PAGAMON

The ORC systems

A mature and reliable technology for the energy and economic efficiency of gas or diesel powerplants

April 2021

Summary

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

The ambitious goals of the Paris Climate Agreement call for more energy efficiency initiatives

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

To address climate disruption and its consequences, the Paris Agreement in 2016 sets the main goal of **keeping the global temperature increase below 2 °C** compared to the pre-industrial levels.

However, after almost 5 years of its signature, we are in one of the worst scenarios established in 2014 by the Intergovernmental Panel on Climate Change (IPCC)[1,2]: global warming already rose +1 °C, and **provided the current rate of GHG emissions, a beyond 5 °C warming in 2100 is now foreseen**.

In this context, **a more appropriate use of financial resources and more effective carbon pricing policies, primarily by States**, seem essential to initiate the technological and societal initiatives needed to achieve Paris Agreement objectives. A shift seems to be taking place as a result of the economic crisis linked to the Covid-19 pandemic.

In addition, in same report, the IPCC[1] indicates that in 2010, **energy sector - including mining, electricity and heat - is responsible for more than one third of the world's cumulative anthropogenic GHG emissions**. It therefore represents a major challenge.

Apart from debates on the availability of fossil resources (coal, oil and gas), it is essential to reconsider **the energy efficiency of existing solutions**, which, according to the International Energy Agency, is the primary source of CO_2 emissions reduction (44%), **particularly in terms of fossil fuels**.

In this field, mature and reliable solutions which already exist, but do not seem to be exploited to their full potential given the challenges ahead.

This study focuses on one of these energy efficiency solutions: **Organic Rankine Cycle (ORC) systems**. When installed on thermal power plants or industrial plants, they are powered by "free" energy - **the waste heat from processes** - to produce competitive and low-carbon electricity.

The study outlines **the potential of this technology for diesel and gas-fired power plants**, both in economic and environmental aspects, as well as the available means for operators to finance what can be considered as a large investment.

Sources: 1. IPCC report n°5 for 2010 emissions (2014); 2. 2019, l'année de la stagnation des émissions mondiales ?

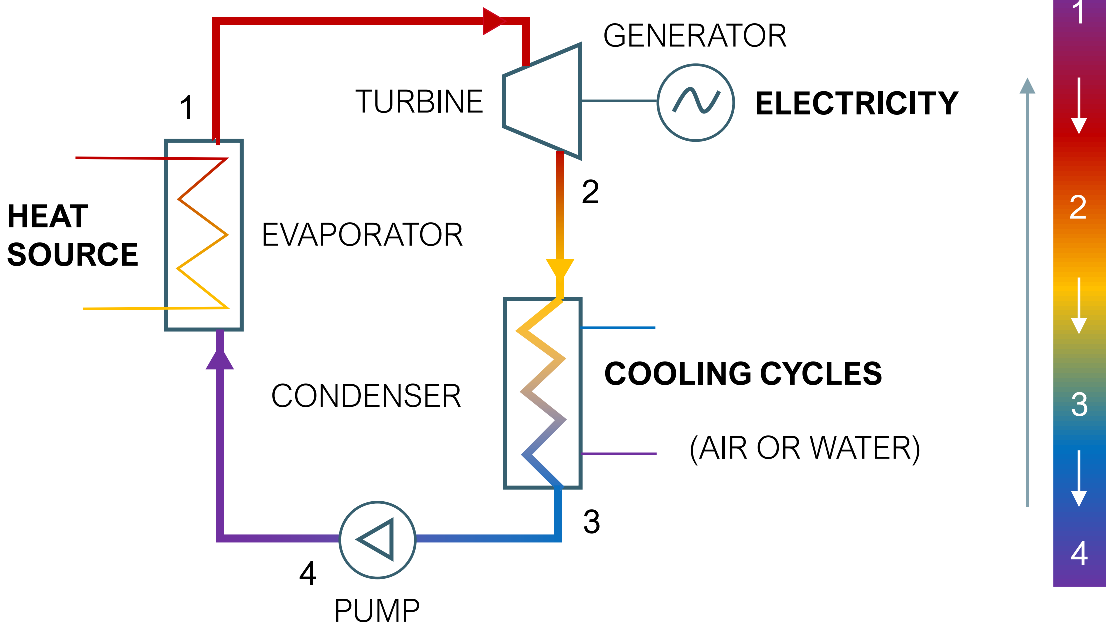
ORC technology for waste heat recovery in engine powerplants

