EUROMOT POSITION

15 September 2014

BAT Associated Energy Efficiency Levels

1. INTRODUCTION

In the June 2014 TWG meeting in Seville the set BAT-AEPL efficiency values were discussed and it was decided there is a need to gather more data on this issue due to the big change in operation profiles of the power producing plant in recent years.

In fact **already** in submitted BREF LCP final TWG comments (by end of September 2013) many of the aspects raised in Seville were given in writing; (table "10.19 HFO fired engine" and "table 10.26 natural gas fired engine plants"):

Table 10.19

- Comment 6028 (UK small plant and islands):
    - BAT associated energy efficiency levels for new diesel engines are too high. → Efficiency span to be reduced to 40 .. 48 % for new and 38-45 % for existing engines.
    - Given efficiency levels might be achievable at **test bed conditions for new engines but at real –life operation and cyclic conditions applicability to be checked**
- Comment 7573 (Italy) :
    - General concerns on BAT-AEPLs derived for energy efficiency → Set instead once in the life time BAT AEPL figures measured at plant acceptance test calculated to ISO conditions

  - The 48 % efficiency figure is probable achievable in an engine plant equipped with a steam turbine. Issue to be checked.

- Comment 8394 (VDMA):
  - BAT lower value **too optimistic** for new plant. A single cycle engine electrical efficiency should start from 40 %. → Given span for **new** engine to be reduced to 40 .. 48 %

<u>Table 10.26</u>

- Comment 1468 (UNESA):
  - Energy efficiency should consider **load factor** → Load factor to be included, at which values were obtained.
- Comment 1469 (UNESA):
  - Thermal efficiency range can vary substantially with running load factor, particularily at low loads. As fossil generation plants are **increasingly supporting renewable generation by increased flexibility, operating load ranges are being extended**. … → **Reduce lower limit of thermal efficiency range to account for wider load mode operation and load ranges.** Include explanation of how efficiency is to be assessed stating one off tests - such as a single test at the start of plant life for performance guarantee verification.
- Comment 7584 (Italy):
  - General concerns on BAT-AEPLs derived for energy efficiency. → It is proposed to set out BAT AEPL for energy efficiency referring to a characteristic value measured once in the plant lifetime and referred **to standard ISO conditions** (e.g. the value obtained during the performance test for acceptance of the power plant).

    Further assessments are needed on such an issue.
  - **T**hermal efficiency range ca**<u>n vary substantially with running load factor and start-up and shut-downs.</u>** As fossil generation plants are increasingly supporting renewable generation by increased flexibility, operating load ranges are being extended and starts and stops are being increased. **Lower minimum loads faciliates this, but often has the consequence of lower thermal efficiency.** The ranges suggested can limit the required flexibility, especially if a distinction on plant size is not introduced, this will become more important as levels of renewable generation increase.

In below text some more text is given about above mentioned tables in regard of new stationary RICE (Reciprocating Internal Combustion engine) plants. A typical currenty plant loading/operating situation is briefly showed by an example and typical impacts of part load operation, etc. on the RICE plant performance are given.

2. LCP BREF DRAFT JUNE 2013

In LCP BREF draft dated June 2013 BAT-AEPL (Associated Efficiency Performance Level) yearly average values are given for HFO-fired diesel engines in table 10.19 and for (lean burn ?) gas engines in table 10.26.

Table 10.19: "*BAT associated efficiency levels in the combustion of HFO in* ***engines***":

- new HFO engine combustion plant**:**
    - net electrical efficiency (based on LHV) span is 45 .. 48 %

Table 10.26: "*BAT associated environmental performance for the energy efficiency of natural gas fired combustion plants"*

- new (lean burn ?) gas engine **plant:**
    - net electrical efficiency (based on LHV) span is 42 .. 46.5 % %

<u>**No text** can be found in the LCP BREF draft informing about (as also clearly indicated in above TWG comments):</u>

- <u>if given efficiency figures are given at 0 % tolerance or calculated with a +/- 5 % tolerance</u> allowed by ISO 3046-I standard for the fuel consumption of the RICE. At different site conditions from the reference one the above mentioned standard gives formulas how to adjust the fuel consumption.

