DEPARTMENT OF
ELECTRICAL AND ELECTRONIC
ENGINEERING

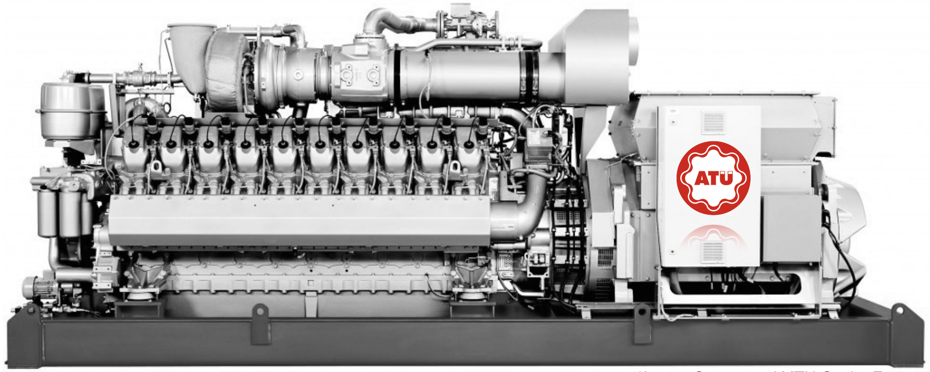


*Image Courtesy of MTU Onsite Energy

COGENERATION AND TRIGENERATION PLANTS

Dr Kasım ZOR
EEE407-Renewable Energy

Contents

INTRODUCTION

- Cogeneration:

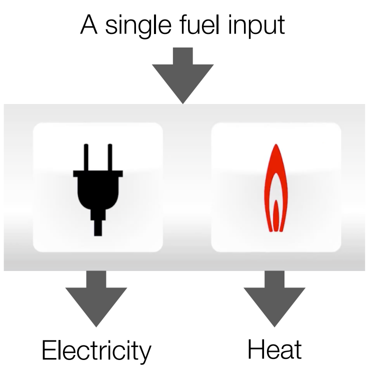


*Image Courtesy of MTU Onsite Energy

INTRODUCTION

- Trigeneration:

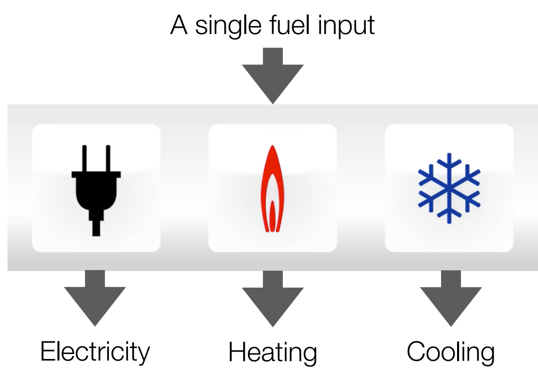
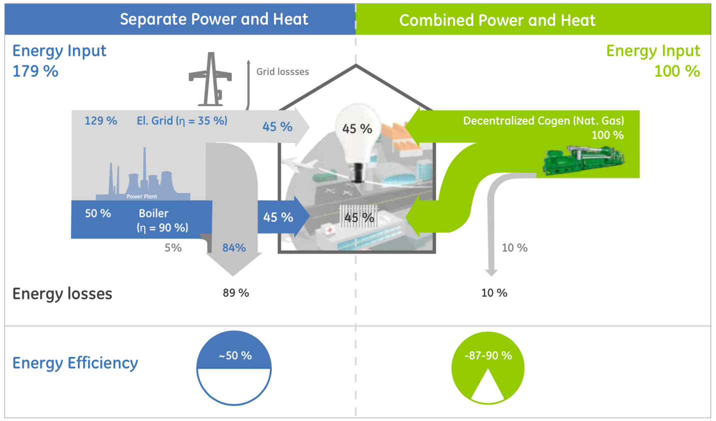


*Image Courtesy of MTU Onsite Energy

INTRODUCTION



Prime energy savings* through CHP: 36 %

*naturally occurring energy sources such as e.g. natural gas, crude oil, coal, wood without loss of downstream conversion and transport processes

*Image Courtesy of GE Jenbacher

INTRODUCTION

- Most common prime mover technologies:

Production Technology	Power Range	Electrical Efficiency	Overall Efficiency
ICE	50 kW-5 MW	25-44%	95%
Gas Turbine	500 kW-500 MW	20-45%	80%
Fuel Cell	5 kW-2 MW	30-40%	75%
Microturbine	30 kW-250 kW	25-30%	75%

INTRODUCTION

- Most common prime mover technologies:

Technology	ICE	Gas Turbine	Fuel Cell	Microturbine
Power/Heat Ratio	0.5-1	0.5-2	1-2	0.4-0.7
Part Load	Ok	Poor	Good	Ok
Availability	92-97%	90-98%	>95%	90-98%
Hours to Overhauls	>50,000	25,000-50,000	32,000-64,000	20,000-40,000
Start-up Time	10 sec	10 min-1 h	3 h-2 days	60 sec
Fuel Pressure (bar)	1.1-4.1	7.9-35.5 (Compressor)	1-4.1	4.5-6.5 (Compressor)
Fuels	Natural Gas, Biogas, Propane, Landfill Gas	Natural Gas, Biogas, Propane, Oil	Hydrogen, Natural Gas, Propane, Methanol	Natural Gas, Biogas, Propane, Oil
Noise	High	Moderate	Moderate	Low
Uses for Thermal Output	Hot Water, LP Steam	Heat, Hot Water, LP-HP Steam	Hot Water, LP-HP Steam	Heat, Hot Water, LP Steam
NO_x (lb/MWh)	2-30	0.3-4	0-0.02	0.4-2.2

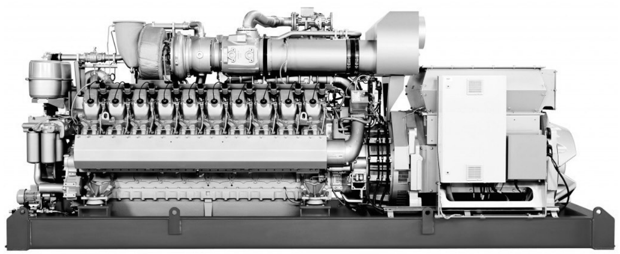
INTRODUCTION

- Most common prime mover technologies:

Technology	Advantages	Disadvantages
ICE	• High power efficiency with part-load operational flexibility. • Fast start-up. • Relatively low investment cost. • Can be used in island mode and have good load following capability. • Can be overhauled on-site with normal operators. • Operate on low-pressure gas.	• High maintenance costs. • Limited to lower temperature cogeneration applications. • Relatively high air emissions. • Must be cooled even if recovered heat is not used. • High levels of low frequency noise.
Gas Turbine	• High reliability. • Low emissions. • High-grade heat available. • No cooling required.	• Require high-pressure gas or in house gas compressor. • Poor efficiency at low loading. • Output falls as ambient temperature rises.
Fuel Cell	• Low emissions and low noise. • High efficiency over load range. • Modular design.	• High costs. • Low durability and power density. • Fuels requiring processing unless pure hydrogen is used.
Microturbine	• Small number of moving parts. • Compact size and light weight. • Low emissions. • No cooling required	• High costs. • Relatively low mechanical efficiency. • Limited to lower temperature cogeneration applications.

INTRODUCTION

- Internal Combustion Engines:
  - Spark ignition engines,



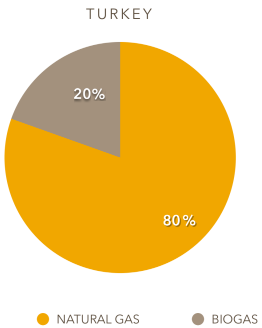
  - Compression ignition engines.

INTRODUCTION

- History of Cogeneration Plants:
  - 1914, German engineers were recovering heat from ICE to warm factories,
  - 1924, London, World First Power Congress, Waste Heat Utilisation,
  - 1926, London, Bank of England, Oscar Faber,
  - 1932, Berlin, Full session Cogeneration,
  - 1978, PURPA, Encouragement of Cogeneration,
  - 1995, Yenibosna-İstanbul, Pisa Textile Factory, Borusan Power Systems, 1.02 MW.