An under-exploited market

Organic Rankine Cycle systems (ORC) are used to value heat by converting into electrical energy

Nowadays, the ORC system is a mature technology: The initial developments date back to the 19th century, and accordingly, thousands of these systems have been installed worldwide since then. In order to generate mechanical or electrical energy, an ORC cycle operates between a hot source (the heat to be recovered) over a temperature range between 120 °C to 350 °C and a cold source (air or water for cooling). The greater the temperature difference between the hot and cold sources, the more efficient the installation.

Operating principle of a simplified ORC cycle (without recuperator)



CONSTANT PRESSURE EVAPORATION

The organic working fluid inside the ORC module is evaporated by receiving thermal energy from a recovery loop (the fluid can be thermal oil, vapor or pressurized water)

ISENTROPIC EXPANSION

The obtained organic fluid's steam (at high pressure) is then expanded in the turbine. It drives a generator, which allows electricity production. In the turbine's outlet, the organic fluid will still remain in a gaseous state.

CONDENSATION AT CONSTANT PRESSURE

A condenser ensures the transition of the low-pressure steam back to the liquid state.

ISENTROPIC COMPRESSION

A pump completes the cycle and recirculates the working fluid in the evaporator.

It should be noted that the recovery of residual heat from ORCs often allows for additional applications to the electricity generation, such as the supply of heat to a district heating network or for industrial use (cogeneration) or even the production of cold.

While geothermal and biomass energy are the main sources of heat to be valued by ORC systems, waste heat recovery is also a rapidly growing application

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

RECOVERY OF GEOTHERMAL OR BIOMASS ENERGY

Today, most of the ORC units use the renewable heat sources, mainly the **geothermal brines**, as well as **biomass**, and to a negligible extent **solar energy.** In this case, the ORC is the main engine of the plant.

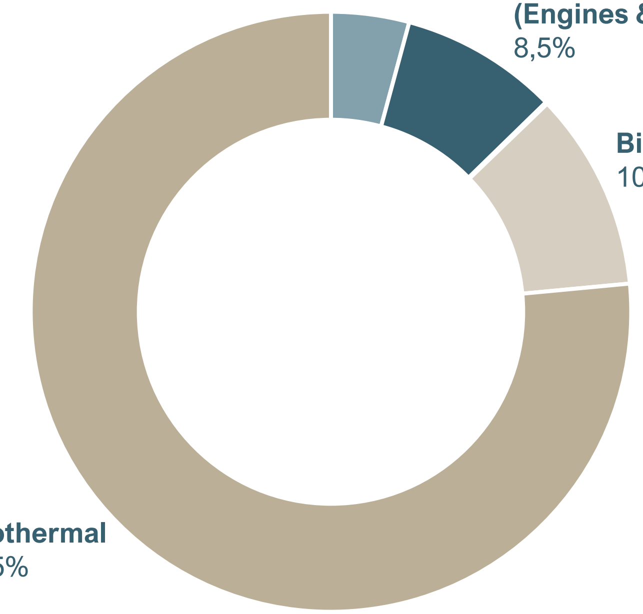
WASTE HEAT RECOVERY

Medium to large scale ORC machines are the most promising technology to valorize heat with temperatures above 150 °C. This enables the energy efficiency improvement of **industrial combustion turbines, internal combustion engines, and industrial processes.** In this case, the ORC modules is externally connected to the production unit from which it recovers the **waste heat, meaning « the heat generated by the process which does not serve its primary purpose and is not recovered. »[2].**

13% of the total installed capacity of ORC machines: waste heat recovery remains an emerging field for the ORC machines.

