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Power Engineer

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the independent technical forum for power generation

June 2018
Volume 22 Issue 2

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The Institution is expressly devoted to the advancement of diesel, dual-fuel and gas engines, gas turbines and related products and technologies.

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Director General's message

It hardly seems possible that it is the end of May already – going out with a roar, including thunderstorms and spectacular lightning displays.

May has been particularly busy at IDGTE – starting with our Seminar and Luncheon on the 3rd May at the Grange Tower Bridge Hotel. I felt that this year's event was our most successful since we moved venues to the Grange Tower.

The presentations and speeches were very good and thought provoking, with good food and quite a buzz during the day combined to make a great event. I hope members who were present felt the same. A full report can be found on page 18.

On 16th May, an IDGTE visit to Ricardo at Shoreham and the University of Brighton was organised and hosted by Simon Brewster, CEO of Dolphin N2. This is a "spin out" company from Ricardo focussed on the development and commercialisation of the CryoPower engine.

This was a really great visit with 20 in the IDGTE party who were treated to presentations from senior Ricardo personnel including Professor Neville Jackson and Nick Owen, as well as a tour of the Shoreham Technical centre.

The afternoon visit to the University of Brighton was hosted by Dr Robert Morgan, an IDGTE member. This covered the rig work related to the CryoPower engine and associated systems and gave rise to enthusiastic discussion.

I was struck by how engaged the people in the IDGTE party were throughout the day. A report of the visit is included on page 15.

There are interesting upcoming events being organised by IDGTE as well – as listed in this issue. We hope that these are of interest to members and guests – in particular the Emissions Seminar on 18th September, the Internal Fire Museum of Power weekend in Wales at the end of September and the Gas Turbine Papers day in Peterborough in October – as well as the Annual General Meeting in October.

We are also working with Wärtsilä to arrange the technical visit to their facilities in Trieste which was to be in June but is now scheduled for September – date to be confirmed. It proved difficult to get our "ducks in a row" in time for June and for some reason people like to go away in Summer!

Let us hope that the UK weather is good and I hope that we all have a great summer whether in the UK or abroad. ■

Mike Raine, Director General

IDGTE to support

Primary Engineer® Programmes ...the first step

IDGTE is pleased to become a supporter of Primary Engineer

In this Year of Engineering, IDGTE and Primary Engineer are delighted to announce that they are working together to enthuse young people to consider a great career in engineering and all the industry has to offer them.

In this new initiative, IDGTE will support Primary Engineer in promoting engineering through its schools programmes in primary schools and also through its partner organisation, Secondary Engineer, in secondary schools.

To find out more about how to get involved and make a difference to the lives of young people and the world of engineering, go to www.idgte.org and check out the Ambassadors page – or contact Dr Susan Scurlock, CEO and Founder of Primary Engineer at susan.scurlock@primaryengineer.com.

Look out for future updates on progress with this important work and this exciting new partnership. ■

Team Britannia

An update on Portsmouth-based Team Britannia's attempt to break the round the world powerboat record

Work on the round the world powerboat "Excalibur" proceeds apace at ABC Marine's Hayling Island boatyard.

All six of the boat's 6,000 litre fuel tanks have been installed, along with all the bulkheads which divide the boat into various compartments.

At the time of writing, the first panels of deck have been attached, so it is looking a lot more like a boat than simply open framework. This will be followed up with the wheelhouse - already assembled - being craned into place and attached.

The engine room space at the stern has been prepared to accept the two FPT diesel engines, Castoldi jet drives and Clean Fuel mixing apparatus; so with the major engineering on the boat drawing to a close, work on fitting her out can begin before launching her into the water - hopefully in July.

Crew member Steve Mason standing on one of the fuel tanks through the deck frames. The stern is in the distance.

Slav and Stas, two of our fantastic welders, providing a bit of scale to the fuel tanks and boat

"*Everyone working on the boat has done a first class job*," says Team Britannia principal and skipper Alan Priddy. "*After all the delays, it's fantastic to see things happening so quickly. Getting her in the water and starting sea trials is now just weeks away!*"

More news in the September 2018 issue. ■

Fuel tanks five and six, with the final bulkhead leaning against the wall to the right

Background

Team Britannia is a multi-million pound British bid led by ocean adventurer Alan Priddy to design and build the fastest and most fuel-efficient wave-slicing powerboat to circumnavigate the globe for the much coveted UIM world record, currently held by New Zealander Pete Bethune at 60 days 23 hours 49 minutes.

Wärtsilä's support for development of Bangladesh continues with another power plant delivery

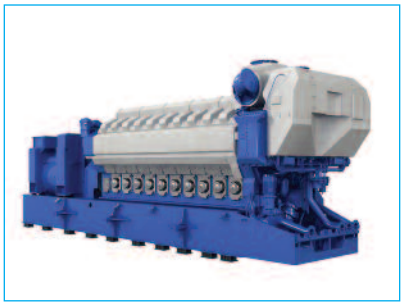
For 20 years, the technology group Wärtsilä has supported the economic development of Bangladesh through the provision of electricity generating capacity. This support is continued with the latest contract for a 113MW power plant to be delivered to Chowmuhoni, Bangladesh. The order was placed by HF Power Ltd and was booked in April. HF Power is part of the Hosaf Group, one of the largest and fastest growing companies among the private sector manufacturing and service-based enterprises in Bangladesh.

An important element in Wärtsilä's successful share of the Bangladeshi power market has been its ability to deliver on a fast-track basis. The country's government is committed to providing a reliable electricity supply to both industrial and domestic consumers. For example, in 2016 only 76 percent of the country's houses were connected to the grid, and the aim is to increase this to 98 percent by the year 2021. The urgency of this programme calls for the fast development of new generating facilities. Wärtsilä has repeatedly shown that it has the flexibility and capacity to meet this need.

This latest order for 12 Wärtsilä 32 engines running on heavy fuel oil (HFO) is scheduled for delivery in October of this year. The new plant is expected to be fully operational by June 2019.

"Our need is for generating equipment that is highly efficient, highly reliable, and that can be delivered in line with a very tight schedule. Wärtsilä's reputation and local presence is strong and we feel very confident that they are the right company for this project," commented Mr Moazzam Hossain, Chairman of HF Power.

"This is another very important order that will help bring additional electrical power to this region. This in turn will encourage the growth of local industries and, therefore, will create new jobs. We at Wärtsilä are delighted to be able to be involved in this positive development," noted Mr Jillur Rahim, Managing Director, Wärtsilä Bangladesh.



During the past 12 months, Wärtsilä has previously booked orders for 10 power plant projects in Bangladesh. Today, Wärtsilä provides about 25 percent of the total grid capacity in the country and when fully operational in summer 2019, the new plant will bring Wärtsilä's total power supply to Bangladesh to more than 4,300MW. ■

Final commissioning at oil refinery in South Korea

James Richmond, Business Solutions Director at Peter Brotherhood Ltd recently reported that Peter Brotherhood engineers are currently in the process of the final commissioning of a 22MW extraction back pressure steam turbine generator set in an oil refinery in South Korea.

Included in their scope is the API 612 steam turbine, the API 613 gearbox and the API614 oil system and the generator and control and protection system. ■

Final commissioning currently taking place

Upgrading combined heat and power generation plant at Thames Water Mogden Sewage Treatment Works

David Linsell BSc MSc CEng FIMarEST FIMechE MIDGTE
Thames Water – CHP Specialist

Introduction

This paper describes the work in 2016 to install 3 x 2MWe biogas combined heat and power (CHP) generators at Mogden Sewage Treatment Works (STW). These were to replace the 4 x 2.4MWe dual fuel engines installed in the early 1990s. The current project was achieved in good order despite the challenges provided by limited space, an operational site, a new to Thames Water contracting strategy and the regulatory deadline imposed by closure of the Renewable Obligations Certificate (ROC) regime.

This paper follows on from an IDGTE technical visit to Mogden STW in October 2016. The paper includes a summary of sludge processing by Thames Water, operations at Mogden STW, the Mogden CHP Project, the Thames Water CHP fleet and maintenance and some future developments.

CHP has been part of the Thames Water, and its predecessors, business at Mogden since 1936. In the 1980s the state of CHP developments across Thames Water were presented in papers written by the late Harry Maurer and published in the IDGTE *Power Engineer*:

- Paper 458 - *CHP Installation in Medium Sewage Treatment Works*

  H F Maurer, FIPlantE, MBIM, MIDGTE
- Paper 483 - *Small Scale Combined Heat & Power Plants in Thames Water Provinces*

  H F Maurer IEng FIPlantE FIDGTE MIMgt

Thames Water Sludge Processing

Thames Water is the UK's largest water and waste water company serving some 10 million customers, delivering ~2,700 million litres of clean tap water per day and 15 million customers, treating ~4,500 million litres of sewage waste per day. The difference in the customer and volume numbers for clean and waste waters is accounted for by the differences in the clean and waste water catchments, see Figure 1. To achieve this there is a network of around ~87,000km of pipework across clean and waste water connecting our

Figure 1 Thames Water Area Map

customers with 102 water treatment works and 350 sewage treatment works.

The ~4,500 million litres of sewage per day results in a loading of ~1,300 tonne Dry Solids (tDS) per day, or ~500,000 tDS per year. The primary purpose of all the sewage treatment works is to return clean water to the environment. To achieve this the solids in sewage sludge must be extracted and treated to achieve pathogen kill, to remove e-coli and similar, and hence to create quality clean 'cake' for disposal to land. Cake disposal to land is a challenge as there are restrictions on the quality of cake, the times of the year when cake can be spread and the time between cake spreading and crop harvesting. And, as anyone living in the south-east of England will be aware, cake spreadable farm land is disappearing to be replaced by housing and other developments. More houses, means more people, means more sludge but less land for final disposal. This conundrum has driven developments in sludge processing technology, described below.

At 25 of the sewage treatment works, designated as sludge centres, the sludge drawn from primary and secondary settlement is digested to produce biogas, a mixture of methane and carbon dioxide.

Presently Thames Water is using three digestion schemes:

- Mesophilic Anaerobic Digestion (MAD) – see Figure 2
- Pasteurisation before MAD – see Figure 3
- Thermal Hydrolysis Process (THP) before MAD – see Figure 4

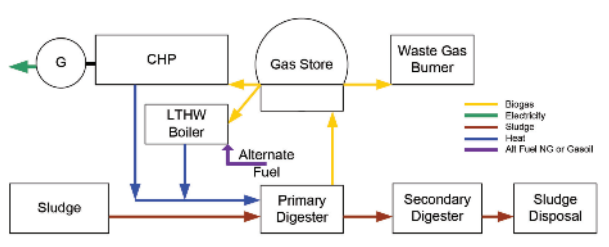


Figure 2 Mesophilic Anaerobic Digestion (MAD)

Mesophilic Anaerobic Digestion (MAD), Figure 2, has been used at Mogden STW since the mid-1930s. MAD is used extensively throughout the water industry, and now increasingly in treating farm and food wastes. In the basic MAD process sludge is taken into a digester which acts like a large stomach operating at 35-40°C. The sludge composition is ~77% volatile material capable of break-down to yield biogas and ~23% non-volatile material. Bacteria in the digesters break down the sludge, initially to form volatile fatty acids (VFA) and release carbon dioxide. In a second stage of digestion the VFAs are converted into methane. The resulting biogas is typically 60% methane, 40% carbon dioxide. The process of releasing biogas destroys ~55% of the incoming volatile solid material. After approximately 15 days in the primary digester the gas liberation is substantially completed but the sludge still requires a longer time to achieve the necessary pathogen kill. This additional time is carried out in a secondary digester. The MAD process yields approximately 350 Nm^3/tDS.

MAD is presently employed at 14 Thames Water sludge centres.

As a means of improving pathogen kill, pasteurisation plants, Figure 3, heat incoming sludge to 65-70°C and lock-in the temperature for up to 30 minutes. Thereafter the sludge is cooled and transferred to digesters operating at circa 40°C. Due to the good pathogen kill, achieved by the initial elevated temperature, there is no need for secondary digestion, resulting in a lower plant foot print. The pasteurisation process yields approximately 380 Nm^3/tDS and destroys ~65% of incoming volatile solids.

Pasteurisation is employed at two STWs.

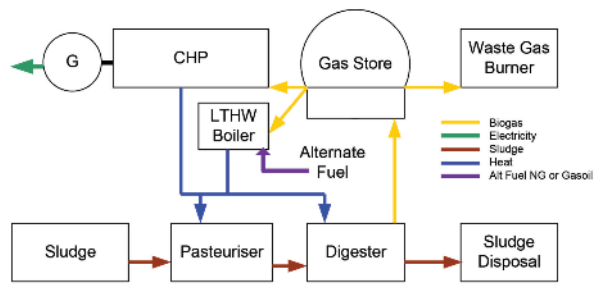


Figure 3 Pasteurisation with MAD

A further improvement in sludge treatment is achieved using thermal hydrolysis plant, Figure 4 and Figure 5. In this scheme the sludge is heated and pressurised using steam injection to 6 Barg and locked-in for 30 minutes. The lock-in period, with elevated temperatures, allows for pathogen kill. At the end of the lock-in period the sludge is rapidly decompressed which results in the sludge cell walls bursting

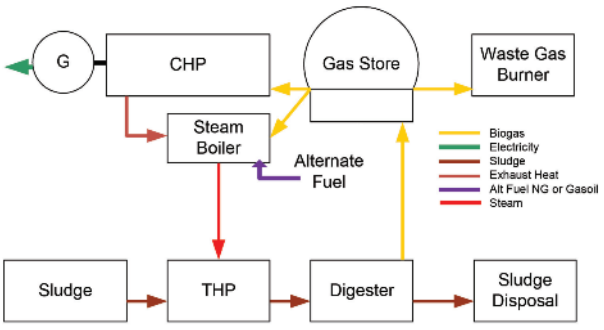


Figure 4 Thermal Hydrolysis Process with MAD

Figure 5 Typical small THP plant

open and allowing the subsequent digestion bacteria unfettered access to the 'food' within the cell. Again, the improved pathogen kill eliminates the need for secondary digestion.

The full THP process is:

- Sludge admitted to the pulper
- In the pulper sludge is pre-heated by steam discharged from the flash tank
- Preheated sludge transferred from pulper to a reactor. Each THP plant has several reactors as the reactor lock-in time is longer than the pulper or flash tank phases of treatment
- The reactor is charged with live steam to 6 Barg. The pressure is locked in for 30 minutes
- At end of the lock-in period the sludge is released/decompressed into the flash tank, the arising flash steam is sent to the pulper
- From the flash tank, sludge is discharged via a cooler to enter the digesters at 40°C.

The THP process yields approximately 420 Nm^3/tDS, destroying ~70% of incoming volatile solids.

The THP process is now employed at eight Thames Water sludge centres and is presently the process of choice for future plant upgrades.

Necessarily with 350 STWs but only 25 sludge centres (24 generating power, 1 running gas-to-grid) there are regular road tanker movements to transfer sludge from satellite sites into the appropriate sludge centre. See Figure 6.

The bottom line for power generation from sewage sludge is as follows:

Sludge	~77	g
DS/person/day	~13,000	people/tonne
MAD		
Biogas	350	Nm3/tDS
CHP	2.5	kWh/Nm3
Electricity	875	kWh/tDS
Contribution	67	Wh/p/d
THP		
Biogas	420	Nm3/tDS
CHP	2.5	kWh/Nm3
Electricity	1050	kWh/tDS
Contribution	80	Wh/p/d

Thames Water is now generating ~310GWh per year from sewage, ~24% of our total electricity consumption and making a significant contribution to reducing customer bills.

The majority of Thames Water generation from sewage is directly consumed by the host site. Small volumes are exported where host site demands are below the generating capability: exported power earns only half the value of off-setting imported electricity. Generation from sewage sludge qualifies for receipt of Renewable Obligation Certificates (ROCs) and provides a welcome additional income stream.

Figure 6 Typical sludge tanker

ROCs are issued, banded, based on the technology employed and on the date of commissioning. The ROC scheme is now closed to new generating plant.

