system size is 1-800 MWe
- In some cases surplus heat can also be used to meet the heat requirements of the surrounding local community (district heating networks)
- CHP facilities are concentrated in a few industries: **Paper (20%), Chemicals (40%) and Petroleum Refining and related products (15%) represent more than two thirds of the total electric and steam capacities at existing industrial CHP installations**.
- These industries have been traditional hosts for CHP facilities: **these plants generally have high process-related thermal requirements that are not subject to daily or seasonal weather-related fluctuations**
- Typical prime movers for industrial CHP are **steam turbines, gas turbines, reciprocating engines (compression ignition) and combined cycles (larger systems).**

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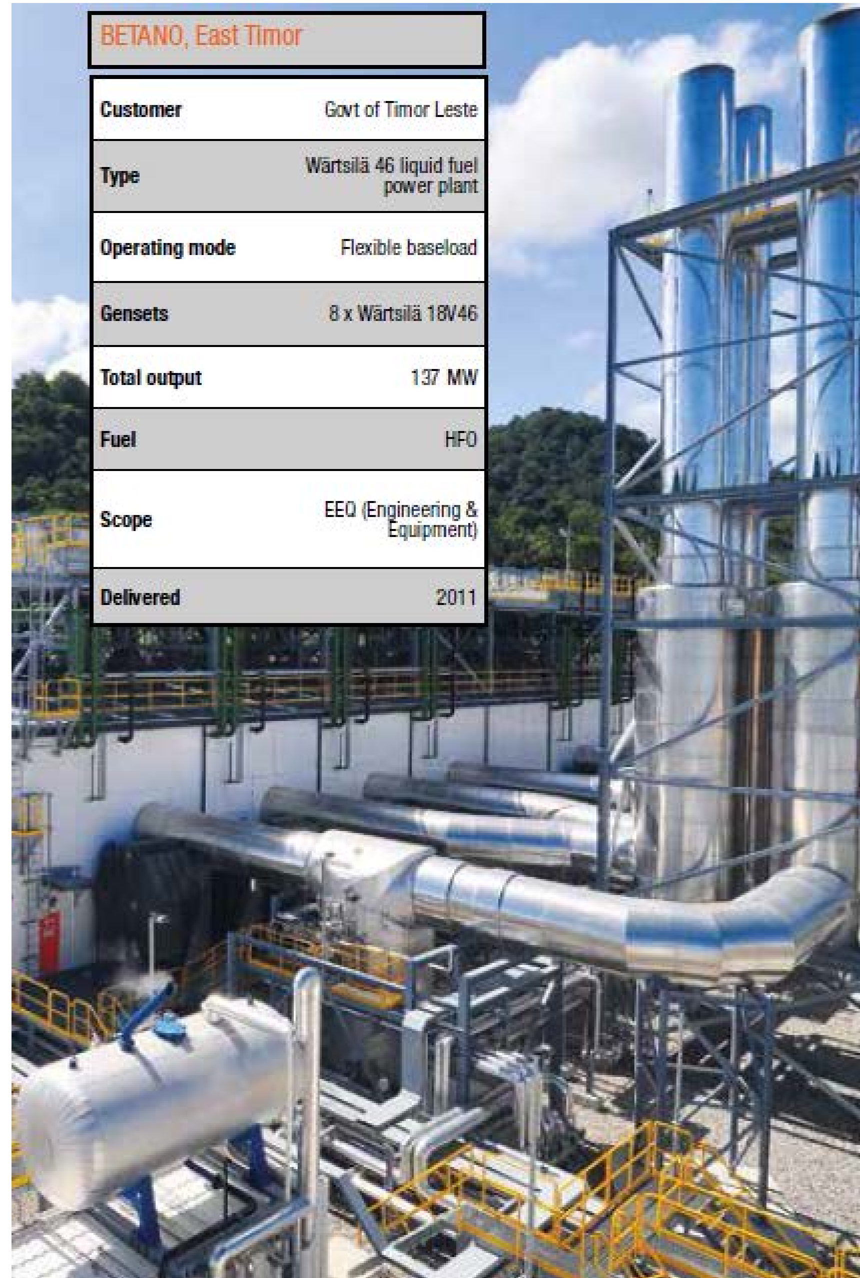
Energy saving technologies ::: *Cogeneration*

Energy saving technologies ::: *Cogeneration*



BETANO, East Timor	
Customer	Govt of Timor Leste
Type	Wärtsilä 46 liquid fuel power plant
Operating mode	Flexible baseload
Gensets	8 x Wärtsilä 18V46
Total output	137 MW
Fuel	HFO
Scope	EEQ (Engineering & Equipment)
Delivered	2011

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Thank you for your attention