2/3 of waste heat recovery applications concern thermal powerplants (gas turbines or internal combustion engines). Given the high temperatures to be valorized, these applications represent a large potential in both energetic and economic aspects.

Total installed capacity (%MW), by application, 2016[1]



- Total installed capacity: 2 701 MW_e for 1 754 ORC units
- Planned new capacity: 460 MW_e

Sources: 1. Energy Procedia, A World Overview of the Organic Rankine Cycle Market, Thomas Tartière (2017); 2. ADEME, La chaleur fatale, Edition 2017

Despite their high CO_2 emissions, engine powerplants are difficult to be replaced in the short or medium term for the electricity supply in specific areas of the world

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

USE CASES

Engine powerplants have different operational configurations that meet the contemporary and possibly the future energy needs:

- **Base load production power plants** in areas not inter-connected to the main power grids (i.e., islands far from the coasts), or regions where the industries with high electricity consumption are located (i.e., mines), or even where electricity consumption is growing rapidly (i.e., Africa, South America, South-East Asia, as well as the US. indeed, these powerplants can be commissioned to generate electricity in a short time),
- **Peak supply power plants,** to compensate the intermittent electricity production (solar or wind) or of a production difficult to modulate. This ensures a certain reliability of electricity supply, particularly thanks to a very short start-up time (when the full load is reached in a few minutes).

FUELS

Engines can consume a wide variety of fuels, depending on the availability, economic or environmental factors/ considerations/ parameters:

- **Heavy fuel oil** more economic
- **Low sulfur fuel oil** less pollutant (SOx)
- **Natural gas** and **biofuels** less CO_2 emissions per kWh produced

INSTALLED CAPACITY

23 GW[1,2] which is the equivalent of 25 medium power nuclear reactors (900 MW), distributed over several thousand powerplants with capacities ranging from a few hundred kW to more than 500 MW

CO_2 EMISSIONS

54 M tons per year[3]

Equivalent to the total emissions of Portugal in 2019[4]

Assumed direct emissions of CO_2:

- Fuels: 424 g/kWh
- Natural gas: 227 g/kWh

Sources: 1. Global Energy Observatory; 2. U.S. Preliminary Monthly Electric Generator Inventory; 3. Le contenu en CO_2 du kWh; 4. BP Statistical Review of World Energy 2020

For isolated islandic systems, Diesel generators are often the best choice for baseload generation

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

ISSUES OF ELECTRICITY PRODCUTION FOR ISOLATED ISLAND SYSTEMS

- Geographic remoteness from mainland infrastructure does not allow to connect to the main electrical networks
- Lack of economy of scale prevents the installation of large capacity and cost-efficient plants
- For generators on islands, the choice of fuels is limited: difficult access to storable fuel, no gas or coal terminal…
- A high need for flexibility to meet daily and seasonal variations in the electricity demand
- Intermittency of the renewable energy sources (Hydraulic, solar, wind, etc.)

RELEVANCE OF DIESEL POWER PLANTS FOR ISOLATED ISLAND SYSTEMS

Advantages

- Good operational flexibility
- Quick start-up
- Efficient operation over a wide range of power requirements
- Reasonable investment
- Required maintenance skills is widely available in the world