Mogden STW

Mogden STW is sited near to the rugby stadium at Twickenham. The works treats the sewage from a population of over 2 million people in south west London. The works were originally built by the Metropolitan Water Board in 1936. As most sites of the time a location was chosen that was then reasonably well separated from nearby habitation, see Figure 7.

Figure 7 Aerial photograph of Mogden STW under construction circa 1935

Since then the site has been extended and now occupies all the ground to the lower half of the photograph (inside the white line). The site, like many others within Thames Water, has also become fully and closely surrounded mostly by housing and small industrial units pressing up to the boundary.

Today sewage treatment at Mogden is based on activated sludge processing with pasteurisation. The sewage treatment sequence is described below, see also Figures 8 and 9:

- Inlet works – providing screening of rag and other materials, and de-gritting
- Primary settlement tanks – slowing the flow to allow settlement of solid material. This settles out approximately 50% of the solid material in the inflow stream. Sludge is drawn off and sent to the sludge stream
- Aeration lanes – bubbling of air through the remaining flow to destroy solid material

- Final settlement tanks – slowing the flow to allow settlement of the now activated sludge. Sludge is drawn off and sent to the sludge stream. The liquor passes through a final stage of filtration before being discharged into the River Thames
- Sludge drawn from Primary and Final settlement stages is at less than 1% dry solid material.
- The sludge is thickened to ~5% dry solids using a range of plant; picket fence thickeners, centrifuges, drum thickeners and belt presses
- Thickened sludge is sent to pasteurisation plant. This heats the sludge to 65-70°C to achieve pathogen kill
- Pasteurised sludge is cooled and fed to the 16 operational digesters. Under anaerobic conditions the digestion releases biogas, a mixture of methane and carbon dioxide, over an average retention period of 15 days
- From the digester the sludge is transferred by a sludge main to a satellite works at Perry Oaks for de-watering to form cake, which is then sent to farm land as fertiliser.

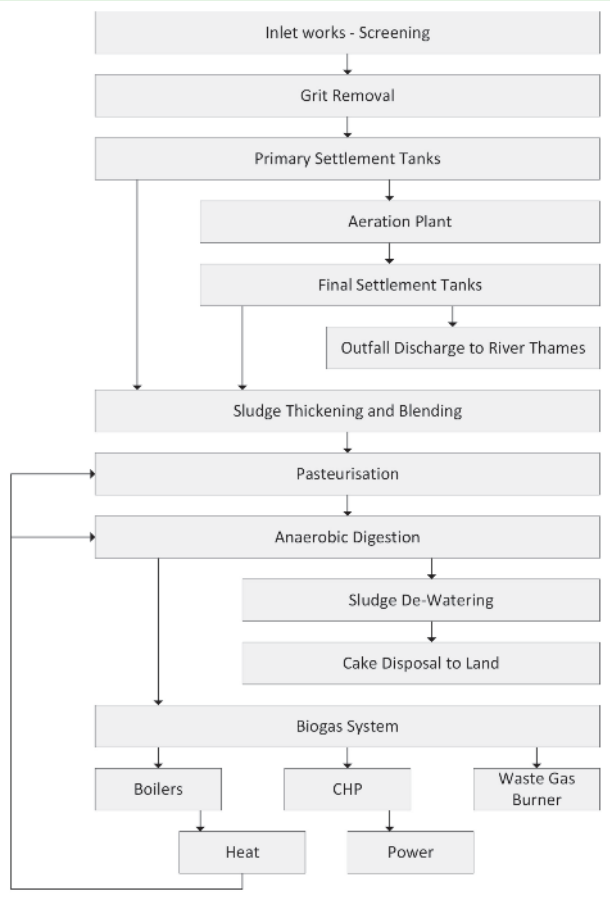


Figure 8 Mogden STW simplified process diagram

Mogden is treating approximately 100 tonnes of dry solid sludge per day. The works is manned by an Operations Team of 56 personnel. The site has a permanently manned control room, manned by one Process Control Engineer and two Technicians per shift. In addition, there is a day-works and maintenance team comprising 30 personnel.

The Mogden site is also home to circa 50 other Thames Water staff providing a diverse range of services, eg

Figure 9 Mogden STW - aeration lanes and final settlement tanks

Occupational Health, Operational Excellence, Customer Field Services, Maintenance Projects and HV services.

The Mogden CHP Project

The 2015-16 CHP project was part of a larger Thames Water wide AMP 6 upgrade of CHP facilities. In total the investment affected 12 of the 24 CHP generation sites with 18 engines totalling 22MWe.

New for AMP 6, Thames Water had embarked on an alliance arrangement for the delivery of major projects. The alliance partners, known as eight2O comprise:

- Atkins
- Balfour Beatty
- Black + Veatch
- Costain
- IBM
- MWH
- Skanska
- Thames Water

For the Mogden CHP project the active partners were:

- Atkins – M&E and process design
- Costain – Programme management and construction management
- Thames Water

Underpinning the alliance are a series of agreements and statements of shared objectives:

The alliance agreement holds the partners together in such a way that success can only be achieved through collaborative effort to meet the shared goal. This is supported by a shared incentive arrangement, at the heart of which is a ROI (Risk, Opportunity and Investment) fund.

There is no client managing the contract, all the Thames Water people are embedded across eight2O. The leadership team is accountable to the eight2O Board, which has representation of all parties and an independent Chairman. There is also no defined scope – the alliance is

in place to deliver outcomes and works alongside Asset Management and Operations teams to define projects that deliver targeted outcomes most effectively. And the eight2O leadership team is embedded within Thames Water governance, performance and meeting structure. The success of the business plan is dependent on the success of the alliance.

The Mogden CHP project was technically challenging from the very start. All other CHP projects in Thames Water were able to use outdoor containerised CHP units on a new location on each site. Thus, the new CHPs could be substantially installed and commissioned without significant interference to normal site operations. At Mogden this was not an option. The Mogden site is heavily developed with very little spare ground. The only option was to install the new CHPs inside the 1930s Power House.

The Power House contained aeration blowers at the west end, the 1990s 4 x 2.4MWe MAN KP Major dual fuel diesel engines in the middle and, fortunately an unoccupied space to the east end. That space was, just, big enough for the new 3 x 2MWe biogas CHPs. The dual fuel were configured and run as N+1, there was normally enough biogas for 2.5 engines. The 2016 project installed three new CHPs but space and some facilities have been allowed for a fourth gas engine at a later date.

The engines chosen for Mogden were selected through a lengthy procurement exercise. In the end all the engines supplied in the 2015-17 CHP developments are MWM TCG range engines supplied and packaged by Edina Ltd. At Mogden the engines type is MWM TCG 2020V20 rated at 2MWe and 1.94MWth. The MWM engines offer electrical efficiencies on Net Calorific Value in the low 40%s, converting biogas to electricity at a rate of circa 2.5 kWh/Nm^3. This can be compared with the previous fleet average of 1.9 kWh/Nm^3, thus providing approximately a 30% improvement in generation output for the same volume of biogas.

To enable the re-use of the 1930s Power House, the design team required accurate drawings of the building, which with the passage of time were not available. The solution adopted was a detailed laser survey of the building which was used to develop an accurate 3-D CAD model. This model was then overlaid with 3-D model blocks of the CHPs and associated equipment to demonstrate how and where everything would fit.

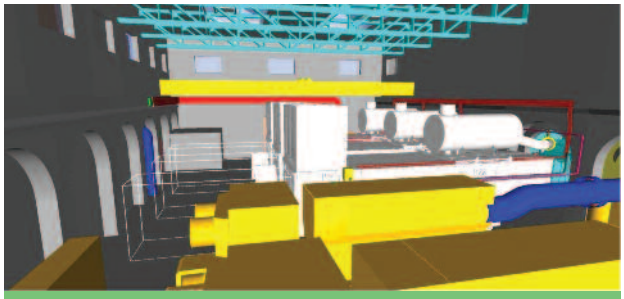


Figure 10 Eastern end of the Power House

Figure 10 shows the eastern end of the Power House. The old dual fuel engines are in the foreground, the three new CHPs in the middle-ground. Air inlet ducting on top of the containers was constrained by the traverse of the Power House over-head travelling crane. The CHP controls and associated switchgear which would normally be in a cubicle at the end of the container are distributed around the Power House, partly as a means of limiting the container overall length. The containers, complete with pre-installed engines, were skidded into the Power House through the east-end doors with only a few millimetres to spare, after removing the door handles.

Figure 11 CHP module entering the Power House

A heat recovery station for each CHP is in the Power House annex, to the right of the picture in Figure 10. Air cooled heat rejection radiators associated with each CHP needed to be in the open air. The Power House roof was not suitable, spare ground around the Power House was not available and so a steel mezzanine deck was constructed on the south side of the Power House, see Figure 12.

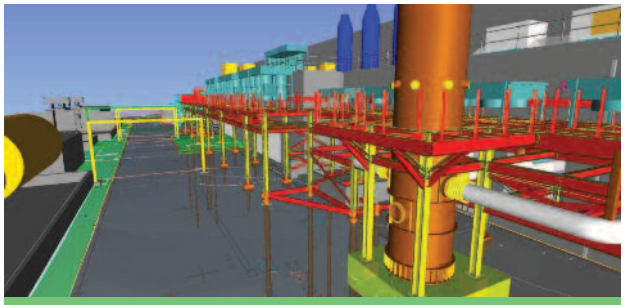


Figure 12 Mezzanine structure 3-D external view looking east to west

The mezzanine deck accommodated the gas pressure control and filtration plant, jacket water radiators (1 per engine), after-cooler radiators (1 per engine) and the EA compliant emissions sampling ports associated with each engine flue contained within a 27m high chimney. Due to the proximity of the building and extent of existing underground services, a decision was made to support the mezzanine on screw piles, thus minimising the effect of piling activities in the area. The CHPs generate at 11kV. Connection into the Mogden site high-voltage system required the creation of a new 11kV switchboard and the inclusion of fault limiting reactors to satisfy the DNO fault limits.

Heat from the CHPs was needed for two systems:

- Pasteurisation heating with a supply temperature of 70°C and
- Digester heating with a supply temperature of 45°C.

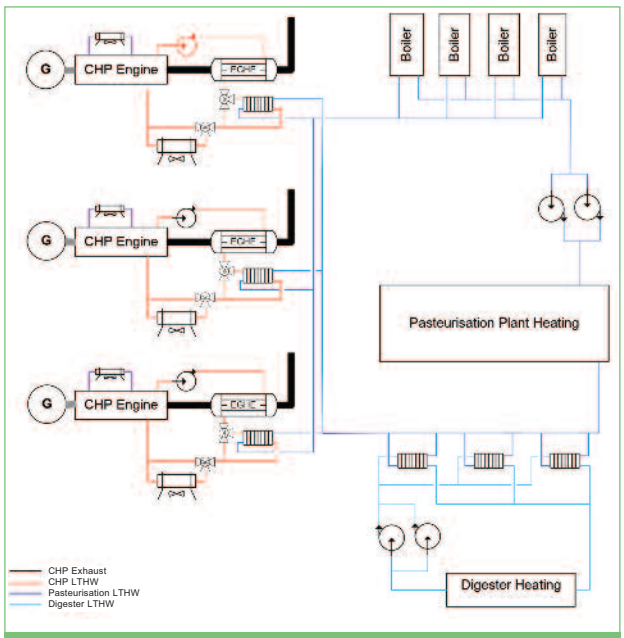


Figure 13 LTHW simplified schematic

From the old dual CHPs, the two heat streams were separately supplied, high grade heat from the engine exhausts and low-grade from jacket water systems. For the new CHPs there was only a combined stream of exhaust and jacket water heat. This is sent preferentially to the pasteurisation systems with a secondary circuit to transfer heat into the digester system when required, see Figure 13. As pasteurisation discharges sludge to the digesters at over 40°C the digester heating system is not always in demand.

Figure 14 Engine Hall looking east to west Edina/MWM CHP modules in the foreground

The work area for the project was very congested and in the Power House the existing dual fuel engines were running continuously making a difficult and noisy working environment. It is a great credit to all parties involved that these impediments were set aside and that the project proceeded very closely to plan.

The CHPs have been operating for over 12 months and are proving to be a very effective and efficient means of extracting value from the biogas and now look fully part of the Power House, Figure 14.

CHP Maintenance

Thames Water has an in-house team focussed on CHP maintenance, covering all sites except for the Long Reach site at Dartford. As Figure 15 shows, the parish covered by the CHP Maintenance Team is geographically extensive. The team, totalling 20 including the management element is a mixture of mechanical, electrical and ICA technicians. The

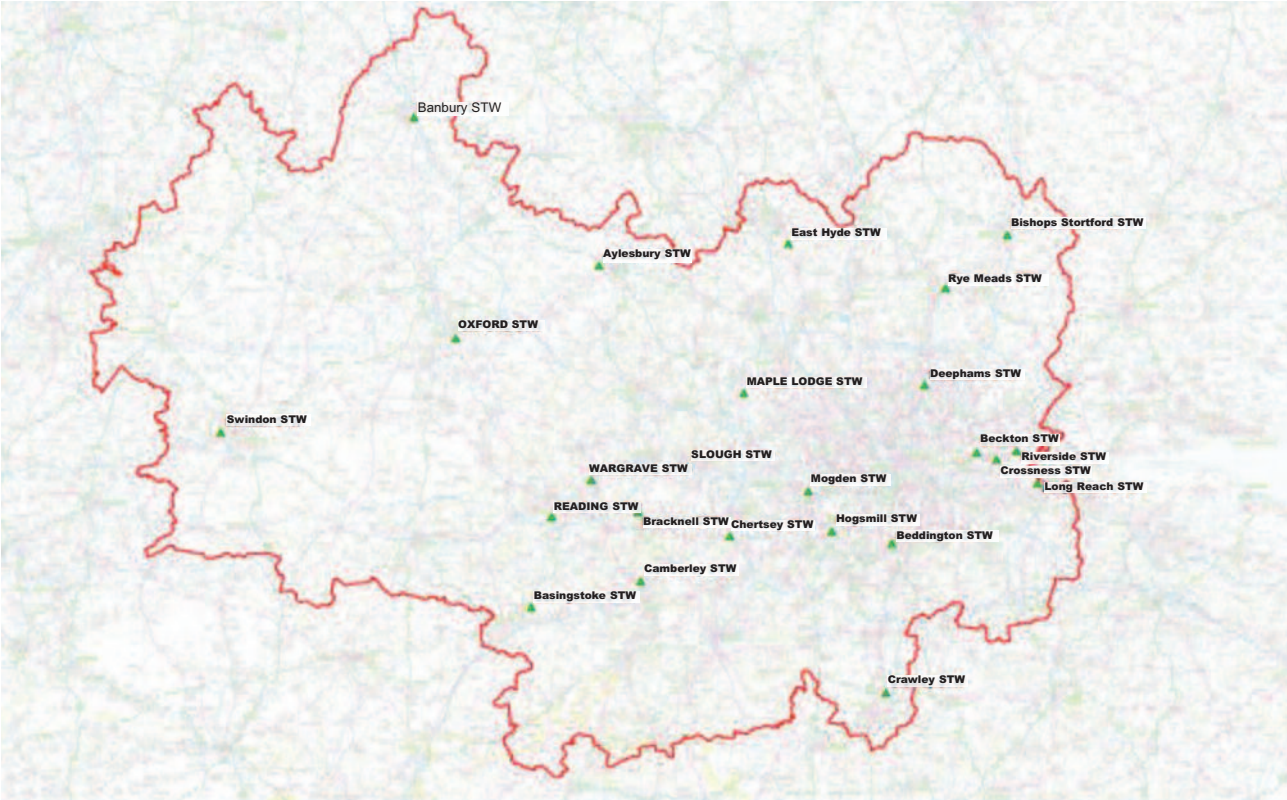


Figure 15 Thames Water area showing CHP sites

Location	Unit rating kWe	No.	Make	Model	Fuel	Commissioned
Aylesbury	340	1	Caterpillar	3412 SI	Biogas	1992
Banbury	190	1	EMG - Mercedes	G12 183A	Biogas	2005
Basingstoke	1,200	2	MWM	TCG 2020V16	Biogas	2017
Beckton	2,000	3	MWM	TCG 2020 V20	Biogas	2014
Beddington	526	2	Jenbacher	JMS 312 GS-BL	Biogas	2011
Beddington	600	1	MWM	TCG 2016V12	Biogas	2016
Bishops Stortford	290	1	MAN	2842 LE312	Biogas	2008
Bracknell	600	1	MWM	TCG 2016V12	Biogas	2016
Camberley	600	1	MWM	TCG 2016V12	Biogas	2016
Chertsey	635	2	Jenbacher	JMS 312 GS-BL	Biogas	2011
Crawley	526	2	Jenbacher	JMS 312 GS-BL	Biogas	2011
Crossness	2,000	3	MWM	TCG 2020 V20	Biogas	2014
Deephams	1,560	2	MWM	TCG 2020V16	Biogas	2016
East Hyde	450	1	Caterpillar	3508 EIS	Biogas	1996
Hogsmill	470	2	Jenbacher	JMS212 GS BL	Biogas	1998
Hogsmill	400	1	MWM	TCG 2016/V08	Biogas	2017
Long Reach	1,150	3	Caterpillar	G3516	Biogas	2002
Maple Lodge	840	4	Allen	BS37E	Dual Fuel	1988
Mogden	2,000	3	MWM	TCG 2020V20	Biogas	2017
Oxford	650	1	Caterpillar	3512 SI	Biogas	1992
Oxford	844	2	Jenbacher	JMS 412 GS-BL	Biogas	2011
Reading	511	2	Jenbacher	JMS212	Biogas	2004
Riverside	2,000	3	Cummins	QSV91G	Biogas	2012
Rye Meads	1,200	2	MWM	TCG 2020V20	Biogas	2016
Slough	1,200	1	MWM	TCG 2020V20	Biogas	2016
Swindon	1,200	1	MWM	TCG 2020V20	Biogas	2016
Wargrave	600	1	MWM	TCG 2016V12	Biogas	2016

Table 1 Thames Water CHP Fleet

average age of the team is in the mid-40s but does include an apprentice in his early 20s and the experience of the oldest member of the team well into his 70s.