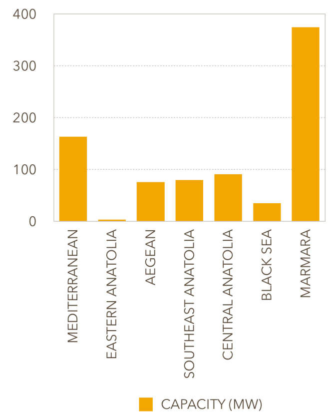
INTRODUCTION

- Current status of gas engine driven cogeneration and trigeneration plants in Turkey, by January 2015:
  - Natural gas, 822.020 MW,
  - Biogas, 199.665 MW,
  - Total, 1,021.685 MW.



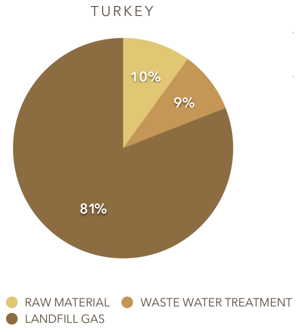
INTRODUCTION

- Regional status of NG engine driven plants in Turkey, by January 2015:
  1. Marmara Region, 374.629 MW,
  2. Mediterranean Region, 163.160 MW,
  3. Central Anatolia Region, 90.965 MW,
  4. Southeast Anatolia Region, 79.819 MW,
  5. Aegean Region, 75.379 MW,
  6. Black Sea Region, 34.630 MW,
  7. Eastern Anatolia Region, 3.438 MW.



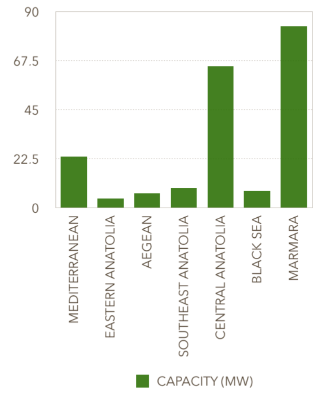
INTRODUCTION

- Current status of biogas engine driven cogeneration and trigeneration plants in Turkey:
  - Landfill Gas, 161.598 MW,
  - Raw Material, 19.961 MW,
  - Waste Water Treatment, 18.106 MW.



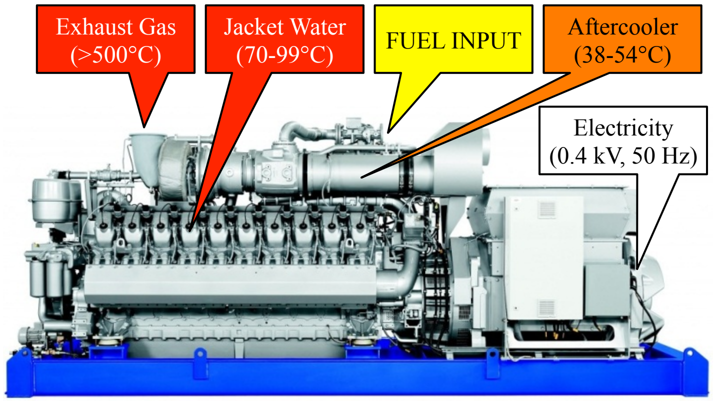
INTRODUCTION

- Regional status of biogas engine driven plants in Turkey, by January 2015:
  1. Marmara Region, 83.305 MW,
  2. Central Anatolia Region, 64.948 MW,
  3. Mediterranean Region, 25.593 MW,
  4. Southeast Anatolia Region, 8.966 MW,
  5. Black Sea Region, 7.731 MW,
  6. Aegean Region, 6.701 MW,
  7. Eastern Anatolia Region, 4.421 MW.



Cogeneration and Trigeneration Plants

- Fundamentals of Cogeneration and Trigeneration Plants



Cogeneration and Trigeneration Plants

- Fundamentals of Cogeneration and Trigeneration Plants
  - Electrical Efficiency

$$\eta_e = \frac{P}{F}$$

  - Thermal Efficiency

$$\eta_t = \frac{P_t}{F}$$

Cogeneration and Trigeneration Plants

- Fundamentals of Cogeneration and Trigeneration Plants
  - Overall Efficiency

$$\eta_o = \frac{P_t + P}{F}$$

  - Reliability

$$Ra = \frac{T-(S+U)}{T-S} \times 100$$

Cogeneration and Trigeneration Plants

- Fundamentals of Cogeneration and Trigeneration Plants
  - Availability

$$Av = \frac{T-(S+U)}{T} \times 100$$

  - Primary Energy Savings Ratio

$$PESR = \left[1 - \frac{1}{\left(\eta_e / \eta_{spe} + \eta_t / \eta_{sph}\right)}\right]$$

Example: Efficiency Calculation

Calculate electrical efficiency, heat efficiency and total efficiency of an ideal cogeneration plant for generator voltage of 0.4 kV with respect to the following data. (Assume whole produced energy is utilised and consumed on-site.)