  Reference site conditions (ambient air temperature, height above sea level or charge air coolant temperatures are not mentioned either) in context with the tables. ISO 3046-I stipulates as reference conditions:
    - total barometric pressure: 100 kPa
    - air temperature: 298 K
    - Relative humidity 30 %
    - Charge air coolant temperature 298 K

Note ! For gas fired engines engine manufacturer calculation procedures are often used instead of ISO 3046-I.

- Plant **load conditions** are not specified
- Plant efficiency is highly dependent on the plant configuration – which affect the parasitic electrical load of the plant. In a multi engine plant individual engines can be stopped and remaining ones be operated at optimized load points when plant load is varying – plant efficiency remains high, See Annex I. Thus different plants are difficult to compare with each other at part loads. → **preferable gross efficiency should be given at unit alternator terminals**.

A check of the plant specific data questionnaires gathered for the review of the LCP BREF document showed that many times item "*4. Energy Efficiency*" was not assessed properly and a lot of data is missing in this item. The parasitic load in a power plant might vary a lot due to plant construction, e.g. a plant producing electricity only operating on gas do not need FGD (Flue Gas Desuplurization) units as a liquid fired plant operating on high ash/sulphur HFO do. As a consequence the parasitic load in the plant operating on the clean fuel will have a much lower parasitic load (typically in order of 2 .. 4 % of total produced plant electricity) compared to the plant equipped with comprehensive emission secondary abatement techniques. The power consumption varies also a lot between different secondary abatement techniques such as FGD. Thus it should be more logical to give efficienciy as **brutto on electrical terminals with 0 % of the RICE** otherwise is a big risk of errors/confusions. E.g. according to the obtained questionnaires only one diesel plant equipped with a steam turbine achieved the 48 % **gross** electricity (**NOT** net !), other plant efficiency figures were much lower. Most plans were operating at almost full 100 % load or at a high loading conditions, **NOT** at lower part loads !

Thus a thorough check of above efficiency tables are to be done at least for the new plant cases, associated plant loads, tolerances, etc. to be shown.

The efficiency values in the questionnaires are said to be based on plant data gathered in year 2010. In recent years due to the increased penetration of intermittent renewable energy sources such as wind, many thermal power plants have been stopped/got fewer operating hours or are running today at part loads outside their optimal design point with lower efficiencies as a result.

3. RICE PLANT OPERATION PROFILE EXAMPLE IN THE FIELD

Due to the increased penetration of intermittent renewable power sources such as wind and solar thermal power plants are more frequently used today as grid frequency and back up plants in order to maintain the electrical capacity balance of the electrical grid. Thus steady high load operation is not today the normal operation in many power markets. Prices on oil and natural gas in the EU market today are high and in combination with low electrical retail prices, base load electrical power production is not economically feasible (at the time being) with these fuels. Spot market (peaking, grid stabilization, etc.) electrical prices are more of interest for plants using these kind of fuels.

Below figure 1 is showing a typical operation profile of a 130 MWe gas fired RICE plant, seen big plant load variations occur depending on TSO (Transmission System Operator) needs.