The CHP Maintenance Team undertakes all routine maintenance activities up to and including full overhauls of the dual fuel engines. The team scope extends from the biogas supply point, including booster, chiller and siloxane filters, through the engine on to the heat recovery and rejection systems and through to power take off and all associated CHP controls. External resources are used selectively to supplement the in-house resource.

Maintenance is scheduled principally against CHP hours run, but this may be adjusted to take account of site operational requirements, other associated plant statutory outages and TRIAD season requirements. Overall the team is maintaining the Thames Water CHP fleet to an availability of over 93% at an average maintenance cost of 3.1p/kWh. The Maintenance Team's safety record is of over 103,000 man-hours without a lost time incident.

The successful completion of the Mogden CHP project is a significant milestone in Thames Water's journey to achieve:

- ~25% improvement in CHP engine efficiency
- Zero fossil fuels consumed for CHP/sewage generation
- £930k saving in maintenance
- 70 per cent reduction in downtime for CHP planned maintenance

CHP Fleet Development

The Thames Water CHP fleet as now composed is shown in Table 1, totalling 52.9MWe across 49 engines.

The Maple Lodge dual fuel engines are scheduled for retirement in 2018, being replaced by MWM TCG2020V16 1,560kWe units packaged by Edina.

Particularly now that a substantial part of the CHP fleet is new (75% of fleet is 2011 or later), work is continuing to ensure that Thames Water can maintain and improve plant availability. Initiatives being pursued include:

- Plant remote visibility and control
- Central generation control desk
- Trials of engine oils
- Measurement of siloxanes
- On-line vibration analysis
- Acquisition and use of spare engines for upkeep by exchange

Plant visibility and control is already being enhanced using ComAp control systems. In its simplest form this allows immediate visibility of performance to management and

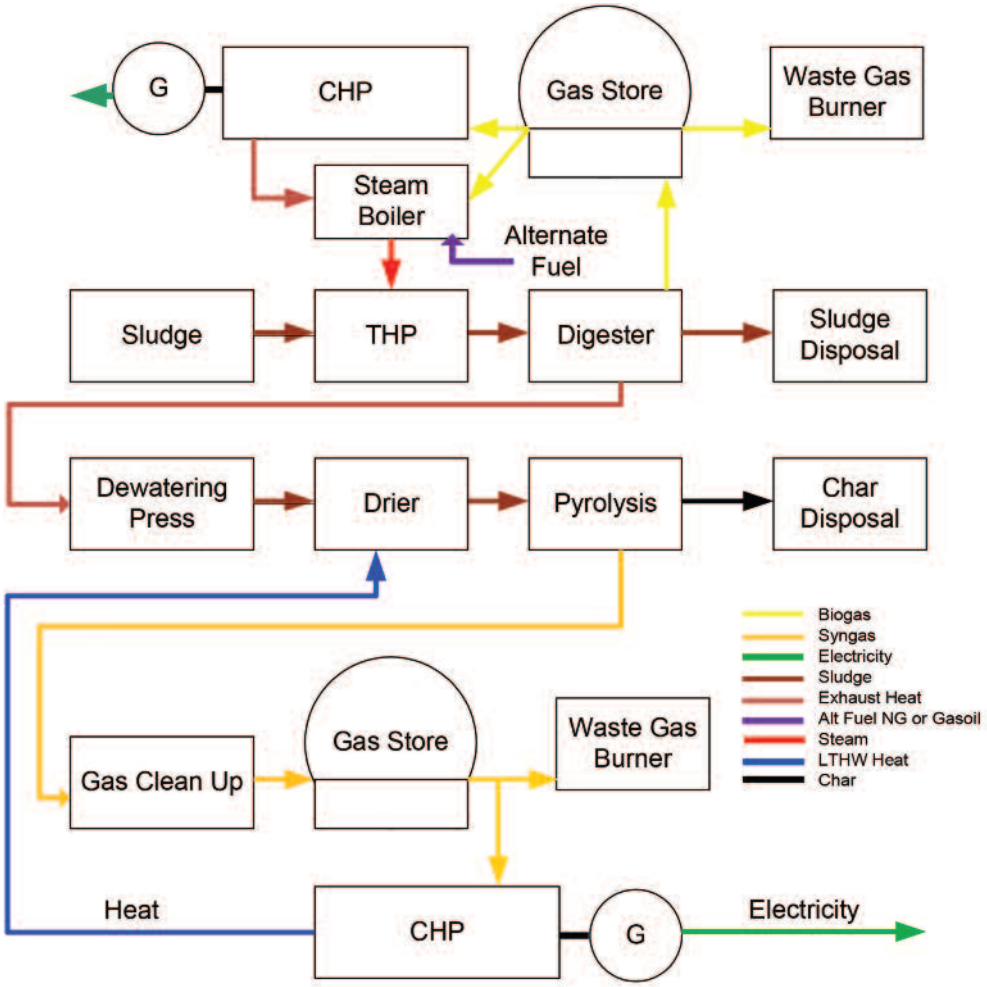


Figure 16 AER Process

maintainers via a web link. The system also allows maintainers to undertake remote diagnostics and, in some cases, to take corrective action to re-set and re-start plant. This is particularly important for out of hours engine defects. A future planned improvement is the establishment of a centralised manned control desk to actively manage CHP operation, plant performance monitoring and initial defect diagnosis and rectification.

However, life in CHP is not all one-way. Thames Water, along with other water company CHP operators, faces the continuing challenges provided by:

- Environmental compliance requirements. This can be a combination of new national legislations and/or local requirements, for example on local amenity.
- Restrictions on access to engine management control systems imposed by engine manufacturers
- Requirements for cyber security
- The over-riding requirement to maintain sewage works operation
- Selecting optimal regimes for the CHPs

With the significant recent investment in CHP the momentum is in place to keep CHP operations on the front foot. The older CHP plants; 9 units installed before the year 2000 and a further 7 units installed 2000-2010; are already under review for upgrading with new units in AMP 7 (2020-2025) or AMP 8.

Other developments include a demonstration plant for Advanced Energy Recovery (AER) presently being developed at Crossness. AER will use digested sludge from an existing THP-MAD plant. The THP digested sludge will be de-watered and dried before undergoing pyrolysis in an oxygen deplete atmosphere to generate a syngas. The syngas will be a mixture of methane, carbon monoxide and hydrogen and other non-combustible gases. After a gas clean up stage, to remove oils and tars, the syngas will then power CHP gas engines, see Figure 16.

While technically more complex than any existing process, the prize is a final solid waste stream of around 36% of the original sludge dry solids. This compares very favourably with ~62% for MAD, ~55% for pasteurisation and ~50% for THP. It is this significant sludge volume reduction that is the principal driver for AER. Electricity generation is a beneficial by-product.

Summary

CHP generation in Thames Water is an undoubted success story. With a combination of new plant and optimising

Nomenclature

Symbol	Meaning
AER	Advanced Energy Recovery
AMP 6/7/8	Asset Management Period 6/7/8. The water industry funding cycle managed/ approved by OfWat (the economic regulator of the water sector in England and Wales)
Barg	Pressure measured in Bar above atmospheric pressure
Cake	The output solid product from sewage sludge processing
CHP	Combined Heat and Power
DNO	Distribution Network Operator
g DS/person/day	Grams Dry Solids per person per day
kV	Kilo volt
kWe	Kilo watt electric. Instantaneous rate of electricity production
kWh	Kilo watt-hour. Volume of electricity produced over time
kWh/Nm^3	Kilo watt hour per Normal metre cubed
kWh/tDS	Kilo watt hour per tonne Dry Solids
kWth	Kilo watt thermal. Instantaneous rate of heat production
MAD	Mesophilic Anaerobic Digestion
Nm^3	Normal metre cubed. Gas volume as at zero degrees Celsius and one Atmosphere
Nm^3/tDS	Normal metre cubed per tonne Dry Solids
ROC	Renewable Obligation Certificate
THP	Thermal Hydrolysis Process or Thermal Hydrolysis Plant
Wh/p/d	Watt-hour per person per day

existing plant, the volumes generated from sewage have risen from 126GWh in 2008-09 to 310GWh in 2017-18. The upward trajectory is expected to continue as more sites are converted to THP and/or AER operation. Thames Water is also looking at other methods of maximising value from biogas production including; gas to grid and battery systems. This is all part of the continuous journey to deliver the lowest cost of sewage treatment while maintaining full compliance with all regulatory requirements. However, for now, CHP systems are the dominant proven solution.

Any opinions expressed in this paper are those of the author and do not necessarily reflect those of the organisations represented.

Acknowledgements

Thanks are given to the following for their help in preparing this paper: Rob Cullen and Owen Elson of eight2o, Richard Dennett, Ian Ruffell and Darren Rule of Thames Water Utilities Limited. ■

The Author

David Linsell trained as a Marine Engineer in the Royal Navy. After initial officer training at BRNC Dartmouth and sea training in HMS Intrepid and HMS Apollo he studied for a Marine Engineering degree at RNEC Manadon. On completion of training David served as Assistant Marine Engineer Officer in HMS Naiad, a steam turbine driven frigate, and Engineer Officer in HMS Speedy, a Boeing Jetfoil, before returning to RNEC Manadon for a Master of Science degree course. Following the MSc David's career included serving as Double Bottoms and Propulsion Engineer Officer in HMS Illustrious (Olympus gas turbine GOGAG drive), Propulsion Commissioning Engineer at HM Dockyard Rosyth, Senior Engineer Officer in HMS Invincible, Marine Engineer Sea Training Officer in HMS Juno and as a MoD(N) contract project manager at the privatised Devonport Dockyard.

Leaving the Royal Navy after 24 years, David was employed for 12 years by McLellan and Partners Limited, engaged in projects as diverse as feasibility studies for CHP at pharmaceuticals works in the UK and commissioning a U O-E Longitudinal Submerged Arc Weld pipe mill in Saudi Arabia while progressing from Senior Engineer to Divisional Director.

In a return to 'kick-able engineering' David joined Thames Water Utilities Limited in 2009 as CHP Specialist. In this role David provides professional advice and support to managers, operators and maintainers on all aspects of the Thames Water CHP fleet.

Passionate about engineering, David is a STEM Ambassador. His flagship talk 'Power from Poo' always gets a warm reception from school groups and professional societies.

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Forthcoming events

The IDGTE hosts a wide range of social events, courses and conferences. All of our events focus on topical issues and developments within the energy industry and give an insight into the challenges facing the industry today.

Midsummer Mingle

27 June 2018

The Anson Engine Museum will once again be holding its 'Midsummer Mingle'. This event is open to anyone associated with the diesel industry past or present.

Further information is available from www.enginemuseum.org

September Seminar

IGEM House, Kegworth

18 September 2018

The seminar *Emissions from Reciprocating Engines and their Abatement* is intended to:

- Forecast where exhaust emission regulations in UK/Europe are likely to go in the short term – say 2025.
- Establish what abatement technologies are available (or being developed) to achieve the anticipated ELVs. Evidence of how well existing techniques work in practice is especially valuable.
- Establish the cost implications of abatement and thus the likely impact on market prospects for generators.

Speakers from the Environment Agency, Ricardo, OEMs, Johnson Matthey and a lubricating oil company are planned for the day's programme.

Technical visit

Wärtsilä, Trieste

September/October 2018

Later in the year a joint IDGTE/IMarEST technical visit to Wärtsilä, Trieste, Italy is being planned.

Visitors will be able to follow the engine production lines, extending one kilometre through the heart of the factory, for a close-up view of the production process and the advanced technology and innovation that characterise the Group's operations in 70 countries.

Wärtsilä, Trieste

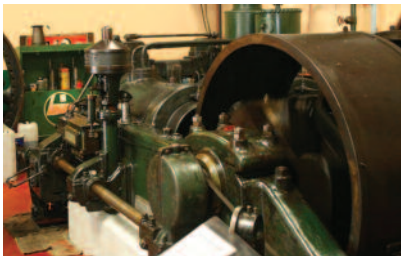
The visit will be arranged near to a weekend so that people can extend their stay to visit Venice and the surrounding area.

Social visit

Wales Weekend

29/30 September 2018

A weekend social event in Wales is being planned based around visiting the Internal Fire Museum of Power at Tanygroes near Cardigan.



The event programme is based on two previous successful IDGTE weekend visits to the same location over the past decade. The event starts with a trip on the Welshpool and Llanfair Light Railway and can conclude with a visit to the National Trust property at Llanerchaeron.

A more detailed programme is available from www.idgte.org

Please email enquiries@idgte.org if you are interested in attending.

Papers day

Venue - TBA

October 2018

Following on from the successful papers days held previously at MAN Stockport, University of Lincoln and RWE Ferrybridge, plans are being finalised to hold a Gas Turbine Papers Day in October 2018.

If you are interested in presenting a technical paper at this event, please contact the IDGTE office.

Dates for your diary:

Annual General Meeting

RAE, Prince Philip House

Wednesday 31 October 2018

Technology Seminar and 72nd Annual Luncheon

Grange Tower Bridge Hotel

Thursday 2 May 2019

If your company or employer is able to host a visit to a manufacturing facility, launch of a new product or has a particular project that would be of interest to IDGTE members please contact us.

IDGTE visit to Ricardo's Technical Centre and University of Brighton

Report by John Kitchenman, IDGTE Member

Visit by members and guests of IDGTE to Ricardo UK Ltd, Shoreham Technical Centre and University of Brighton on Wednesday 16th May 2018

Twenty members and guests of IDGTE met at 9.00am in the Centenary Room to be welcomed by Simon Brewster, CEO of Dolphin N2 Ltd - a spin out company of Ricardo whose aim is to develop and commercialise the CryoPower Engine system with other partners.