1.1 Continuous Operating Data in Grid Parallel Mode

8% tolerance for thermal outputs and 5% for total energy input listed. Performance data in accordance with ISO 3046. All data apply to grid parallel operation. Data for site operating conditions other than those mentioned, available on demand. Max. reactive power in kVA, resp. nominal current acc. to nominal output of the generator.

Generator voltage	400	415	6300	10500	11000	V
Electrical output of generator (no overload capacity)	**2145**					kW_{el}
Thermal output (Engine cooling / lube oil / 1st stage HT mixture cooler)		**1155**		**1202**		kW_{th}
Thermal output (2nd stage LT mixture cooling)		**140**		**144**		kW_{th}
Total energy input		**5139**		**5299**		kW
Thermal output by 120°C (8% tolerance)		1204		1263		kW
		NOx < 500		**NOx < 250**		**mg/m_n^3**

ηE = 2145/5139*100 = 41.74%

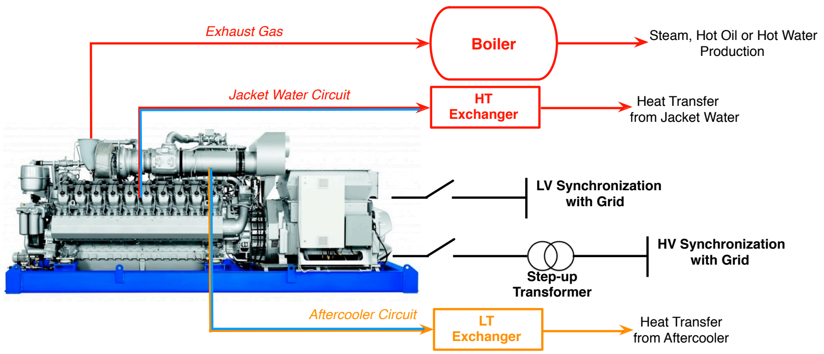
ηH = (1155+140+1204)/5139*100 = 48.63%

ηT = ηE+ηH = 90.37%

*Image Courtesy of MTU Onsite Energy

Cogeneration and Trigeneration Plants

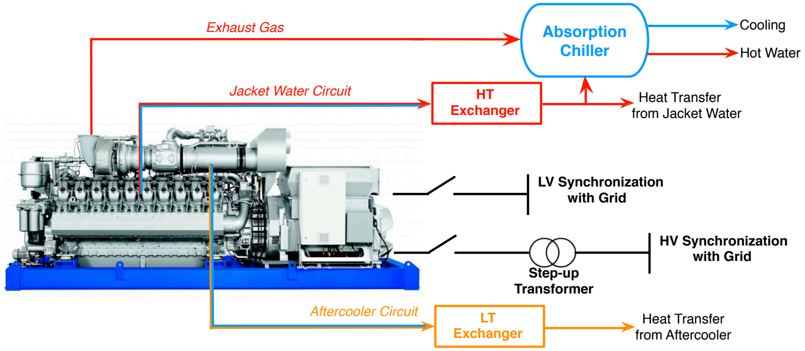
- Fundamentals of Cogeneration and Trigeneration Plants