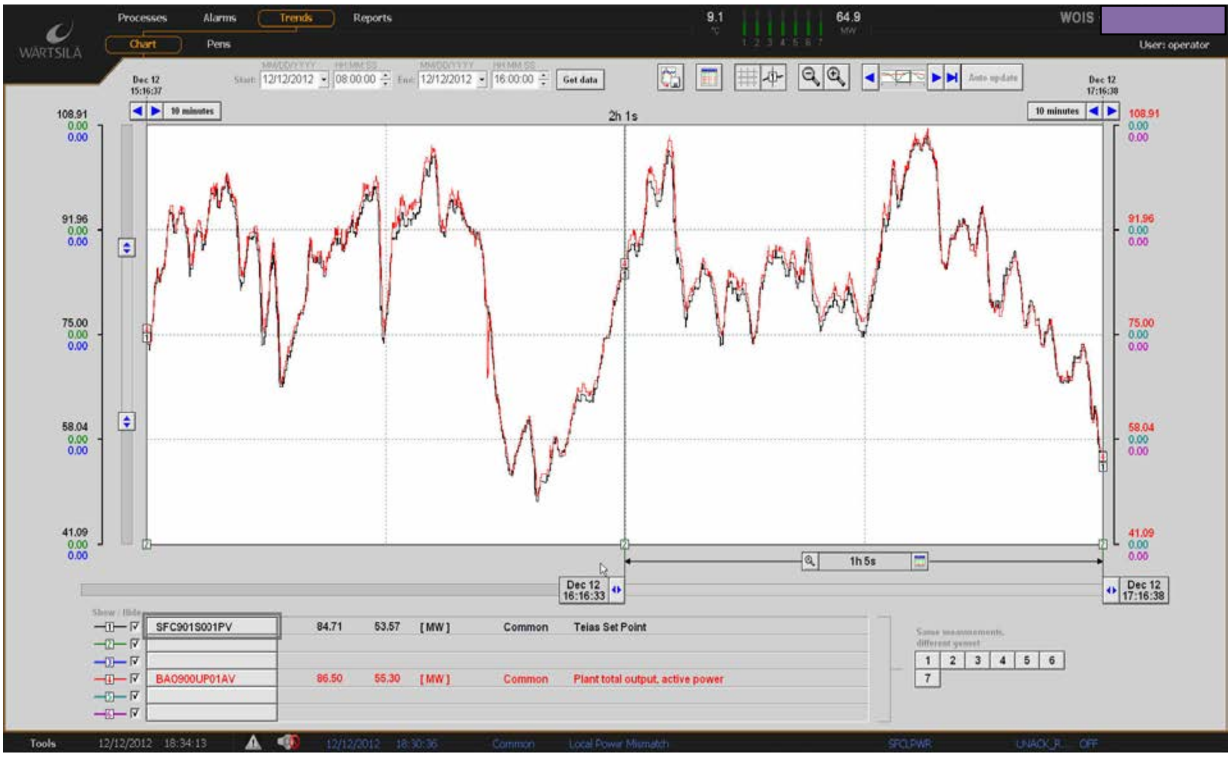

Figure 1: **Gas Engine Power Plant consisting of 7 engine units, 130 MWe, 2 hour Power Plant SCADA Trend. Plant set point signal from the Grid, TSO is typically 40-110 MW in this case.**

In Annex II a typical start up of a SG type gas engine unit is shown, more information about start up /shut down times, part load performance in chapters below.

4. PART LOAD TYPICAL IMPACTS ON EFFICIENCY, START UP/SHUT DOWN TIMES OF RICE PLANTS

4.1 General

At part loads efficiency of the “RICE package” will drop due to amongst all following reasons:

- Turbo Charger (TC) matching is not optimal for low loads
- Electrical alternator efficiency is lower at part loads
- Friction losses are constant so impact of these increases at lower loads
- Engine tuning to keep stipulated emission limits (NOx, unburned gaseous emissions: CO, etc. - peak pressure, etc. not optimal).
- Less efficient combustion at low loads

- Heat balance of engine not optimal: on some engine types flue gas temperature rises (higher flue gas temperature <-> less efficient engine).
- Etc.

Most common RICE used in big engine power plants are of diesel, lean burn spark iginition and low pressure gas dual fuel (DF) types. Minimum size of prime mover unit affected by IED 2010/75/EU is 15 MWth (= about 6 ..6.5 MWe gross at engine alternator terminals). Below text is describing some impacts on big Diesel, DF and SG unit types.
For more information on typical engine sizes see ANNEX III and chapter "OO" of UNECE Gothenburgh Protocol at:

http://www.unece.org/fileadmin/DAM/env/documents/2012/air/Guidance_document_on_control_techniques_for_emissions_of_sulphur__NOx....pdf .

4.2 Diesel Engine and liquid fired DF

In following text HFO engine electrical efficiencies in table 10.19 of the EU LCP BREF draft have been compared to information available on internet by two leading engine manufacturers of bigger power plant RICE /1, 2/ (corrections for tolerances, engine driven pumps, alternator efficiency done when needed). Engine types used in liquid fired power plants are of diesel and low pressure gas dual fuel (DF) (in liquid mode) types. The low pressure gas DF type is designed primarily for gas mode but can also operate for long periods on liquid fuels only (such as HFO) if gas is not available.