The Centenary Room is a new conference and hospitality centre built by Ricardo and opened in 2016 to mark the centenary of the company set up by Sir Harry Ricardo. Harry Ricardo was a talented engineer and inventor of diesel engines, building his own engine at the age of seventeen to power a water pump, and during the first World War working for the British Government to design and build a six-cylinder engine to power the Mk V tank which originally had a Daimler Benz engine. The company is now a world-class engineering consultancy specialising in engine and power systems design, transmissions, vehicle engineering, and environmental impact measures. Currently the market place is experiencing a very high rate-of-change in technologies.

At 9.45am, Professor Neville Jackson, Chief Technology and Innovation Officer of Ricardo PLC, gave a fascinating presentation entitled *"A View of the Future"*; this was an overview of likely future energy demands, power solutions and technology challenges.

Professor Neville Jackson giving his presentation *"A View of the Future"*

Currently 80% of the world energy demand is still met by releasing the potential energy contained in fossil fuels (oil, coal, natural gas). The big issue is that when burned these fuels release carbon back into the atmosphere as carbon dioxide, which is a greenhouse gas that is causing climate warming with consequent upset of eco-systems. Furthermore the current engine technologies which burn the fuel in air at high temperature and pressure can produce oxides of nitrogen and fine carbon particles which are injurious to health. Both problems are life threatening and governments and society are turning to engine-engineering experts to come up with solutions. Ricardo is one of the companies at the forefront of investigating these issues. Population growth and peoples' expectations regarding personal transportation are other big challenges.

Professor Jackson considered these under the headings: Challenges; Technical Options; Future Combustion Engines; Electrification Challenges; Future Liquid Fuel. A simplistic laymen's view is that society can turn to electricity to power everything; after all electric trains, trolley buses and battery powered milk delivery trucks have been around for a century now! The point that is missed by most people is the shear amount of personal transport and the type of journey usage. Also the energy density of fossil fuels compared with battery storage capability and/or the future demand for power distribution network size and capability. There is a big disruption/disconnect between predicted energy growth and required reduction in CO_2.

Governments have decreed that climate change from greenhouse emissions caused by human activity must be halted by 2050, and to this end the use of oil, coal and gas for power generation must be stopped by then! This poses big problems with nuclear, solar, wind, tidal flow, hydrogen and biofuel all potentially being alternatives. In truth it may be impossible to meet demand with these options in the time frame and some form of advanced combustion engine - burning fossil fuels with novel combustion cycle management and exhaust treatment may still be required for (fixed) stationary, (and portable) marine, off highway and road transport applications.

For portable applications – transport engines - size and weight are big issues for the engine and ancillaries, plus the energy source (fuel/batteries). The highest energy density fuels, including the storage tank, (least weight to carry for a given distance travelled) are gasoline, diesel, or kerosene; medium density is ethanol, LNG, and liquefied coal; low density includes Li-ion batteries, hydrogen and CNG. There is a need to separate short distance/light duty applications (cars for personal transport) from long distance/heavy duty application (trucks for distribution of goods) with respect to energy density of fuel requirements. Electric cars utilising Li-ion batteries for energy storage are now quite feasible and the technology also works in urban range delivery vans where home or depot battery re-charging is appropriate. Battery size, weight and charging time are considerably more challenging for long distance trucks or buses. The cost of infrastructure for a universal roll out of a trolley bus style overhead power supply is prohibitive plus voltages would need to much higher to minimise voltage drops and cable sizes.

The thermal efficiency of the internal combustion engine remains a big issue. Typically only 25-35% of the energy released from the fuel is turned into useful work output with a gasoline engine; the remainder is lost as waste heat. There is still significant potential for improvement in thermal efficiency and exhaust emission control/treatment in internal combustion engine technology for vehicles. The best performers are F1 race-car engines, followed by heavy duty diesel, then light duty diesel and lowest are gasoline (petrol) engines. Probably the most efficient real-world engine is the Wärtsilä 31 medium speed (stationary) diesel engine at just above 50%. In stationary engine applications it is possible to recover some of the waste heat from engine jacket cooling water and lubricating oil, but this heat is of 'low quality' which has to be used in low temperature applications (like air conditioning, bottle washing, laundry or process heating like brewing or paper making). Exhaust energy losses offer a source of higher grade heat and a range of technologies are being explored to recover this energy into useful work.

Considering the electric option whereby electric engines (motors) are better than 90% efficient there remains the problem of energy storage and re-charging. To convert the present World capacity of vehicle engines from internal combustion to electric is not possible with current technologies due to the finite availability of lithium and limited battery manufacturing capacity, not to mention the shortfall in mining infrastructure and toxic waste fall-out from battery manufacture. Also a massive increase in electric vehicles would grossly overload the power distribution system – it is also necessary to de-carbonise electricity power generation which in itself has a considerable carbon footprint. [Yesterday's electricity supply structure was simple, ie power station (burning fossil fuel); HV grid; MV grid; distribution network. Tomorrow's power grid will be far more complex incorporating both traditional networks, centralised power supply, local renewables and domestic solar sources and various storage devices and technologies.]

New technologies are actively being investigated. These include hydrogen fuel cell electric generators for use in trucks and marine propulsion. Also 'waste-to-hydrocarbon-fuels' (pyrolysis or bio-digestion) for use in new generation advanced combustion engines.
Professor Jackson's presentation included a number of charts, graphs and graphics that diagrammatically emphasised the various points; they all looked a bit gloomy to the present generation audience!

What is needed to tackle the problem is an integrated energy policy – which is political! Future transport will have to be tailored to (safely and securely) meet the needs of the next generation consumer as well as meet environmental legislation. Personal car ownership will probably decline to be replaced by mobility service providers (autonomous cars) and this will present infrastructure and legal challenges. Every alternative energy system designed to protect the environment is MORE EXPENSIVE than the present consumption of hydrocarbon fuels. On a final note it must be realised that 'zero tailpipe emissions' is not the same as 'zero emissions'.

This paper was followed at 10.30am by a second presentation by Nick Owen of Dolphin N2 Ltd on the CryoPower engine system and development. Dolphin N2 is a new company formed to develop the CryoPower engine.

The goal is to create a large combustion engine having a thermal efficiency of '60% +' as well as having much reduced exhaust emissions. CryoPower is a split cycle engine using cryogenic cooling to achieve isothermal compression, exhaust heat recuperation and Miller cycle for efficiency, and HCCI-like combustion for near zero NOx formation. (Considering the four elements to closed cycle combustion of suck-squeeze-bang-blow, in a split cycle engine the suck-squeeze is separated from the bang-blow with the compressed working fluid – air – being cooled cryogenically with liquid nitrogen sprayed into the gas before admittance to the combustion cylinder and fuel admission.)

CryPower rig at Brighton University

The goal is 30% reduction in fuel use equating to a 20% reduction in operating costs with very clean exhaust potentially eliminating soot and NOx emissions. The target market is heavy trucks and package power generation. The CryoPower aim is to take a much larger step in efficiency than is possible with conventional waste heat recovery. The challenges:

- Diesel technology is now optimised
- The current effort to improve efficiency is focussed on recovery of heat from exhaust but this doesn't fix the emissions problem.
- CryoPower requires a fundamental re-engineering of piston engine thermodynamics for best efficiency.

The adiabatic engine of the 1980s didn't work because the process took place in the same cylinder – hence intake events were compromised by hot surfaces. The current study is for a six cylinder engine configured with two compression cylinders (operating 2-stroke) and four combustion cylinders (operating 2-stroke). Detailed academic study is currently underway at Brighton University on the separate aspects of the thermodynamic cycle and the cryogenic cooling method. Diagrams were presented of the envisaged engine layout.

After the coffee break at 11.00am a tour of the Shoreham Technical Centre was conducted starting in the small museum area adjacent to reception. Here visitors inspected the E35 variable compression engine developed by Sir Harry Ricardo in 1919 which became the standard measuring device for classification of fuels (ignition quality and onset of

combustion knock). Other exhibits included a 3-cylinder automotive diesel engine commission by General Motors for the Indian market, a 4-cylinder 300BHP petrol engine for Ford used in saloon car racing, and an 8-speed automatic transmission for a Chinese company, all demonstrating the diversity of Ricardo work.

Next visitors were treated to a gallery view of the Ricardo engine manufacturing line! This came as a surprise to most. The engine is a very high performance V8 gasoline engine produced for McLaren sports cars fitted to their M838T in 3.8 litre and 4.0 litre versions. The project started out as a design and prototype build contract but morphed into a production manufacturing partnership.

From the production shop the party moved to VERC – the Vehicle Emissions Research Centre where 'real world' emissions testing is carried out on cars mounted on rolling roads running through a comprehensive operating cycle of variable rate acceleration, cruise, slowing/stopping and re-starting with the tailpipe emissions collected and measured continuously. This is in contrast with manufacturer's engine certification processes which test engines on rigs at predetermined test points. A high-speed exhaust gas analyser manufactured in Japan is used as the standard measurement instrument (this is currently industry standard).

The party then moved to VATF – the Vehicle Acoustic Test Facility. This is a large anechoic chamber which can take a whole vehicle for noise testing.

Finally the party visited the Advanced Engine Development Centre [passing an hydraulic digger which is a Ricardo test vehicle for proving their Flywheel Energy Storage unit which has achieved a 10% reduction in fuel consumption (and hence carbon emissions) over the standard diesel-hydraulic power train]. The AEDC is Ricardo's core business of engine test cells where customer engines are coupled to generator or hydraulic brakes for load testing and development. An adjacent building is the large engine development centre with two test beds capable of running 3MW sets against water brakes (Froude dynamometers). Customer engines were observed undergoing trials as well as a Ricardo single-cylinder research engine.

Lunch was taken between 12.45 and 1.15pm following which the party (accompanied by Nick Owen) travelled by car from

Simon Brewster, CEO of Dolphin N2 Ltd and Dr Rob Morgan, Deputy Head of the Advanced Engineering Centre, Brighton University

Ricardo Technical Centre to Brighton University's Advanced Engineering Department. Ricardo has had a working relationship with Brighton University for the past thirty years and has been instrumental in setting up the Sir Harry Ricardo Centre to promote advanced engineering research. Dr Rob Morgan, Deputy Head of the Advanced Engineering Centre at Brighton University welcomed the group and introduced four graduate and post graduate students who are involved with aspects of the CryoPower engine research.

It was pointed out that although the concept of a split-cycle, recuperated isothermal- compression engine has been studied before, the current work in separating out the various parts of the thermodynamic cycle is novel and revealing new physics of compression, combustion, and gas expansion. The work is subject to patent application and consequently details are secret. However we were able to visit three laboratories where experiments to ascertain the performance of various spray patterns are observed and the chilling effect of liquid nitrogen injection was photographed; along with flame propagation experiments. Finally we visited the engine test cell where a single-cylinder engine is run with varying inlet air charge conditions to determine power and exhaust emission parameters.

Such was the interest that it was approaching 4.00pm before the visit finally came to an end. ■

Professional registration

IDGTE has a Registration Agreement, approved by Engineering Council, to enable us to offer Professional Registration at IEng, CEng and EngTech grades to our members.

Cost effective

Existing IDGTE members who have Engineering Council registration with another Institution are also able to transfer their registration to IDGTE.

Professional registration is a worthy goal for all members of the engineering profession and is encouraged by IDGTE. By becoming an Incorporated Engineer, Chartered Engineer or Engineering Technician you will gain an accreditation that is internationally recognised. The Pocket Guide to Professional Registration 2018 can be downloaded from www.idgte.org/professionalregistration.html

the IDGTE Technology Seminar & 71st Annual Luncheon

Meeting the Power Challenge of Today's Global Markets

It was a sunny spring morning in central London on 3rd May as over 200 delegates gathered at the Grange Tower Bridge Hotel for the IDGTE Technology Seminar and 71st Annual Luncheon, looking forward to an opportunity to catch up on the latest industry trends and developments and a chance to network with friends, colleagues and clients in the convivial atmosphere of this flagship industry event.

> "Superb day – seminars, splendid lunch and thought-provoking speeches"

The IDGTE Annual Luncheon has, of course, always been an iconic event in the calendar of the power and prime-mover industries. Now, since its transformation in 2015, and in its fourth year at the new venue of the Grange Tower Bridge, together with the inclusion of the Technology Seminar, it is well established as an industry-leading event which meets the up-to-the-minute needs of today's engineers, technologists and business leaders alike.

Technology seminar

Based on the theme of *"Meeting the Power Challenge of Today's Global Markets"*, the technology seminar brought a broad spectrum of technical content through a multi-stream programme ensuring that there was something relevant to everyone's business.

Andrew Moseley of Chevron presented on Advanced Engine Coolants, focussing on different coolant types, typical properties and heat transfer mechanisms, with particular reference to coolants in CHP units.

Sandy Reid-Peters of ExxonMobil spoke about preventive maintenance strategies and effective lubrication for aggressive gas engine applications, offering an insight into optimum lubricant selection and their part in enhancing the performance of gas engines. He described the latest generation of gas engine oils primarily intended for the lubrication of modern engines using gases containing contaminants such as hydrogen sulphide, halides or siloxanes and discussed mitigating maintenance strategies to help increase productivity, reduce maintenance costs and minimise downtime.

Phil Hatherley, General Manager of Material Solutions Ltd (a Siemens Business) took the title *"Materials Solutions - Industrialising Additive Manufacturing"*, speaking about key trends currently seen in Additive Manufacturing for metals and how Siemens and Materials Solutions is meeting the challenges in industrialisation. Perhaps the most spectacular achievement was the development and testing of a HP gas turbine blade running at full temperature and speed in one of the Lincoln engines.

Alan Priddy, Chairman of Clean Fuel Ltd and Leader of Team Britannia Around-the-World Challenge gave an insight into the latest developments of their hybrid diesel fuel - a revolutionary fuel emulsion being a mixture of diesel, water and emulsifier - referring to its performance in reducing harmful emissions such as particulate matter and nitrogen dioxide. Team Britannia is a multi-million pound

Principal Guest - Melle Kruisdijk, Vice President Europe at Wärtsilä Energy Solutions

British bid led by inventor and ocean adventurer Alan to design and build the fastest and most fuel-efficient wave-slicing powerboat to circumnavigate the globe. Powered by the hybrid fuel, blended on board with sea water purified through a reverse-osmosis process they hope to achieve significant gains in terms of reduced weight of fuel to carry and increased fuel efficiency, as well as showcasing the performance of the fuel from an environmental point of view.

"A thoroughly enjoyable seminar, reception and lunch"

Malcolm Bull of Ricardo UK Ltd, Shoreham Technical Centre addressed the topical question, *"Are we meeting the real world diesel emissions controls challenge?"* He described their work in evaluating emissions from vehicles drawn from different sub-levels of the Euro 6 diesel fleet which feature differing engine and after-treatment NOx control technologies, whilst considering comparative emissions from different regulatory drive cycles - a demanding urban cycle, and from moderate full and urban real driving emissions (RDE). He went on to discuss evaluation of emissions impacts of different after-treatment technologies, including fraction of NO_2 in NOx, and determination of conformity factors for NOx, CO and Particle Number (PN).

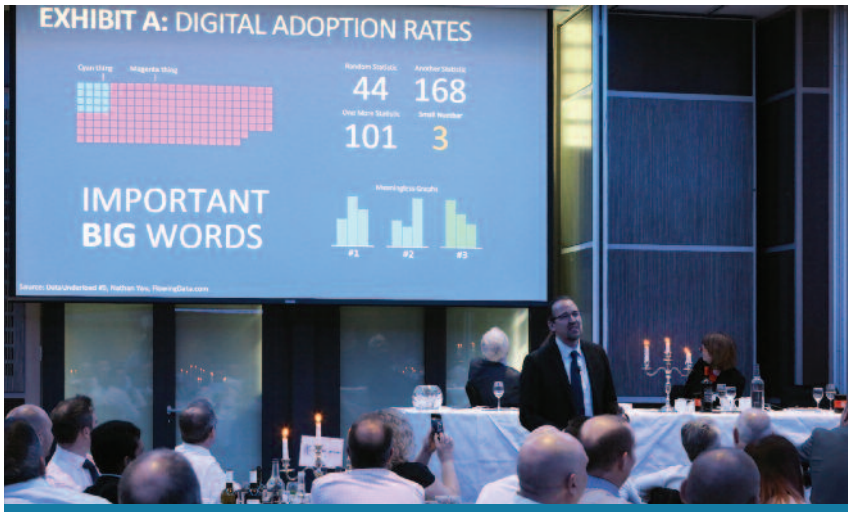
Don Wootton of Spectro | Jet-Care considered the apparent paradox that *"Low cost oil analysis can be expensive!"* Looking at the impact of investment and method on accuracy and repeatability issues versus costs of engine re-builds and the influence of these on accuracy margins of lube oil life and life cycle costings, Don demonstrated that cost-cutting in this area can be false economy and can cost dearly.