COGENERATION PLANT

Cogeneration and Trigeneration Plants

- Fundamentals of Cogeneration and Trigeneration Plants



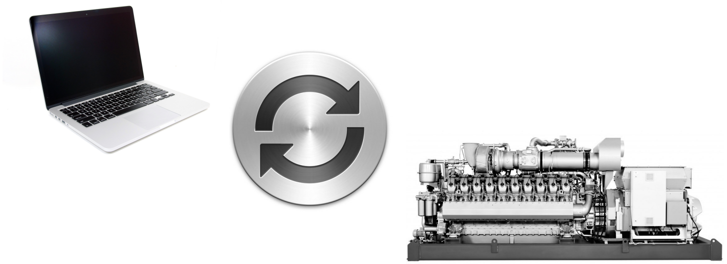
TRIGENERATION PLANT

Cogeneration Plant: Video

Youtube Link

Cogeneration and Trigeneration Plants

- Connecting to a Real Plant



Biogas Application

Biogas is created by the digestion or fermentation of organic materials. The basic material is often slurry or solid manure. Regenerative raw materials or waste from the food industry are generally used as cofermentates. 50 – 70 % of the gas produced this way are composed of the high-quality fuel methane. Carbon dioxide (CO_2), nitrogen and trace gases (such as hydrogen sulfide) are its other constituents.

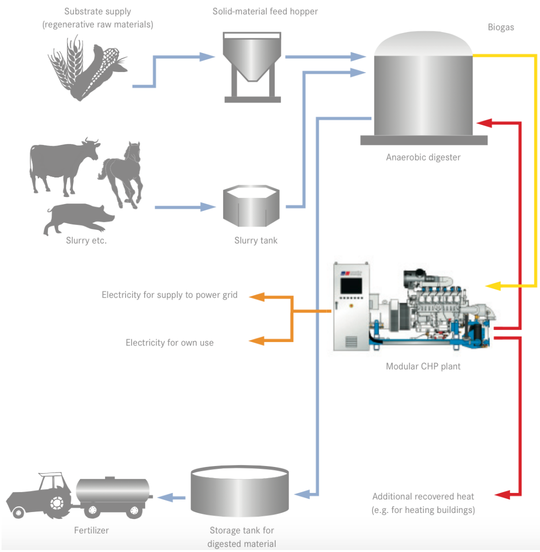
A multiplicity of organic materials can be used in a biogas plant. Some systems run entirely on slurry and solid manure, while others exclusively use regenerative raw materials. Frequently, a mixture of materials is used.

Biogas Application

*Image Courtesy of MTU Onsite Energy

1 MW electric power:

- 7,200 dairy cows
- 1,400,000 laying hens or chicken
- 5000 daa cultivated corn



Biogas Application: Video

Youtube Link

Biogas Application: Video

Youtube Link

Sewage Application

From 6 m^3 of sewage, current systems manage to generate on average 1 kWh of electric power and 1.2 kWh of thermal energy. The efficiently and ecologically generated electric power can either be used to supply the sewage plant itself, or it can be fed into the electricity grid. In the latter case, compensation according to government subsidy schemes, like the YEKDEM. During the combustion process, heat is being generated inside the gas engine. This thermal energy can be utilised for heating up the sewage sludge in the digester or for heating the whole facility. In large-scale plants, excessive high-temperature heat may be available that can be used to pasteurize or dry the sewage sludge.

Sewage Application

1 MW electric power:

- 500,000 populated city

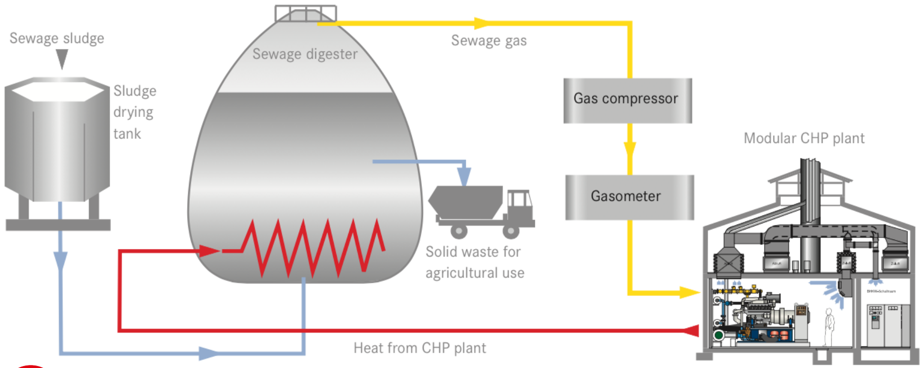


*Image Courtesy of MTU Onsite Energy

Sewage Application: Video

Youtube Link

Landfill Gas Application

From the waste deposited in the landfill body, a gas is created consisting mainly of methane and carbon dioxide. This is then extracted via the installed gas well and the connecting pipelines from the landfill. The gas is prepared in the compressor station to produce the required primary pressure. If the methane content of the gas is below 40%, it is burned in the high-temperature flare systems at 1200°C. Gas with a methane content above 40% is supplied to the landfill gas genset. Electricity (and possibly also heat) is produced here. In the transformer station, the electrical current is transformed to the power grid voltage and is measured and supplied to the grid of the local power supplier. The gas volume is usually used up after an operation period of 10 years. The practical and economic use of the gases is thus temporally limited.