Gross efficiency (at 0 % tolerance) **at alternator terminals at ISO 3046-I conditions** for a **new** HFO fired RICE (**IFC 2007/2008 NOx rated***) varies typically dependent on unit/size/type as follows:

a) Diesel engine:

100 % unit load

42.5 – 44.8 % **Gross**

Engine efficiency drops (see text above) at lower unit load (compared to full load) and will at 50 % MCR load of the unit be typically about: 2.5 - 3 %-units lower (gross at engine alternator terminals) than figures at full load (MCR), to be checked case by case.

A typical liquid fired engine plant producing electricity only using primary emission abatement (engine IFC 2008 NOx emission optimized, low ash/sulphur liquid fuel) techniques (**no** FGD, ESP, etc.) own consumption of produced power is typically in order 2 .. 4 %.

Then plant net (at alternator terminals of the RICE) efficiency will then be in order:
100 % unit load (with 0 % tolerance), typically:

40.8 – 43.9 % **Net**

Note also above text on lower efficiencies at part loading !

Plant configurations might be very different from simple to comprehensive and thus parasitic loads will vary from plant to plant. **Thus unit efficiencies should be given as gross alternator output of the RICE (at MCR, at ISO 3046-I conditions) in order to be meaningful.**

→Table 10.19 efficiency values are to be checked !

RICE are fast and thus can be fast started and stopped depending on the electrical need of the grid. RICE are kept preheated in order to have a fast response. Below are given some typical span times /3/.

- **Regular start** –

"Warm stand-by (preheated or operated in the last 12 hours)":

- Synchronization to the grid in typically less than 1- 3 minutes (depending on engine type)
- O % to 100 % load in typically less than 6 - 15 minutes (depending on engine type)

- **Fast start** –

"Hot stand-by (preheated to a higher temperature or operated in the last 6 hours):

- Synchronization to the grid in typically less than 1 minute
- O % to 100 % load in typically less than 3 - 10 minutes (depending on engine type)

-Stop time (time to decrease output from 100 % to 0% load, disconnect from grid and complete stop operation):

- typically less than 1 minute

Minimum continous load of a single unit: 30 % of MCR (might vary due to engine type). **Note if plant consists of 10 engine units, plant minimum loading is then down to 3 % !**

b) Low pressure gas DF engine in liquid mode:

100 % unit load (with 0 % tolerance), (**IFC 2008 NOx rated***) at engine alternator terminals typically:

41.5 – 43 % **Gross**

Engine efficiency drops (see text above) at lower unit load (compared to full load) and will at 50 % MCR load of the unit be about: 2.5 - 3 % units lower (gross at engine alternator terminals), to be checked case by case.

See above plant net efficiency text. **Engine efficiencies should be given as gross alternator output in order to be meaningful.**

→Table 10.19 efficiency values to be checked !

RICE are fast and thus can be fast started and stopped depending on the electrical need of the grid. RICE are kept preheated in order to have a fast response. Below are given some typical span times /3/.

- **Regular start** –

"Warm stand-by (preheated or operated in the last 12 hours)":

- Synchronization to the grid in typically less than 1- 3 minutes (depending on engine type)
- 0 % to 100 % load in typically less than 6 - 15 minutes (depending on engine type)

- **Fast start** –

"Hot stand-by (preheated to a higher temperature or operated in the last 6 hours):

- Synchronization to the grid in less than 1 minute
- O% to 100 % load in less than 3 - 10 minutes (depending on engine type)

-Stop time (time to decrease output from 100 % to 0% load, disconnect from grid and complete stop operation):

- typically less than 1 minute

Minimum continuos load of a single unit: 30 % of MCR (depending on engine type). **Note if plant consists of 10 engine units, plant minimum loading is then down to 3 % !**

4.3 Lean Burn spark gas engines of SG and DF types

In following text given (lean burn) gas engine electrical efficiencies in table 10.26 of the EU LCP BREF draft has been compared to information available on internet by two leading engine manufacturers of bigger power plant RICE /1, 2/. Engine types used in power plants operated on are of spark ignited (SG) and low pressure gas dual fuel (DF) types. For the GD (high pressure gas) diesel, see liquid fired chapter above (NOTE ! in this case the high power consumption of the gas compressor which vary greatly due to gas inlet pressure from the pipeline).