Networking reception in the Atrium

Following the seminar there was an opportunity to meet up with colleagues, other guests and friends at the pre-luncheon reception in the Atrium. As always this proved to be very popular, allowing time for table hosts to meet and greet their guests and for everyone to catch up.

Luncheon in the Trinity Suite

Peter Tottman, Immediate Past President, welcomed everyone, thanked our seminar presenters, sponsors and supporters and said grace before a delicious lunch was served comprising breaded brie, caramelised onion, mesclun salad and honey glazed roasted walnuts and wild berries coulis; roasted English rack of lamb, pea puree, caramelised shallots, dauphinoise potato, pancetta wrapped fine beans and rosemary jus; apple and plum crumble tart, vanilla ice-cream and chocolate custard sauce followed by tea, coffee and petit-fours.



Guest speaker - Dave Coplin, Author, alchemist, catalyst, Founder and CEO of The Envisioners.

"A lovely meal, good company and an inspirational speaker – what more can you ask"

Following the luncheon

We were delighted to have as our Principal Guest, Melle Kruisdijk, who is responsible for leading Wärtsilä Energy Solutions' sales and project execution activities in Europe. It was very interesting to hear how Wärtsilä have changed their focus in the electricity market to providing integrated solutions involving various technologies to support the grid and distribution networks – such as battery storage linked to engines. Other areas that he covered such as unmanned ships and "Power into Gas" (another form of energy storage) were thought-provoking and were appreciated by many in the audience.

Responding on behalf of the Institution, IDGTE President, Tony Hancock, thanked Melle Kruisdijk for his toast to 'The Institution" and also noted the increasing range, diversity, and integration of energy resources to meet today's demands. He expressed our appreciation to all the sponsors, presenters and participants for the success of the day's event. He noted this was but the latest of a series of events and highlighted forthcoming plans for the remainder of 2018 all of which form a key part of our programme.

He also reminded the audience of the purpose and aims of IDGTE and the benefits of membership, as well as the responsibility to be a contributor to our institution to the benefit of other members.

And finally, he introduced our guest speaker: Dave Coplin, author, alchemist, catalyst, founder and CEO of The Envisioners.

With a background of over 25 years' experience in the technology industry, not least his former "day job" as Chief Envisioning Officer at Microsoft, Dave Coplin is always at the forefront of

conversations on how individuals and organisations can benefit from the truly transformational potential that technology offers, rather than merely using it to do the same old things, but only slightly better. Referring to his book, *"The Rise of the Humans: How to Outsmart the Digital Deluge"*, he took a sideways look at the world of IT in business and manufacturing and how so often we allow computers to rule the roost in a classic "poacher turned gamekeeper" scenario. With his engaging and entertaining style, Dave took us on a walk through the world of "Machines versus Humans", punctuated with a wealth of amusing anecdotes about how we humans are so easily led by the "machines".

In choosing Dave as our Guest Speaker for this event, it became evident that he had an unexpected and interesting link with the world of gas turbines. His father, John Coplin, is a retired aeronautical engineer and was Chief Designer of Rolls-Royce's RB211 aero-engine from 1968-1977, following which he held a number of senior management roles within the company, including Director of Technology and Design. As the story further unfolded, it emerged that IDGTE Director General, Mike Raine, worked in John's team during the 1980s. We were delighted to have with us John and his wife, Jean, as our guests at this year's Annual Seminar and Luncheon.

Sponsors

Thanks are expressed to our Platinum Sponsor - Spectro | Jet-Care for their continued support of this event.

We are also grateful to Chevron, Clean Fuels, ExxonMobil, Ricardo and Siemens who took part in the seminar and supported IDGTE with sponsorship of the day.

Next year - a date for your diary

Next year's Technology Seminar and 72nd Annual Luncheon has been booked for Thursday 2nd May 2019.

If you or your company wishes to participate in next year's seminar, become a sponsor or just get involved by booking a table - please contact the administration team at:

IDGTE
Bedford Heights
Manton Lane
Bedford MK41 7PH
enquiries@idgte.org
+44 (0)1234 214340

pdfs of seminar technical presentations are available from www.idgte.org

Student-organised gas turbine seminar

Report by Ronald Hunt, IDGTE Member

On 5-6 April 2018 Cranfield University students organised and held their own Gas Turbine seminar. There were 120 students taking part with 99 presentations during the two days, all given by the students themselves. The sessions included:

- Aero Applications Civil Gas Turbine Engines Evolution
- Aerospace and Aircraft Propulsion Methods
- Subsystems and Testing
- Space and Operations
- Comparison of Aero Engine Companies
- Spatial (Rockets and Ramjets)
- Closed Cycle Gas Turbine
- Alternative Fuels
- Gas Turbine based Heat and Power Systems
- Industrial Gas Turbines
- Marine Applications
- Steam Turbine Power Plants
- Wind Turbines
- Testing and Maintenance
- Energy Storage

The full programme is available if anyone is interested.

Cranfield University organising team: Infrastructure Director - Akhil Dinesh, Editing Director - Maria Matsiota, Marketing Director - Stanislav Milkov, Finance Director - Ernesto De La Torre, Deputy Czar - Jordi Grasso, Czar - Davide Corda, Deputy Czar - Alessia Gloder

The two-day seminar was entirely run by the students and proved to be a great success. As a visitor I was really impressed with the enthusiasm and professionalism of the students.

There were two invited guest presentations, the first being Rob Dare and Iain Gordon from a company called Evolution on precision measurement systems. The second was Ronald Hunt from Power + Energy Associates who was invited to present The Development and History of the Industrial Gas Turbine (Update). The guest presentations were well received. ■

Is there an author amongst us?

Could you help to sustain the legacy of the late IDGTE Fellow Dr Meherwan Boyce* by being a co-author for the update of his world-renowned gas turbine text book? Dr Boyce was part way through an update of his book - Gas Turbine Engineering Handbook, 4th Edition - when he sadly passed away in December 2017.

Dr Boyce's wife and the publishers are seeking engineers with the knowledge to complete the update. Dr Boyce had completed the update of chapters 1 to 9, the content of the remaining chapters can be seen at https://www.elsevier.com/books/gas-turbine-engineering-handbook/boyce/978-0-12-383842-1.

If you think you can rise to this challenge and be appropriately remunerated, please contact the Boyce Consultancy Group via their web site, see details below.

* Dr Meherwan P Boyce, PhD. PE. CEng (UK), was the Chairman and CEO of The Boyce Consultancy Group, LLC and a Fellow of the following societies: American Society of Mechanical Engineers (ASME (USA), Institution of Mechanical Engineers (IMechE (UK)), National Academy of Forensic Engineers (NAFE (USA)) and the Institution of Diesel and Gas Turbine Engineers (IDGTE (UK).

Use your expertise

The Boyce Consultancy Group is seeking engineers to be a part of their on-going business of providing consultancy services in the turbomachinery industry and power generation field.

Boyce Consultancy has its headquarters in Houston, Texas but also operates as a "virtual" engineering consultancy company. They are looking for engineers in the fields of turbomachinery and power generation who would like to join them as they continue the company in Dr Boyce's honour.

The Boyce Consultancy Group have projects that they expect to come to fruition shortly.

Please contact Zarine Boyce at The Boyce Consultancy Group:

WhatsApp/mobile	011 713 306 9777
Office phone	011 713 807 0888
E-mail	zmboyce@boycepower.com
Website	www.boyceconsultancy.com

THE BOYCE CONSULTANCY GROUP LLC

Optimizing the performance of a 500kW Diesel Generator: Impact of the Eo-Synchro concept on fuel consumption and greenhouse gases

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Abstract

The power generation for many remote areas such as telecommunications infrastructures, mining facilities and isolated residential areas, is historically ensured with diesel engine generators. The economical cost of energy is therefore very high not only due to the inherent cost of fuel but also due to transportation and maintenance costs. The environmental cost of energy is also high as the use of fossil fuels for electricity generation is a significant source of greenhouse gas emissions. On the other hand, the shipping industry is under great pressure to reduce its environmental impact. If no measures are taken, CO_2 emissions are projected to increase 50-250% by 2050, while the Paris convention requires a significant reduction to achieve 2ºC global warming target. Moreover shipping already contributes to 15% of the global NOx emissions, which is also projected to increase if no measures are taken. In previous work, we have explored and evaluated a new technique based on the Eo-Synchro concept to reduce fuel consumption and minimize the unit cost of electricity; a general saving of 7% of fuel consumption was found when the Eo-Synchro concept was applied on a 75KW Diesel Generator (DG). As a continuity of these previous works, experimental tests have been carried out on a 500KW DG to evaluate the performance of fuel consumption and gaseous emission characteristics when the Eo-Synchro concept is applied. The experimental results show a significant fuel saving up to 15% can be obtained at low power loads and up to 5% at high power loads. On the other hand, the emission of nitrogen oxides (NOx) and of carbon dioxide (CO_2) are 5.8% lower when the Eo-Synchro concept is used. The results for the other emissions are also shown in the figures and tables. Based on our results, an assessment of fuel savings and greenhouse gas reduction is presented for an off-grid mine site located in the Canadian North. A saving of 4% on fuel consumption and GHG emissions has been registered at high power loads.

Keywords: Diesel engine, diesel generator, Eo-Synchro concept, performance, emissions, greenhouse gases, power ship, off-grid mine.

1 Introduction

Motor generators are a wide class of electric power systems, which include plants of the diesel generator (DG) type, gasoline engine generator plants, marine and other shaft generator plants, wind farms, and a number of other power generating systems [1]. Of the above mentioned systems, the most widely used plants are those of the DG type. They, having high reliability, a long service life, and durability, are indispensable as autonomous sources of primary or backup power supply for both marine vessels and onshore facilities. Classic gensets based on internal combustion engines are equipped with synchronous generators; therefore fixed speed operation is required. They operate at low efficiency during low load operation (Figure 1). It is not critical in emergency power applications, but very important in continuously operated systems, where fuel consumption is a significant economic and logistic aspect. In fact, remote areas with relatively small communities generally show significant variation between the time of peak loads and the time of minimum loads. A typical example of a load profile of a remote community in Western Australia is shown in Figure 2 [2].

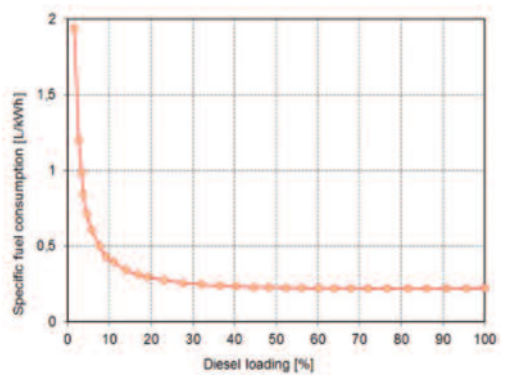

Figure 1 Example of variation of a diesel fuel consumption with loading [2]

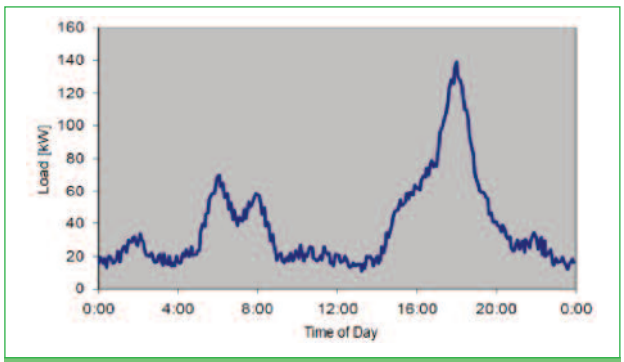

Figure 2 Typical load profile of a remote community in Australia

Diesel-powered electric generators are typically sized to meet the peak demand during the evening, but must run at very low loads during "off-peak" hours during the day and night. This low-load operation results in poor fuel efficiency and increased operation and maintenance costs [3]. Moreover, low load operation of a diesel genset at synchronous speed reduces the engine lifetime, by incomplete combustion of the fuel; therefore an additional dump load is required to improve the combustion process. The efficiency and fuel combustion at low-load conditions can be improved by use of load adaptive adjustable speed operation of the genset [4]. Power electronics based designs use an engine driven generator along with power transistor (or controllable thyristors) inverters in back-to-back intermediate circuit connection, power electronics filters and a control scheme to create resulting voltage and current waveforms comparable to that generated by a fixed speed synchronous genset. The line side inverter provides constant voltage and frequency output during most load conditions and may also provide fault protection. In the solution with AC voltage output of the line side inverter and varying rotational speed there is a problem of rapid load changes which may cause a voltage collapse [5].

In some remote locations, a dual diesel generator system is employed. When the load is light, the smaller generator is used; as the load increases, the manual switch is transferred to the larger generator. This approach results in some fuel savings, however managing this dual system is time consuming and impractical [3]. High fuel costs have translated into tremendous increases in the cost of energy generation [3]. In Quebec for example, as the fuel is delivered to remote locations, some of them reachable only during summer periods by barge, the cost of electricity produced by diesel generators reached in 2007 more than 50 cent/kWh in some communities, while the price for selling the electricity is established, as in the rest of Quebec, at approximately 6 cent/kWh [6]. The deficit is spread among the Quebec population and the total consumption of the autonomous grids is far from being negligible. Moreover, the electricity production by the diesel is ineffective, presents significant environmental risks (spilling of fuel and lubricants), contaminates the local air and largely contributes to GHG emissions.

In all, we estimate 140,000 tons annual GHG emission resulting from the use of diesel generators for the customers of the autonomous networks in Quebec. This is equivalent to the GHGs emitted by 35,000 cars during one year.

Based on these economic and environmental concerns, this paper proposes and investigates the use of the Eo-Synchro concept on a diesel generator, so as to minimise the performance indices of life cycle cost, net fuel consumption, net CO_2 emissions, dump energy and reliability of DGs. The rest of the paper is organised as follows: Section 2 presents the different factors that influence the efficiency of DGs; Section 3 presents a brief review of the Eo-Synchro concept and the relationship between the magnetic field induced and speed governor in a DG; Section 4 presents the bench test and discusses the results obtained on a 500KW DG; Section 5 presents the case study for on off-grid mining based on the Canadian north and Section 6 provides a conclusion and a perspective for future work.

2 Factors influencing the efficiency of Diesel Generator

2.1 Design Engine Efficiency

A diesel generator set is a combination of two major components: the engine (the driver) and the alternator (driven by the engine to produce power). Thus the efficiency of diesel generator sets is expressed as a combined efficiency of these two sub-components. Typically, the combined efficiency of diesel generator sets varies between 30-55% (for large low speed units) while stand-alone efficiency of a diesel engine and alternator ranges between 35-50% and 85-95% respectively [7]. The wide range of engine efficiency is mainly attributed to design, size or capacity, mechanism for fuel control, operating speed, type of cooling mechanism, and material of construction. However, the efficiency during operation deviates from the design value because of load conditions, ambient conditions, and operation and maintenance (O&M) practices [8]. In order to analyze the efficiency pattern of diesel engines, efficiency information for a sample number of models [9] was analysed as shown in Figure 3.