Landfill Gas Application

1 MW electric power:

- 125,000 populated city

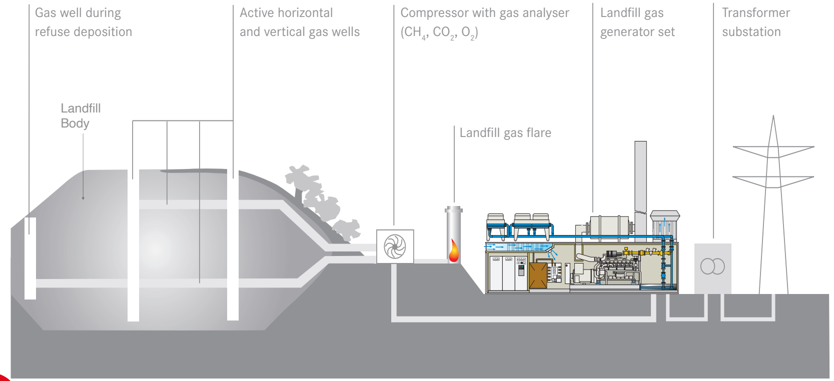


*Image Courtesy of MTU Onsite Energy

Landfill Gas Application: Video

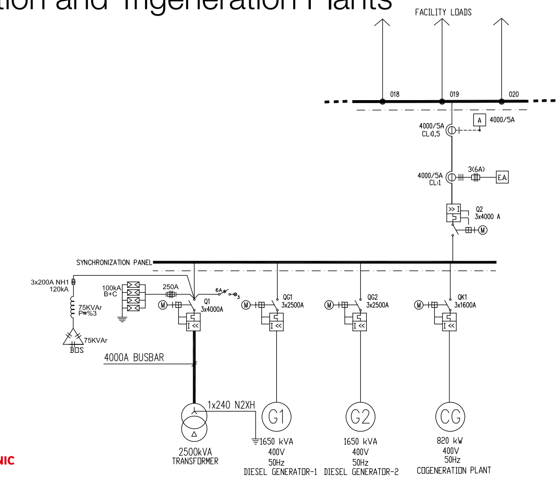
Youtube Link

Cogeneration and Trigeneration Plants

- Synchronisation
  - Electrical Modes of Operation
    - Island Mode
    - Standby
    - Peak Shaving
    - Base Load
    - Export

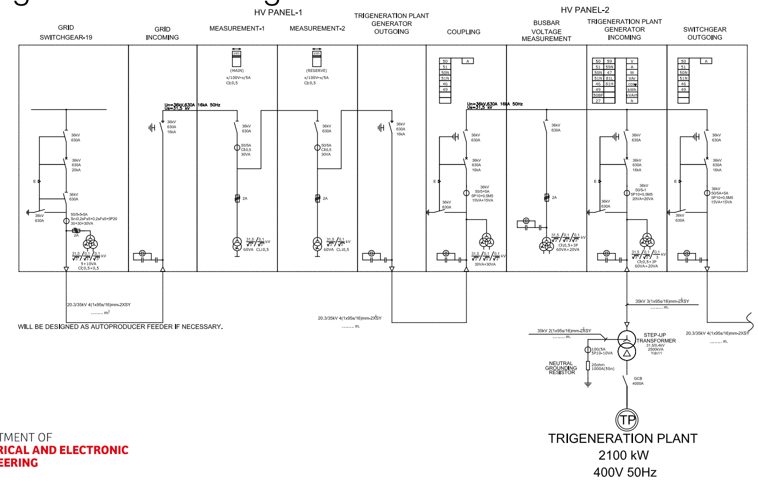
Cogeneration and Trigeneration Plants

- LV Switchgear Synchronisation of Gas Engine Driven Cogeneration and Trigeneration Plants



Cogeneration and Trigeneration Plants

- HV Switchgear Synchronisation of Gas Engine Driven Cogeneration and Trigeneration Plants



Cogeneration and Trigeneration Plants

- Current Legislation of Cogeneration and Trigeneration Plants in Turkey
  - Before amendment of Electricity Market Law in 14 March 2013, there were two alternatives for licenses:
    - Autoproducer license, (20-50%)
    - Electricity generation license. (Up to 100%)

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

Cogeneration and Trigeneration Plants

- Current Legislation of Cogeneration and Trigeneration Plants in Turkey
  - By the amendment:
    - Autoproducer license became void,
    - Unlicensed generation of electricity,
    - Electricity generation license.