Gross efficiency (with 0 % tolerance) <u>at alternator terminals at ISO 3046-I conditions</u> for a **new** gas fired SG/DF varies typically dependent on type as follows (**IFC 2007/2008 NOx rated***):

a) DF (gas mode):

100 % unit load, typically high compression):

42 – 45.6 % (**MN > 80**) **Gross**

With lower Methane Number of the gas engine fuel consumption will increase (less efficient) and engine output might have to be derated. Lower NOx rating will also detrimentally affect efficiency.

See above plant net efficiency text. **Engine efficiencies should be given as gross alternator output in order to be meaningful.**

Engine efficiency drops (see text above) at lower unit load (compared to full load) and will at 50 % MCR load of the unit be typically about: 6 % units lower (gross at engine alternator terminals), to be checked case by case.

- ➔ **Table 10.26 is rather optimistic and needs to be corrected !**

- **Regular start** –

"Warm stand-by (preheated or operated in the last 12 hours)":

- Synchronization to the grid in less than typically 3 minutes (depending on engine type)
- 0 to 100 % load in less than typically 10 - 15 minutes (depending on engine type)

- **Fast start** –

"Hot stand-by (preheated to a higher temperature or operated in the last 6 hours):

- Synchronization to the grid in less than typically 2- 3 minute (dependent on engine type)
- 0 to 100 % load in less than typically 6 - 10 minutes (depending on engine type)

-Stop time (time to decrease output from 100 % to 0% load, disconnect from grid and complete stop operation):

- typically less than 1 minute

Minimum continous load of a single unit: 30 % of MCR (depending on engine type). **Note if plant consists of 10 engine units, plant minimum loading is then down to 3 % !**

b) SG (NOx 190 mg/Nm3 (15 % O2) tuning, natural gas with Methane Number > 80), 100 % unit load, typically:

43 – 46.2 % **Gross**

With lower Methane Number of the gas engine fuel consumption will increase (less efficient) ditto for lower NOx rating and engine output might have to be derated.

See above plant net efficiency text. **Engine efficiencies should be given as gross alternator output in order to be meaningful.**

In Annex IV some typical efficiency (note given at HHV) figures at 50 .. 100 % engine loads are shown with different size engine types.

- ➔ **Table 10.26 is rather optimistic and needs to be corrected !**

- **Regular start** –

"Warm stand-by (preheated or operated in the last 12 hours)":

- Synchronization to the grid in typical less than 2 minutes
- to 100 % load in typically less than 10 minutes

- **Fast start** –

"Hot stand-by (preheated to a higher temperature or operated in the last 6 hours):

- Synchronization to the grid in typically less than 2 minutes
- to 100 % load in typically less than 5 minutes

-Stop time (time to decrease output from 100 % to 0% load, disconnect from grid and complete stop operation):

- typically less than 1 minute

Minimum continous load of a single unit: 30 % of MCR (depending on engine type). **Note if plant consists of 10 engine units, plant minimum loading is then down to 3 % !**

5. CONCLUSIONS

Above has been shown with help of information available in the open literature that the given efficiency figures in LCP BREF June 2013 draft in tables 10.19 (HFO engine plant) and 10.26 (Gas engine plant) are too optimistic. It is unclear if fuel tolerance used often by RICE manufacturers have been considered or not (shall be deducted if efficiency given with 0 % tolerance!), given figures seem (as shown in text above) to be similar to gross efficiency figures at engine alternator and not plant net output, gas fuel not specified, etc.

Thus a thorough correction is needed of the figures in the table especially for the new engine plant.

Prime mover (reciprocating internal combustion engine) efficiencies should be given as gross alternator output in order to be meaningful.

***IFC 2007/2008 at**
http://www.ifc.org/wps/wcm/connect/Topics_Ext_Content/IFC_External_Corporate_Site/IFC+Sustainability/Sustainability+Framework/Sustainability+Framework+-+2006/Environmental%2C+Health%2C+and+Safety+Guidelines/ :

- IFC General EHS Guidelines 2007
- IFC Thermal Power Plants EHS Guidelines 2008

6. SOURCES

/1/ Wärtsilä Power Plant Product Catalogue 2012 at
http://www.google.fi/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CCgQFjAA&url=http%3A%2F%2Fwww.wartsila.com%2Ffile%2FRussia%2F1278526776145a1267106724867-Power-Plants-Product-Catalogue-2012-2nd-edition.pdf&ei=AdL6U4H8Foev0QXIiIC4BQ&usg=AFQjCNEWm2KLdVrT7O5G8IGmYi51ItO6wQ&bvm=bv.73612305,d.ZWU