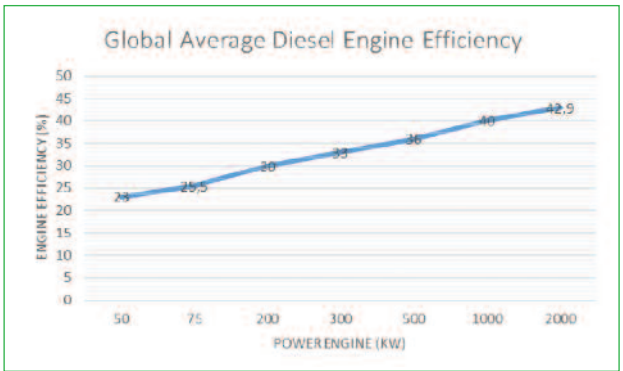

Figure 3 Comparison of design engine efficiency for a sample number of models

The analysis shows an increase in engine efficiency with increase in size of the sets. For up to 50kW to 1,000kW categories, efficiency varies between 20% and 40%. This is due to a wide variety of engine types and technologies (such as number of strokes, cylinders, fuel injection system, cooling type) adopted by manufacturers. Variation in efficiency is much lower in larger diesel generator sets (above 300kW or 375kVA). This is largely because scope for

for improvement in engine design, engine geometry, and sophisticated fuel control mechanism.

2.2 Fuel Engine Efficiency

Fuel efficiency is another metric of expressing the efficiency performance of a diesel generator set and it is directly linked to energy efficiency of the diesel generator (combined efficiency of engine and alternator). Specific Fuel Consumption (SFC) expressed in litre/hour or gm/kWh is an indication of the quantity of diesel required to generate one unit of electricity. The variation in SFC is influenced by operational factors such as loading, O&M practices, and ambient conditions. The following are the observations on parameters affecting the SFC of diesel generator sets [7]:

- SFC varies with size: the SFC becomes better in larger sized sets, specifically over 500KVA categories. For example, a 500KVA diesel generator at 100% loading has typically 12% better SFC than a 25KVA set at the same loading. For diesel generators capacity beyond 800KVA, SFC continues to improve as size increases to 2MW, 4MW, 6MW and greater.
- SFC varies with loads: SFC is typically optimum at 75-80% loading of the rated capacity. SFC worsens substantially at 25% load or below for all capacity ratings. For instance, a 500KVA set is observed to have 20% better SFC at 75% than at 25% loading.

2.3 Transmission Loss

From engine shaft to load, there are transmission losses of around 10% at full load rating [10]. The power efficiency of the generator is usually considered to be around 96%, where power efficiency is defined to be its output power divided by its input shaft power. Power loss is typically assumed to be negligible when it comes to the switchboard, while the power efficiency of power converter (transformer) is assumed to be around 98%-99.5%. Meanwhile, the power efficiency of electric motors is around 96%. However, all these values are specified on product's data sheet at rated conditions by manufacturers. This is because many notable regulatory bodies and trade organizations have tried to establish international standards for the way in which efficiency is calculated and stated on product data sheets. As a result, power supply efficiency is usually specified based on the operating conditions that are most favourable to the figure concerned, for example, at maximum rated load. However, for the rest of the time, it will be operating below full load, and efficiency is likely to be much lower than the stated figure. To assess the impact on heat generation within a product, one needs to dig deeper into the data sheet and find the efficiency versus load curve, if one is provided. Figure 4 shows an example of converter efficiency against load percentage. Across a wide span of load range from 40% to around 100%, there exists relatively flat efficiency. However, converter efficiency degrades significantly as load percentage drops to 40% and below where converter efficiency approaches 77% at close to 0% load.

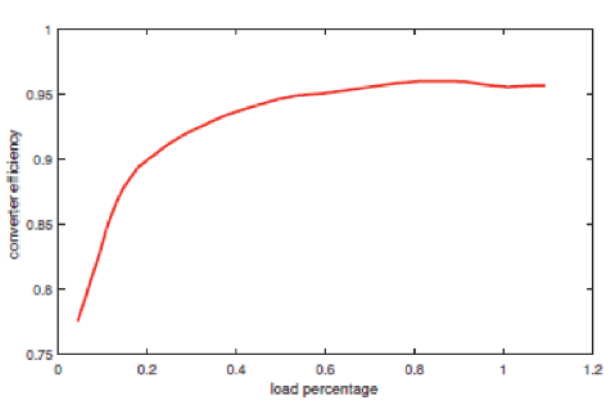

Figure 4 Converter efficiency against load percentage [10]

3 The Eo-Synchro concept and relationship between the magnetic field induced and speed governor in a diesel engine

3.1 The Eo-Synchro concept: A brief review

The Eo-Synchro concept is a control system which proposes a highly original approach based on a new alternator design. The concept employs a new non-static stator where the stator rotates around the axis of the rotor. A motor mounted on the alternator provides full control of the position and the rotational speed of the stator [11]. Figure 5 shows a prototype of the Eo-Synchro alternator, rated at 75kW.

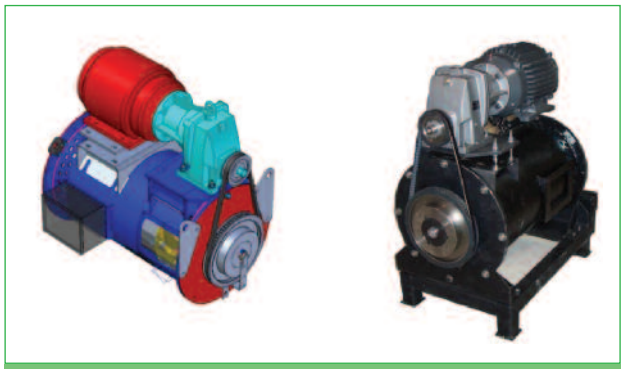

Figure 5 The concept and prototype of Eo-Synchro [11]

In our previous work [11], we have demonstrated the positive effect of the Eo-Synchro concept on fuel consumption when applied to a 75kW DG. A general fuel consumption saving of 7% was found for the different ranges of the applied loads. In the following section (3.2), we discuss the relationship between the magnetic field induced and the speed governor's reaction according to the applied loads when the stator is fixed, followed by an explanation of the Eo-Synchro concept as a variable speed generator.

3.2 Relationship between the magnetic field induced and speed governor in a diesel generator

A synchronous electrical generator is designed to be operated at a constant speed ie synchronous speed. When the generator rotor is rotated, the magnetic flux of the

generator rotor induces a voltage in the generator stator windings, called the generator terminal voltage [12]. When the speed of the generator rotor is constant and the excitation is constant, the generator terminal voltage will be constant. The magnitude of the generator terminal voltage is a function of the strength of the magnetic field of the generator rotor, since the generator rotor is being rotated at constant speed, which is the synchronous speed. To do so, an Automatic Voltage Regulator (AVR) adjusts the magnetic fields as needed. During heavy power demands, voltage decreases causing the AVR to increase the magnetic field. Conversely, when power demands are low, the AVR tempers the field. Mechanical power is given by P = Torque x Rotational speed. Speed is normally regulated to be a constant value in order to keep the voltage and frequency constant. Torque varies as required to supply the mechanical power that is converted to electrical power. If the generator requires more torque, the fuel flow must increase to supply the additional power. Power available from burning fuel is proportional to fuel mass per unit of time. As electrical load increases the mechanical load increases. If the throttle position was fixed the speed would drop. The governor opens the throttle to allow more fuel in to maintain speed at set point.

3.3 The Eo-Synchro concept as variable speed generator

Applying the Eo-Synchro concept by allowing the free rotation of the stator, the diesel generator set (DGS) can be operated at variable speed. The synchronous speed of the alternator can remain constant through three different methods of speed control:

- Rotor speed only
- Stator speed only
- Both speeds simultaneously

A number of sources reported that a variable speed diesel generator is more efficient than a constant speed diesel generator. The minimum recommended continuous load for a constant speed diesel engine is about 40%, this value is approximately 23% for a variable speed diesel engine [15]. The main advantage of the operation of engines at variable speed is the ability to reduce fuel consumption and to generate more power from the diesel engine without exceeding its rated torque. The best fuel consumption by considering the restriction such as rated torque and engine speed can be achieved when the DG set operates at or near to its rated torque. In order to reduce the fuel consumption, the diesel engine has to be operated based on its fuel efficiency map. It can be provided by experimental analysis and extracting the fuel efficiency map for a 500kW variable speed DGS used in this study by controlling the stator speed only as presented in Figure 6.

4 Test bench

Figure 7 shows the bench test studied. It consists of a diesel engine (DE) as a prime mover coupled to a synchronous alternator (SA). The model tested is a 3412C 500kW genset manufactured by Caterpillar.

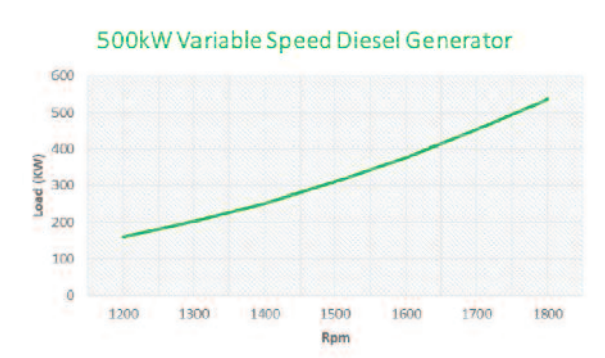

Figure 6 Optimal rotational speed versus load curve

The DE was instrumented with a torque sensor and speed sensor. This allowed us to measure the mechanical power supplied to the SA. Also, the output of the SA was instrumented with the global output. We were able to measure the current and voltage of each line with the power factor (PF) and the total harmonic distortion (THD) of the current and voltage. Tests were performed with a mechanical power between 134kW and 537kW at 600V and a speed ranging from 1,200rpm to 1,800rpm. To finish, we integrated the industrial combustion analyzer TESTO 300 to analyze the greenhouse gas (GHG) emissions emitted by the engine. Figure 8 shows the schematic of the bench test studied.

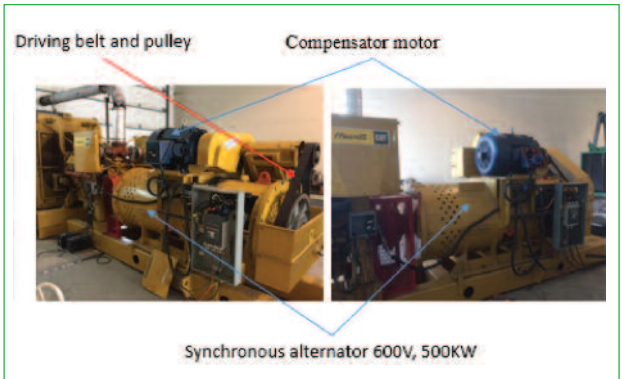

Figure 7 Genset 3412C adapted to Eo-Synchro concept

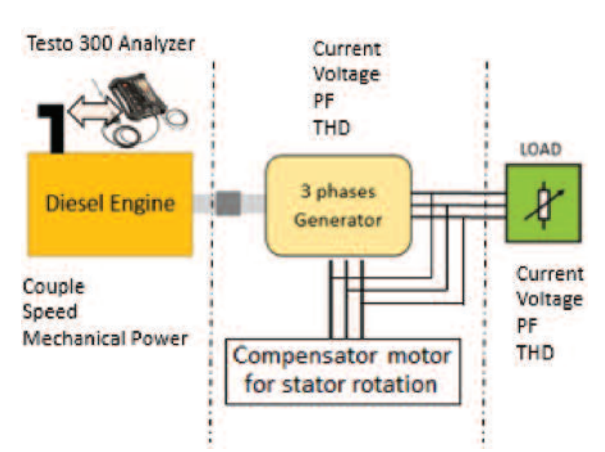

Figure 8 Schematic of the bench test

4.1 Results obtained concerning the fuel consumption

In order to evaluate the fuel consumption of the 3412C genset at different loads, we used a fuel tank load cell and we made the first test without introducing the compensator motor. Table 1 shows the fuel consumed when the stator is fixed.

Blocked stator without Eo-Synchro intervention

Load (%)	Load (KW)	Engine speed (rpm)	BSFC g/kW-hr	Fuel rate (L/hr)
25	134,2	1200	234.4	39
40	214,8	1323	231.7	60
50	268,5	1424	228.2	74
60	322,2	1518	224.0	87
70	375,9	1600	219.9	98
80	429,6	1680	220.0	113
90	483.0	1725	221.2	128
95	510,5	1755	222.2	135
100	537.0	1800	223.1	142

Table 1 Evaluation of fuel consumption with a blocked stator (conventional mode)

Subsequently, we performed the same tests mentioned above, but with the application of Eo-Synchro technology. Tests were performed by applying a fixed speed stator rotating at 200rpm. Table 2 illustrates the fuel consumption results when stator rotation is applied.

With Eo-Synchro (stator runs at 200 rpm)

Load (%)	Load (KW)	Engine speed (rpm)	BSFC g/kW-hr	Fuel rate (L/hr)
25	134,2	1200	205.1	33
40	214,8	1250	208.0	54
50	268,5	1350	215.6	70
60	322,2	1470	220.0	85
70	375,9	1550	219.1	96.9
80	429,6	1605	209.0	107
90	483.0	1700	212.3	123
95	510,5	1725	215.7	131

Table 2 Evaluation of fuel consumption with Eo-Synchro concept (with rotating stator)

As we can see, the load tests cannot exceed 95%. This can be explained by the fact that the compensator motor is powered by the main generator and absorbs a power equivalent to 27kW. Table 3 shows the fuel consumption difference between the conventional DG and when Eo-Synchro technology is applied.

Blocked Stator Vs Eo-Synchro

Load (%)	Load (KW)	Difference (%)
25	134,2	+15.4
40	214,8	+10
50	268,5	+5.4
60	322,2	+2.29
70	375,9	+1.12
80	429,6	+5.30
90	483	+3.90
95	510,5	+2.96

Table 3 Fuel consumption variation

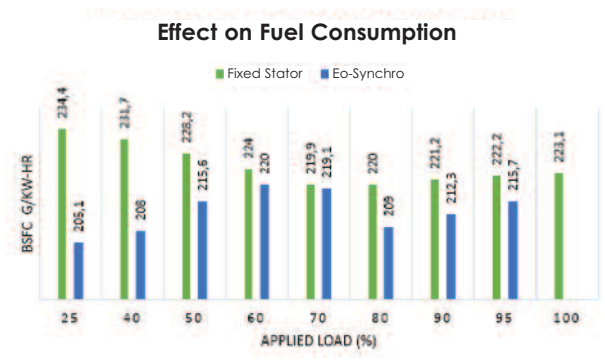

Figure 9 Effect of the Eo-Synchro on fuel consumption applied to the 3412C, 537KW, 600V, 60Hz

Figure 9 further illustrates the effect of the Eo-Synchro technology can have on improving DE fuel consumption for different loads.

According to Table 3 we can consider that the Eo-Synchro technology has a positive impact on fuel consumption on the 3412C DG. An average saving of 5.8% was found for the different loads while the highest fuel consumption improvement was registered at 25% of applied load and the lowest at 70%. This can be explained as most of the DGs are designed and optimised to run between 70 and 80 percent of total load rating.

4.2 Results obtained concerning the GHG emissions

In order to evaluate the GHG emissions emitted by the DE, we used the industrial combustion analyzer TESTO 300. We recorded the data collected for carbon dioxide (CO_2), sulphur oxide (SOx), nitrogen oxide (NOx) and particulate matter (PM). Tests were performed for conventional operation (fixed stator) and with the Eo-Synchro concept for different loads at 25°C and number 2 diesel fuel with 35° API (American Petroleum Institute gravity) and LHV (Lower Heating Value) of 18,390btu/lb. Table 4 shows the results for conventional operation while Table 5 shows the results with the Eo-Synchro concept.

In order to make a comparison on the value of the carbon dioxide emissions, we created Table 6 to compare the emission results and calculate the rate of change by percent.