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

Cogeneration and Trigeneration Plants

- Current Legislation of Cogeneration and Trigeneration Plants in Turkey
  - Unlicensed generation of electricity:
    - There is no installed capacity limit
    - Total efficiency must be ≥ 75%, Electricity/Heat Ratio ≤ 1.5 (*0.7 for Gas Turbines)
    - Surplus energy can not be sold, YEKDEM
    - For biogas plants, produced electricity by plants can be sold to the grid (13.3 ¢/kWh)

Domestically Manufactured Equipment	Extra Addition (¢/kWh)
Fluidized Bed Steam Boiler	0.8
Gasification and Gas Purification Group	0.6
ICE	0.9
Generator and Power Electronics	0.5
Cogeneration System	0.4

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

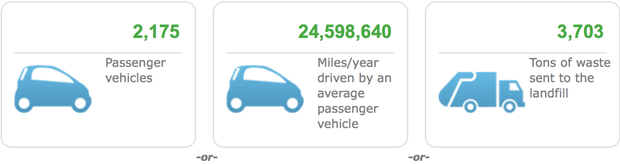
Cogeneration and Trigeneration Plants

- Environmental Effects of Gas Engine Driven Cogeneration and Trigeneration Plants
  - ICE, Lean-burn engines, SCR, 90% NO_x
  - US EPA GHG Equivalency Calculator,
  - 50%, 90%, 41.33%, 48.59%, *PESR*=0.268.
  - 1 MW, 240m^3 NG, 64.4m^3 for 10 years (8400h/year).

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

Cogeneration and Trigeneration Plants

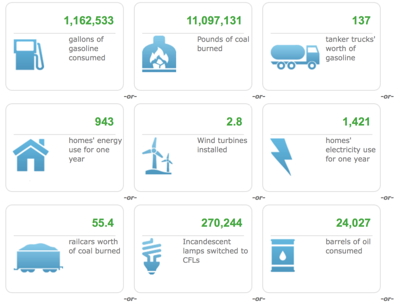
- Environmental Effects of Gas Engine Driven Cogeneration and Trigeneration Plants
  - Equivalent GHG Emissions



DEPARTMENT OF
ELECTRICAL AND ELECTRONIC ENGINEERING

Cogeneration and Trigeneration Plants

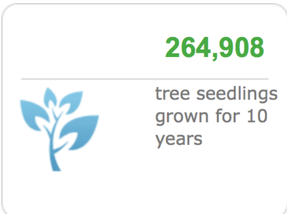
- Environmental Effects of Gas Engine Driven Cogeneration and Trigeneration Plants
  - Equivalent CO_2 Emissions



DEPARTMENT OF
ELECTRICAL AND ELECTRONIC ENGINEERING

Cogeneration and Trigeneration Plants

- Environmental Effects of Gas Engine Driven Cogeneration and Trigeneration Plants
  - Equivalent number of 10 years old tree seedlings



DEPARTMENT OF
ELECTRICAL AND ELECTRONIC ENGINEERING

Conclusions

- Fosters its role in energy efficiency and distributed generation.
- Lower carbon emission, rapid operation for synchronisation, part load operational flexibility, good load following capability, and short payback periods.
- At least 75% efficiency condition changed the cogeneration mentality in Turkey from “Generate, use and sell the surplus energy to the grid” to “Generate as much as you need and utilise the produced energy on-site”.

DEPARTMENT OF
ELECTRICAL AND ELECTRONIC ENGINEERING

DEPARTMENT OF
ELECTRICAL AND ELECTRONIC ENGINEERING

COGENERATION AND
TRIGENERATION PLANTS

Dr Kasım ZOR
EEE407-Renewable Energy