/2/ MAN Diesel Turbo Power Plants Programme 2014 at
http://www.mandieselturbo.com/files/news/filesof16045/Power%20Plants%20Programme%202014.pdf

/3/ Wärtsilä Power Plant Product Catalogue 2014 at
http://www.wartsila.fi/en_RU/power-plants/overview

/4/ Smart Power Generation presentation April 2013 by D. Shelledy (Wartsila Inc.) at
http://www.mcilvainecompany.com/Universal_Power/Subscriber/PowerDescriptionLinks/Dan%20Shelledy,%20Wartsila%20-%205-16-13.pdf

/5/ STEC letter to US EPA at
http://www.epa.gov/region6/6pd/air/pd-r/ghg/stec-redgate-response-letter-final060713.pdf

/6/
http://www.unece.org/fileadmin/DAM/env/documents/2012/air/Guidance_document_on_control_techniques_for_emissions_of_sulphur__NOx....pdf

/7/ http://www.powermag.com/top-plantsgoodman-energy-center-hays-kansas/?pagenum=3

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EU Transparency Register ID number: 6284937371-73

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LOMBARDINI
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ROLLS-ROYCE POWER SYSTEMS
SAME DEUTZ-FAHR
SCANIA
STEYR MOTORS
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EMAK
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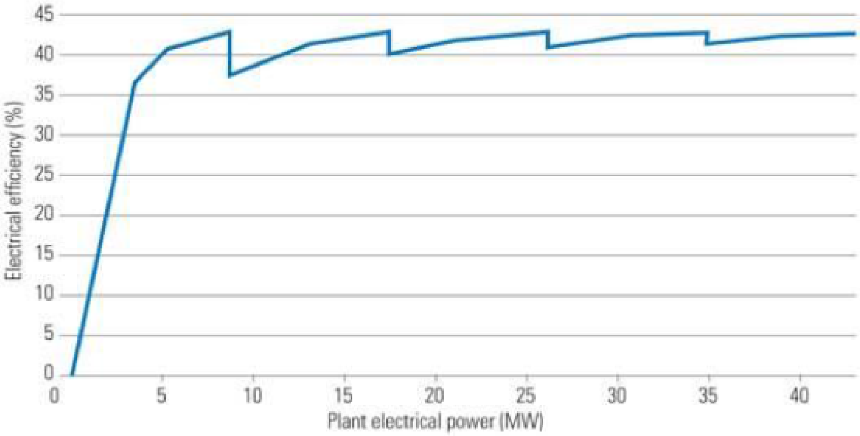
HUSQVARNA GROUP
KAWASAKI EUROPE
KOHLER GLOBAL POWER GROUP
SOLO
STIHL
TORO EUROPE
WACKER NEUSON
YAMABIKO GROUP

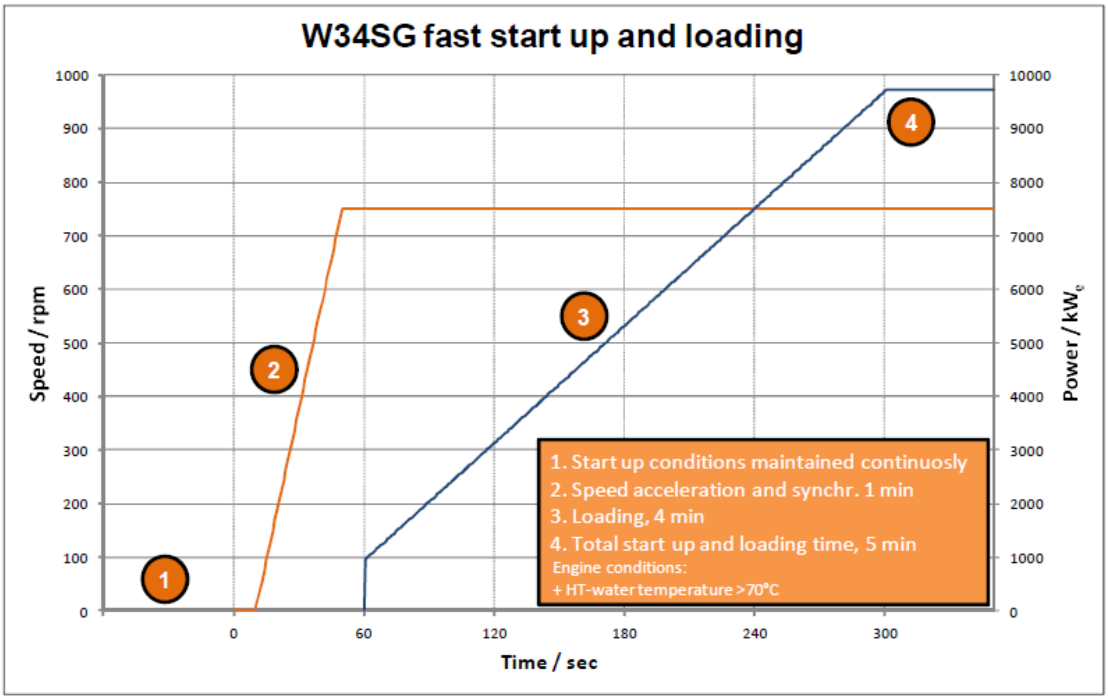
ANNEX-I /7/:



2. Even efficiency. The dispatch plan for the first five of the nine Wärtsilä 20V34SG engines at the Goodman Energy Center shows that very little efficiency is lost with part-load operation. *Source: Wärtsilä*

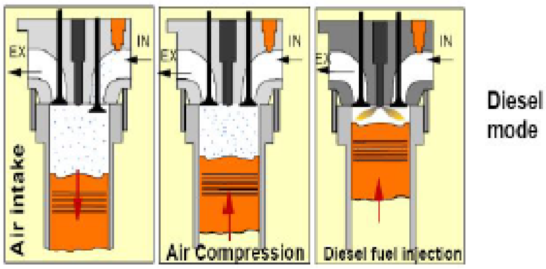
ANNEX-II /4/:

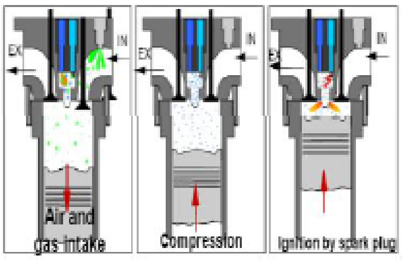
W34SG, fast start up and loading

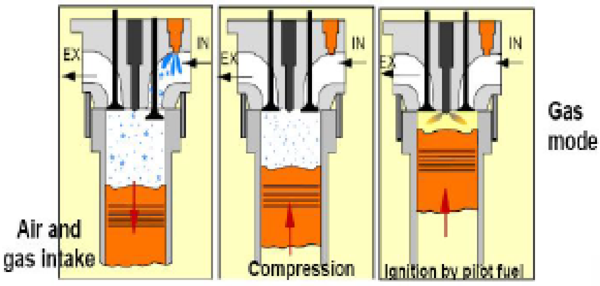


<u>ANNEX-III /6/:</u>

Main engine types according to fuels used

<table>
<tr><th>Engine</th><th>Engine description</th></tr>
<tr><td>


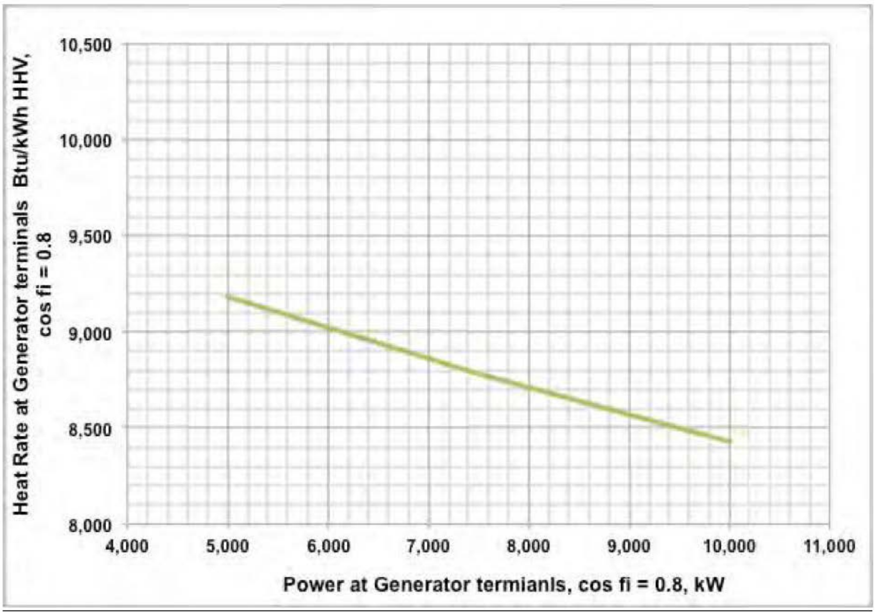
</td><td>Compression ignition engines operate according to a Diesel cycle whereby air and fuel are injected separately (not mixed) into the cylinder: air is injected and compressed by a piston. At the end of the compression stroke fuel is injected, it ignites on contact with the hot air. In gas mode high pressure gas is used</td></tr>
<tr><td>


Gas engine, spark ignition (by a spark
</td><td>Lean-burn gas engines operate according to an Otto cycle, whereby fuel and burning air are premixed before injection into the cylinder. The spark ignited lean burn engine is a "pure" gas engine and the gas fuel is ignited by e.g. a spark plug.</td></tr>