GHG emissions with conventional mode

Load (%)	CO_2 (Kg)	SOx (Kg)	NOx (Kg)	PM (Kg)
25	106.860	0.1660	0.0858	0.0039
40	164.400	0.25548	0.1320	0.0060
50	202.760	0.3150	0.1628	0.0074
60	238.380	0.3704	0.1914	0.0087
70	268.520	0.4172	0.2156	0.0098
80	309.620	0.4811	0.2486	0.0113
90	350.720	0.5450	0.2816	0.0128
95	369.900	0.5748	0.2970	0.0135
100	389.080	0.6046	0.3124	0.0142

Table 4 GHG emissions for 3412C DG

GHG emissions with rotational stator

Load (%)	CO_2 (Kg)	SOx (Kg)	NOx (Kg)	PM (Kg)
25	90.420	0.1405	0.0726	0.0033
40	147.960	0.2299	0.1188	0.0054
50	191.800	0.2980	0.1540	0.0070
60	232.900	0.3619	0.1870	0.0085
70	265.506	0.4126	0.2131	0.0096
80	293.180	0.4556	0.2354	0.0107
90	337.020	0.5237	0.2706	0.0123
95	358.940	0.5577	0.2882	0.0131

Table 5 GHG emissions for 3412C DG with Eo-Synchro intervention

Blocked Stator Vs Eo-Synchro

Load (%)	Load (KW)	Difference (%)
25	134,2	-15.48
40	214,8	-10.00
50	268,5	-5.400
60	322,2	-2.29
70	375,9	-1.12
80	429,6	-5.30
90	483	-3.90
95	510,5	-2.96
Average of :		-5.8096

Table 6 Improvement of CO_2 emissions at different loads

We performed in the same way the emissions for sulphur oxide (Table 7 and Figure 11), nitrogen oxide (Table 8 and Figure 12) and for particulate matter (Table 9 and Figure 13).

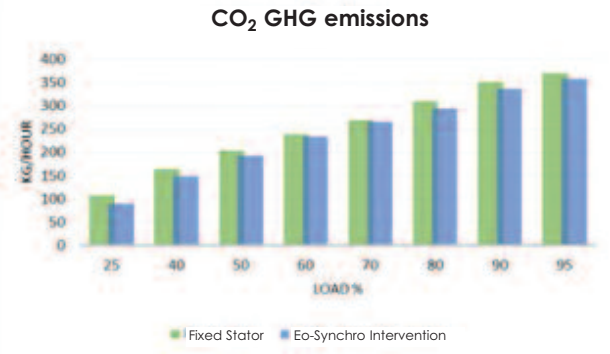

Figure 10 Efficiency of Eo-Synchro on CO_2 emissions

Blocked Stator Vs Eo-Synchro

Load (%)	Load (KW)	Difference (%)
25	134,2	-15.36
40	214,8	-10.01
50	268,5	-5.39
60	322,2	-2.29
70	375,9	-1.10
80	429,6	-5.30
90	483	-3.90
95	510,5	-2.97
Average of :		-5.79

Table 7 Improvement of SOx emissions at different load blocked stator versus Eo-Synchro

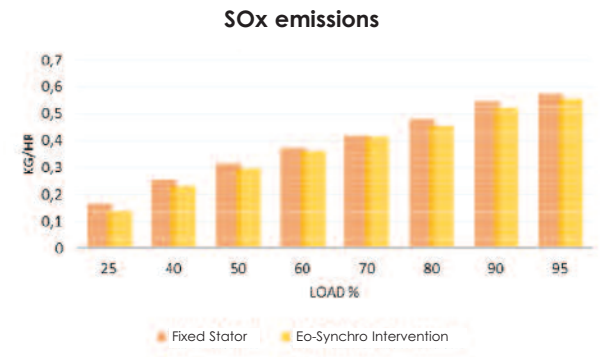

Figure 11 Efficiency of Eo-Synchro on SOx emissions

According to Tables 6, 7, 8 and 9 the Eo-Synchro technology has a positive impact on GHG emissions. We could see a 5.8% decrease compared to the conventional operation and this could be explained by the fact that we had a reduction in fuel consumption. Table 6 shows the difference between value and overall average for all loads.

4.3 Results obtained concerning the total harmonic distortion (THD)

Analysing the compilation presented in Table 10 and Figures 14 and 15, it can be observed that the voltage harmonics and current harmonics have nearly constant

values between conventional operation (fixed stator) and the Eo-Synchro technology. This confirms that the generator meets specified requirements in the standard PN-EN 61000-3 regarding harmonic distortion even with the modifications to allow rotation of the stator.

Blocked Stator Vs Eo-Synchro

Load (%)	Load (KW)	Difference (%)
25	134.2	-15.38
40	214.8	-10.00
50	268.5	-5.40
60	322.2	-2.29
70	375.9	-1.15
80	429.6	-5.30
90	483.0	-3.90
95	510.5	-2.96
Average of :		-5.79

Table 8 Improved NOx emissions at different load

NOx emissions

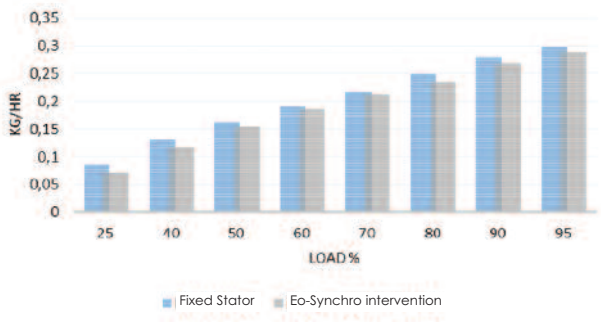

Figure 12 Efficiency of Eo-Synchro on NOx emissions

Blocked Stator Vs Eo-Synchro

Load (%)	Load (KW)	Difference (%)
25	134.2	-15.38
40	214.8	-10.00
50	268.5	-5.40
60	322.2	-2.29
70	375.9	-2.04
80	429.6	-5.30
90	483.0	-3.90
95	510.5	-2.96
Average of :		-5.90

Table 9 Improved PM emissions at different load

Voltage and current harmonics comparison

	Fixed Stator		*Eo-Synchro Tech*	
Load (%)	Current (%)	Voltage (%)	Current (%)	Voltage (%)
25	1,45	4,5	1,7	4,9
40	1,50	8,5	1,4	8,7
50	1,44	9,3	1,42	9,4
60	1,42	9,8	1,4	10,3
70	1,47	11,5	1,5	11,6
80	1,8	13,6	1,5	13,1
90	1,8	14	1,5	13,9
95	1,8	14,3	1,5	14,3

Table 10 Voltage and current THD comparison between all loads

PM emissions

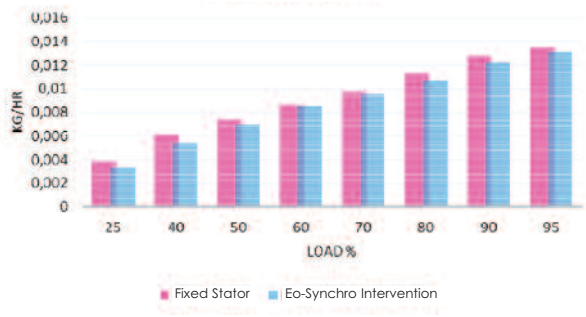

Figure 13 Efficiency of Eo-Synchro on PM emissions

Percentage participation of current harmonics

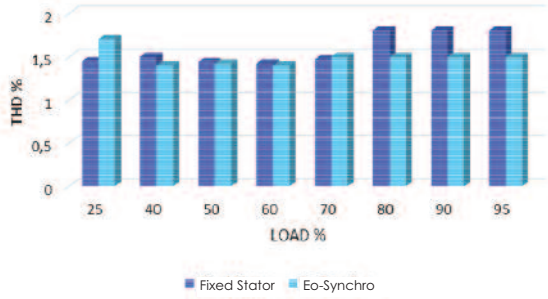

Figure 14 Current harmonics comparison

Percentage participation of voltage harmonics

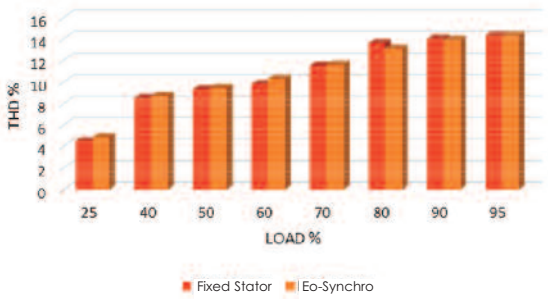

Figure 15 Voltage harmonics comparison

5 Mine Site

In this paper, to evaluate the performance of the proposed technology, a nickel mine in the Canadian North is utilised as a case study.

5.1 Configuration

Figure 16 Raglan Mine site location, from Glencore

The Raglan remote nickel mine site located in the Canadian North (Figure 16/Northern part of the province of Quebec) is fully dependant on diesel fuel for power generation. The electric grid includes 6 base-load 3.6MW diesel generator sets of and one 4.4MW genset, as well as 5 peak-load 1.8MW gensets [16], as well as various additional gensets of smaller capacities. The electric load is relatively constant through the year with a small reduction during the summer months. Electric load variation for one week is presented in Figure 17 while the monthly maximum, average and lows are presented in Figure 18.

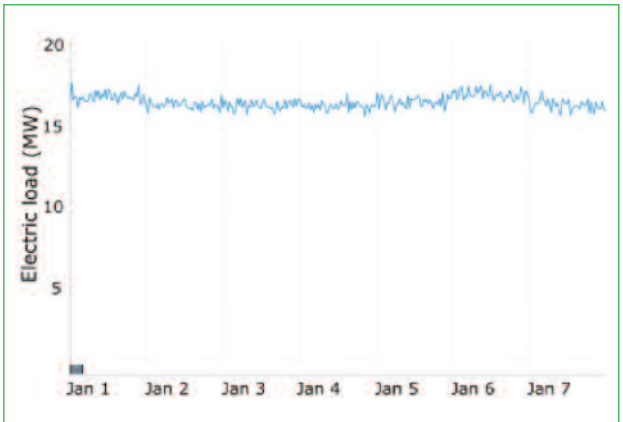

Figure 17 Electric load variation for one week [16]

5.2 Annual diesel fuel consumption and GHG emissions

According to Figures 17 and 18, we fixed the maximum demand in power per day at 17MW for a duration of 10 months per year and 14MW per day for July and August. The baseload DG units consist of 6 x 3.6MW and 1 x 4.4MW units for a total of 22.4MW of capacity. The peak power DG units consist of 5 x 1.8MW units for a total of 9MW and also include additional smaller DGs. The base load units are operated continuously as the main based load power source where 4 x 3.6MW units and the 4.4MW regularly operate, and 2 x 3.6MW units are available as spare

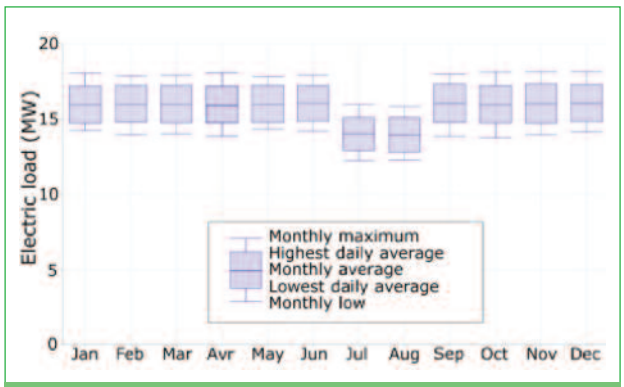

Figure 18 Yearly electric load variation [16]

capacity, one in hot standby, and one typically offline for maintenance. The second group of 5 x 1.8MW units and additional smaller units are operated intermittently during peak load periods, and during maintenance works on the 4.4MW unit. Also, the mine has a 3MW wind turbine generator which operates when sufficient wind conditions are present.

Table 11 illustrates the annual fuel consumption and GHG emissions for both groups for a nominal load of 85-90%. Fuel cost was established at 1.20$CAD/L and each litre of diesel results in 2.64kg of CO_2 emissions.

According to Table 11, the total value of fuel consumption per year is estimated to be approximately at 30 million litres

Group 1: without Eo-Synchro intervention

Genset number	Fuel consumption (L/year)	CO_2 emissions (Tons/Year)	Fuel cost/year (CAD$)
1 X 3.6MW	4,800M	12,672K	5,760M
1 X 3.6MW	4,800M	12,672K	5,760M
1 X 3.6MW	4,800M	12,672K	5,760M
1 X 3.6MW	4,800M	12,672K	5,760M
1 X 3.6MW	0,874M	2,307K	1,048M
1 X 3.6MW	0,874M	2,307K	1,048M
1 X 4.4MW	2,371M	6,259K	2,845M
TOTAL	23,319M	61,561K	27,981M

Group 2: without Eo-Synchro intervention

Genset number	Fuel consumption (L/year)	CO_2 emissions (Tons/Year)	Fuel cost/year (CAD$)
1 X 1.8MW	0,538M	1,420K	0,645M
1 X 1.8MW	0,538M	1,420K	0,645M
1 X 1.8MW	0,538M	1,420K	0,645M
1 X 1.8MW	0,538M	1,420K	0,645M
1 X 1.8MW	0,538M	1,420K	0,645M
TOTAL	2,690M	7,10K	3,225M

Table 11 Economic parameters for the base load DGs and the peak load DGs

at a cost of 35 million $CAD while the estimated emissions of CO_2 for electricity generation amount to 77 kilotons per year. As the current price for one metric ton of CO_2 is established at 14.35$CAD for the year 2018 [17], the Raglan mine will be forced to buy 746,000 $CAD in credits based on regulations and the carbon market which target companies in the industrial sectors that emit 25,000 metric tons of CO_2 equivalent or more per year [18].

5.3 Economic performance

According to the demonstrated performance of the Eo-Synchro technology, the project's economic performance for the Raglan remote nickel mine site is calculated to provide fuel cost savings of 4% based on the fuel savings at 85% load observed during the 500kW unit test work. An economic sensitivity analysis was carried out on the two main economic parameters of the project: fuel cost and carbon credits. Results of the sensitivity analysis are found in Figures 19 and 20 while the economic parameters are shows in Tables 12 and 13.

Figure 19 further illustrates the effect that the Eo-Synchro technology can have on improving DE fuel consumption, while Figure 20 illustrates the impact on CO_2 emissions. Based on our results, the fuel savings are projected to be 1,120,000 litres per year which represent 1,300,000 $CAD. This saving also reduces CO_2 emissions by 4% which allows the mine to save 59,000 $CAD in purchases of carbon credits.