<tr><td>


</td><td>Dual fuel engines operate according to a diesel cycle when firing liquid fuels or, when used with gaseous fuels, to an Otto cycle. In gas mode ignition is at the end of the compression stroke via the injection of a small amount of pilot liquid fuel. In gas mode low pressure gas is used.</td></tr>
</table>

ANNEX-IV /5/:

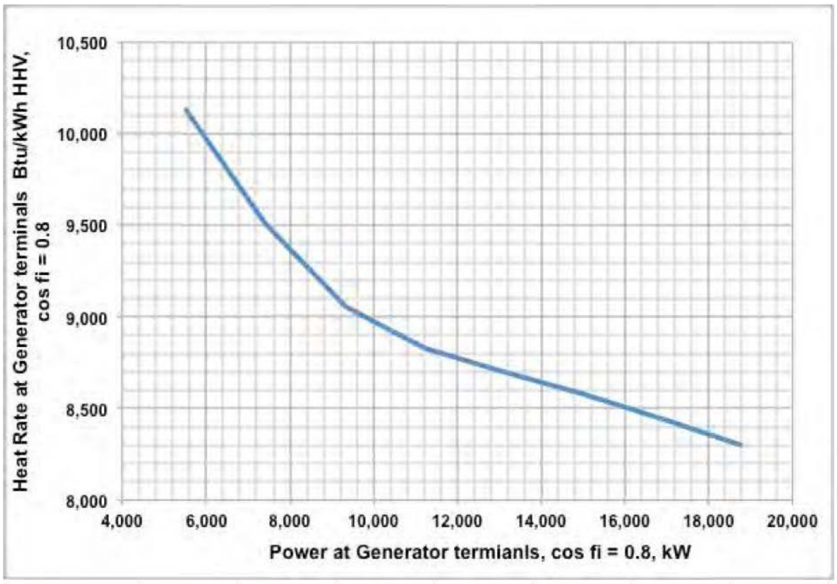
Heat rate (Btu/kWh) as a function of power (gross kW) – Caterpillar G20CM34[(1)(2)]



% load	50%	75%	100%
Load, kW	5,000	7,500	10,000
Btu/kWh (HHV)	9,410[(1)]	9,000[(2)]	8,640[(2)]
% efficiency	36.3	37.9	39.5

(1) From Manufacturer's Published Data (Caterpillar)
(2) Estimated for RICE Generators from Manufacturers Information

Heat rate (Btu/kWh) as a function of power (gross kW) – Wärtsilä 18V50SG[(1)]



% load	40%	50%	60%	70%	80%	90%	100%
Load, kW	7,420	9,341	11,226	13,121	15,007	16,883	18,759
Btu/kWh (HHV)	9,510	9,053	8,829	8,702	8,580	8,443	8,302
% efficiency	35.9	37.7	38.7	39.2	39.8	40.4	41.1

(1) Manufacturer's data (Wärtsilä)