Group 1: with Eo-Synchro intervention

Genset number	Fuel consumption (L/year)	CO_2 emissions (Tons/Year)	Fuel cost/year (CAD$)
1 X 3,6MW	4,608M	12,165K	5,530M
1 X 3,6MW	4,608M	12,165K	5,530M
1 X 3,6MW	4,608M	12,165K	5,530M
1 X 3,6MW	4,608M	12,165K	5,530M
1 X 3,6MW	0,839M	2,214K	1,006M
1 X 3,6MW	0,839M	2,214K	1,006M
1 X 4,4MW	2,280M	6,019K	2,736M
TOTAL	22,390M	59,107K	26,868M

Group 2: with Eo-Synchro intervention

Genset number	Fuel consumption (L/year)	CO_2 emissions (Tons/Year)	Fuel cost/year (CAD$)
1 X 1,8MW	0,516M	1,362K	0,619M
1 X 1,8MW	0,516M	1,362K	0,619M
1 X 1,8MW	0,516M	1,362K	0,619M
1 X 1,8MW	0,516M	1,362K	0,619M
1 X 1,8MW	0,516M	1,362K	0,619M
TOTAL	2,580M	6,810K	3,095M

Table 12 Economic parameters with Eo-Synchro intervention

	Fuel consumption (L/year)	CO_2 emissions (Tons/Year)	Fuel cost/year (CAD$)
Without Eo-Synchro			
Group 1 & 2	26,09M	68,661K	31,206M
With Eo-Synchro			
Group 1 & 2	24,97M	65,917K	29,963M
Difference			
Group 1 & 2	1,120M	2,744K	1,243M

Table 13 Economic parameters comparison

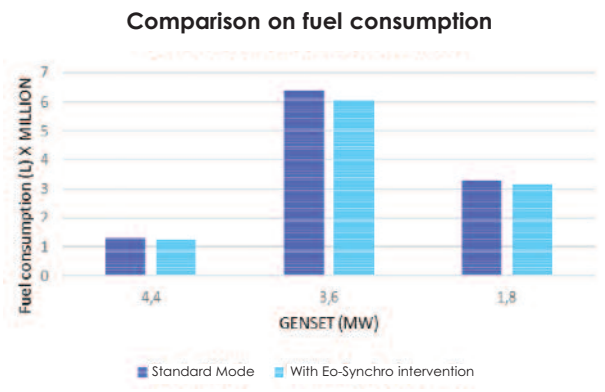

Figure 19 Effect of the Eo-Synchro on fuel consumption applied to the different group of genset used in Raglan mine

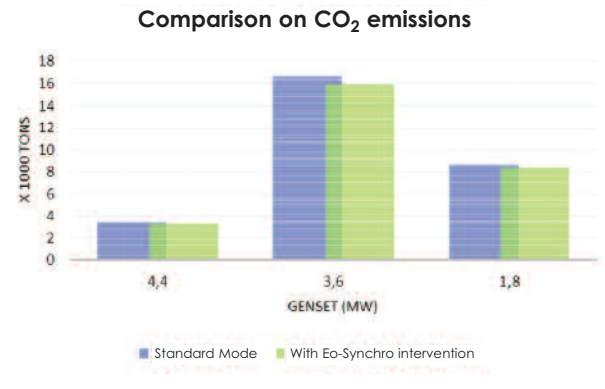

Figure 20 Impact of the Eo-Synchro technology on CO_2 emissions

6 Conclusion

This article presents a new technology based on the Eo-Synchro concept improving the performance of a 500kW diesel generator and aims to minimize the cost of electricity production. The experimental results show that significant fuel savings of 15% can be obtained at low power loads which can be considered very attractive for remote areas where DGs frequently run at lower loads (<50%). On the other hand, a significant fuel saving was observed of 5% for high power loads (80-85%). This allows the Eo-Synchro

concept to cover a wide range of industrial applications and to compete with other conventional techniques such as the use of high power electronic variable speed drives. These fuel savings give positive economic returns on investment for different applications as well as CO_2 emissions. At the Raglan mine site, this study concludes that the Eo-Synchro concept can offer reduced fuel consumption. The concept has been demonstrated as a reliable technology for electricity generation at remote mine sites which offers fuel consumption and carbon emissions savings. Lessons learned at the Raglan Mine site are useful for other similar remote grids operating in Northern Canada and other sites. These sites include remote communities and industrial sites where all electricity needs are provided by diesel generators. In our future work, we will evaluate the Eo-Synchro concept on a 1MW DG and present a mathematical model to characterize the generated power and the results on fuel economy savings obtained and CO_2 emissions for a cargo ship vessel powered by 4 DGs. ■

Nomenclature

DE	Diesel Engine
DG	Diesel Generator
GHG	Greenhouse Gas
THD	Total Harmonic Distorsion
PF	Power Factor
MW	MegaWatt
kW	KiloWatt
CAD	Canadian Dollar
O&M	Operation and Maintenance
SFC	Specific Fuel Consumption
AVR	Automatic Voltage Regulator
SA	Synchronous Alternator
Mlpy	Million litre per year
KTpy	KiloTons per year
Mpy	Million per year
CO_2	Carbon dioxide
SOx	Nitrogen Oxide
PM	Particulate Matter
NOx	Nitrogen Oxide

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[18] http://www.mddelcc.gouv.qc.ca/changementsclimatiques/marche-carbone.asp

Our heritage

Report by Trevor Owen

W H Allen Engineering Association, Bedford

The W H Allen Engineering Association (WHAEA) was formed in 1999 to preserve the heritage of W H Allen and Co Ltd of London and Bedford. The association is open to former employees of this major engineering entity and also anyone who has been involved with the operation and maintenance of the products. The association is currently trying to recruit more members. They organise visits and various reunion events for members. More information can be found at www.whaea.co.uk

A further recent development has been the formation of a 'closed group' on Facebook to encourage dialogue which is of interest to those who have worked at Allens in Bedford. The group is open to anyone with a relevant background who makes the appropriate request via Facebook. The group can be found by searching for 'WH Allen Engineering Association' on Facebook.

Longreach Powerhouse Museum, Australia

For many years the Queensland State Electricity Commission used to submit an annual return to the DEUA/IDGTE covering the operational data for various of their diesel power stations spread across the state. Amongst the list of stations was Longreach with reporting continuing into the 1980s. Longreach is located north west of Brisbane about 700km from the coast and the main industry in the region was originally cattle and sheep.

The complete power station has been preserved in the final operational condition after being developed over the period from 1921 to 1973. It was developed as a rural power station to supply the township initially using Ruston and Hornsby charcoal gas engines driving DC generators via a belt drive. The original equipment was gradually replaced over the following decades with coal gas becoming the primary fuel until in the final days diesel fuel was used. The station was finally decommissioned in 1985.

It was a customary practice in this area to move displaced generating sets to new locations as the power demand increased and new sets were installed. The installed generating sets comprise:

- 3 x 1960/66 Crossley Premier N8 vis-a-vis spark ignition gas sets rated at 650kW at 214rpm
- 1 x 1948 English Electric 7SL diesel set rated at 750kW at 375rpm (ex Bundaberg and Cairns)
- 1 x English Electric 8SK diesel set rated at 400kW at 600rpm (ex Gladstone Rockhampton and Mackay)
- 1 x 1949 Mirrlees HFS8 diesel set rated at 750kW at 375rpm (ex Cairns)
- 1 x 1949 Mirrlees HFBS8 diesel set rated at 750kW at 375rpm (ex Atherton and Mackay)
- 1 x 1948 National F2APX8 dual fuel set rated at 300kw at 500rpm
- 1 x 1948 National RA7 diesel set rated at 125kW at 600rpm

National F2APX 8 cylinder dual fuel engine at Longreach Powerhouse

This makes an interesting list with one set installed in its fourth location since new.

The user was a regular contributor to the DEUA/IDGTE Working Cost and Operational Reports right up to the station closure. In the final phase of operation diesel fuel was used and the Crossley sets were retired from use as straight gas engines, whereas the National F2APX8 dual fuel set continued to be used in diesel mode. By the time the station ceased operation one of the Mirrlees HF engines had run almost 80,000 hours.

Further information about this station is available on-line in the form of an Engineering Heritage Australia nomination document dated July 2012 at

https://www.engineersaustralia.org.au/portal/system/files/engineering-heritage-australia/nomination-title/Longreach%20P.H.Museum%20Nomination.pdf

Walkers No 1 - 3 cylinder A frame air blast engine – update on the renovation

The rebuild of a locally manufactured Mirrlees design A frame diesel is progressing well. The engine is largely reassembled with the fuel and lube oil systems fitted and tested. The air compressor has been renovated and refitted. The starting air cylinders have been passed for further use but the 900psi injection air vessel is being replaced due to severe pitting.

The engine was built around 1927 by Walkers of Maryborough under licence to a design first introduced by Mirrlees Bickerton and Day Ltd many years earlier. This was the first engine produced by the licensee and hence it is known as 'Walkers No 1'. It is interesting that this old-style design with air blast injection was first being manufactured under licence at a time when production of this design was in its final years at Mirrlees. Direct injection fuel systems were being introduced by many manufacturers in the mid to late 1920s with far smaller and lighter engine designs.

The Walkers engine is rated at 220bhp at 300rpm and drives an alternator rated at 150kW. It was installed at the Kalamia Sugar Mill in Queensland to provide power during the 'closed season' when the mill was not processing sugar. During the sugar 'campaign season' power was provided by steam driven machinery using mainly bagass (the remains of the sugar cane after crushing) to fire the boilers. During local emergencies the set could also be used to feed power to the hospital at Ayr.

The bedplate on arrival at Brandon with the preservation team

The set was last used to produce power during cyclone 'Althea' in 1972 when there was a mains power failure. By this time the 150kW set was however proving to be inadequate to cope with the demands of the mill and it was left largely unused for several decades. In 2015 the set was removed for restoration by the Burdekin Machinery Preservationists within the Burdekin Heritage Precinct. A substantial concrete foundation was poured at Brandon and a building created around it to form 'The Powerhouse' (using the same name as used for the engine location at the sugar mill for many years). The engine was moved in parts and relocated onto the new foundation. This was no mean feat as the individual parts are substantial.

The preservation club has collected various old engines and machinery including a Ruston 7-cylinder 425bhp rail traction diesel engine. The club is normally open for visitors on Wednesdays and Fridays at 21/27 Spiller Street, Brandon, QLD 4806. Anyone planning a visit would be advised to check with the tourist office in Townsville in the first instance to establish current opening times and dates.

The engine in the final stages of the rebuild at Brandon

Midsummer Mingle diesel reunion event
Anson Engine Museum

The date for the next event is Wednesday 27th June 2018 between 1400 and 2100. In recent years significant numbers have attended the event in the afternoon with numbers reducing in the evening in complete contrast to ten years ago when the attendance profile was the exact opposite. Once again there have been significant changes at the museum during the winter period.

Future heritage papers

We are still looking for Members to either write a heritage article or provide suitable material on engines or manufacturers which have not yet been covered since the series commenced in 2005.

Any feedback or memories on relevant subjects would be welcome. Anyone with suitable material or memories should contact the Bedford Office in the first instance.

DEUA/IDGTE on-line library of heritage papers of engines and manufacturers

The Members Area of the IDGTE website provides access to past DEUA and IDGTE papers. There is a comprehensive library of more recent papers and then a more limited availability going back in time with significantly more papers being added to the on-line collection in 2017.

A full list of the papers published by the DEUA and IDGTE from 1916 to 2017 is available in pdf format for viewing at www.idgte.org/Papers1913-2017.pdf.

The Anson Engine Museum
Poynton, Cheshire, SK12 1TD

2018 Programme

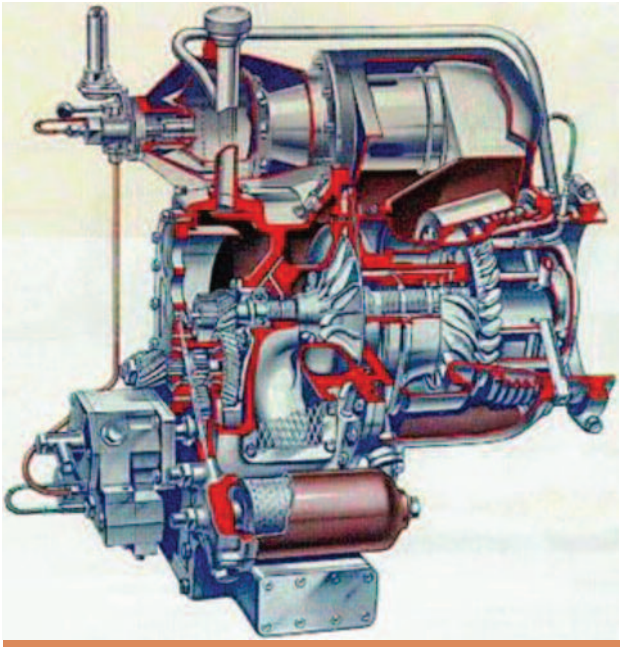
The museum season commences at Easter and continues until the 'Turn the Clocks Back' weekend in October. Certain days are allocated for operating the steam engine collection in addition to the other engines. The dates for special event days are as follows:

27 June	Midsummer Mingle
22 July	Live steam day with craft fair
26/27 August	Live steam days with craft fair
23 September	Live steam day with craft fair
27/28 October	'Turn the clocks back' closing weekend event

Full details of the opening times and special event details can be found on the museum website at www.enginemuseum.org

Rover Gas Turbine

The Rover gas turbine set has been stripped and rebuilt earlier in the year at the museum. This is one of the few remaining units from the Rover developments.



Sales brochure sectional view of a Rover gas turbine

Enhanced Cinema Experience

There has been a cinema within the museum for many years with a number of period films available with a self-selection system in operation in quieter periods. The cinema features seats retrieved from a local entity and earlier in the year some further improvements were made to attract more visitors to this facility.

New cinema entrance at the Anson Engine Museum

Promotional video

A promotional video has been uploaded to YouTube and can be viewed at www.youtube.com/watch?v=TUKfJ_YOUcg; this gives a good over-view of what is available to view at the museum for those who haven't visited previously.

Engine dating enquiries

The museum can provide a dating record service for Crossley, Tangye, Mirrlees, Blackstone and Gardner engines. It is acknowledged that the records are not fully complete but the staff will use their best endeavours to provide a relevant response. To use this facility a form needs to be downloaded from the museum website and completed.

Internal Fire Museum of Power
Tanygroes, Cardiganshire, Wales, SA43 2JS

Opening times

The museum is open until early October with days and times varying according to the month. Planned events for the remainder of the year are as follows:

August Steaming Weekend	26/27 August
End of Season Crank-up	13/14 October
Museums at Night (second event)	31 October

The museum is on the A487 Cardigan to Aberystwyth road, 8 miles north of Cardigan just beyond the village of Tanygroes.

See the museum website for full details of opening times and special events at www.internalfire.com

IDGTE proposed visit 29-30 September 2018

A social weekend visit is planned to the museum with a similar programme to that used on previous trips. Further details are available from www.idgte.org

Steam Hall developments

Much of the winter period activity was devoted to completing the new steam hall and boiler installation along with the commissioning of the various engines which had been in store. This has provided another area of interest for the museum in addition to the diesel and gas turbine sections. It is hoped that the railway system currently on site will be commissioned when time and resources permit.

General view of the new steam hall

Proteus turbine replacement

During the winter closed season a 'zero hours' Proteus gas turbine was donated to the museum to replace the one installed in the ex CEGB Princetown installation which had noisy bearings. This has been installed to enable the set to be run for demonstration purposes.

ABC V4 air cooled engine

Another recent arrival is the ABC air cooled V4 engine which is on display in the Marine Hall. This is an highly unusual engine manufactured by a company which specialised in flat twin motorcycles. The company was at one time known as the 'All British Engine Company Ltd' but this was changed through various liquidations finally ending up as ABC Motors Ltd. The company made various auxiliary power units during WW2 and was taken over by Vickers in the post war period.

Latest news

The museum has now provided a link to their news section on Facebook which can be accessed without a Facebook Account or sign-in being required. The link is https://www.facebook.com/pages/Internal-Fire-Museum-Of-Power/198568506925586

eBay shop

The Museum operates an eBay shop which offers a range of publications such as operational manuals and books recording the history of various engines plus some parts for the renovation of smaller engines. There is a link to the relevant webpage from the museum website at www.internalfire.com

Reference library

The museum offers a considerable volume of reference material on a wide range of engines and other machinery with full access being made available to those who register with the museum website. The content includes brochures and manuals for Lister, Petter and W H Allen products. See www.internalfire.com for more information. ■

Don't ever underestimate experience ....

A short story recently posted on LinkedIn by Steve Laster, Captain at Edison Chouest Offshore, caught our eye.

A ship engine failed and no one could fix it. Then they brought in a chap with 40 years on the job. He inspected the engine very carefully, top to bottom. After looking things over, the guy reached into his bag and pulled out a small hammer. He gently tapped something. Instantly, the engine lurched into life. The engine was fixed!

Seven days later the owner got his bill for $10k.

"What?!" the owners said "*You hardly did anything. Send us an itemized bill*".

The reply simply said:

Tapping with a hammer	$2
Knowing where to tap	$9,998

Don't ever underestimate experience. ■

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01625 874 426

enquiry@enginemuseum.org

Internal Fire
Museum of Power

MLA Accredited Museum

Internal Fire covers the history of the internal combustion engine with an emphasis on larger diesel engines and gas turbines. The museum operates the oldest daily running Diesel engine in the world as well as the only remaining Proteus gas turbine driven "Pocket Power Station".

The museum operates engines on a daily basis, for opening times see the website below.

Website: http://www.internalfire.com Telephone: 01239 811212

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[1]Total cost of ownership is defined by Shell Lubricants as the total amount spent on industrial equipment, including the cost of acquisition and operation over its entire working life and the cost of lost production during equipment downtime.