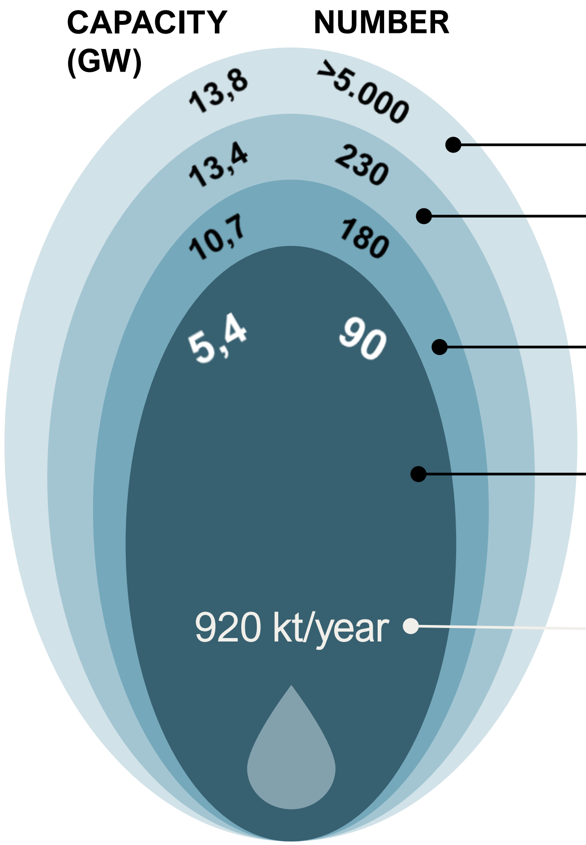
Drawbacks

- Significantly higher operational costs compared to the mainland power plants…
- …further increased by the need to import fuel from far away areas

A much higher cost of electricity on islands represents **a significant burden for the consumers.** Similarly, the tariffs increases could cause economic difficulties in some island territories.

Source: EURELECTRIC – Emissions from diesel generation in Small Island Power Systems - Recommendations for the revision of the Gothenburg protocol

The global fleet of ORC-fit engine power plants can be estimated at ~ 130 units for a total installed capacity of 9 GW



HEAVY OIL / DIESEL

The following criteria are used to determine the potential for application of ORCs

ENGINE POWER PLANTS

WITH INSTALLED CAPACITY > 20 MW

Given the investment required to install an ORC unit, profitability is difficult to achieve on the small units

OPERATING IN BASELOAD PRODUCTION

The low load factor for a peaking power plant does not allow to reach the profitability threshold for an ORC unit

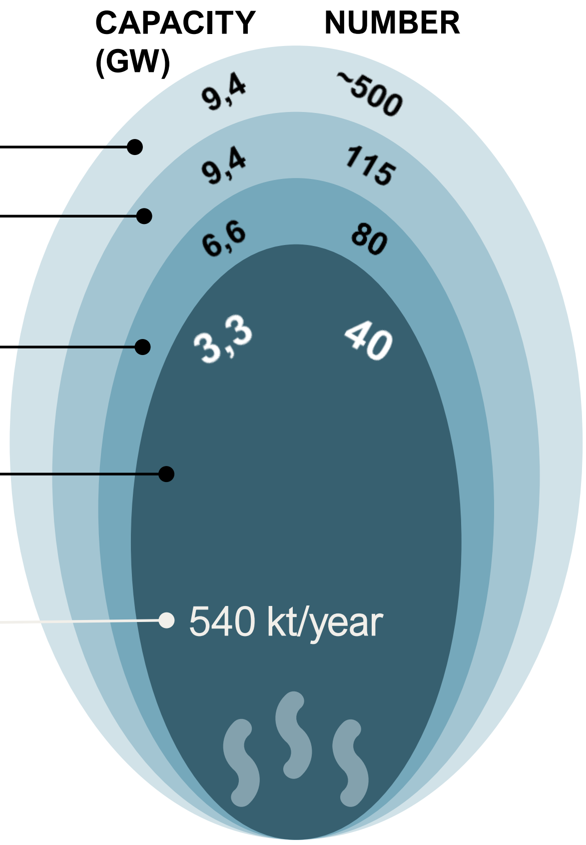
WHOSE ENGINES ARE < 15 YEARS[1]

The replacement of the engines by another technology could make the ORC obsolete

AVOIDABLE CO_2 EMISSIONS

Other second-order criteria that may influence feasibility of an ORC installation exist; for example, the space available nearby to install the ORC, proximity to a cold source such as deep seawater, and the operation of plant in cogeneration

However, these criteria do not fundamentally question the economic and environmental relevance of installing an ORC.



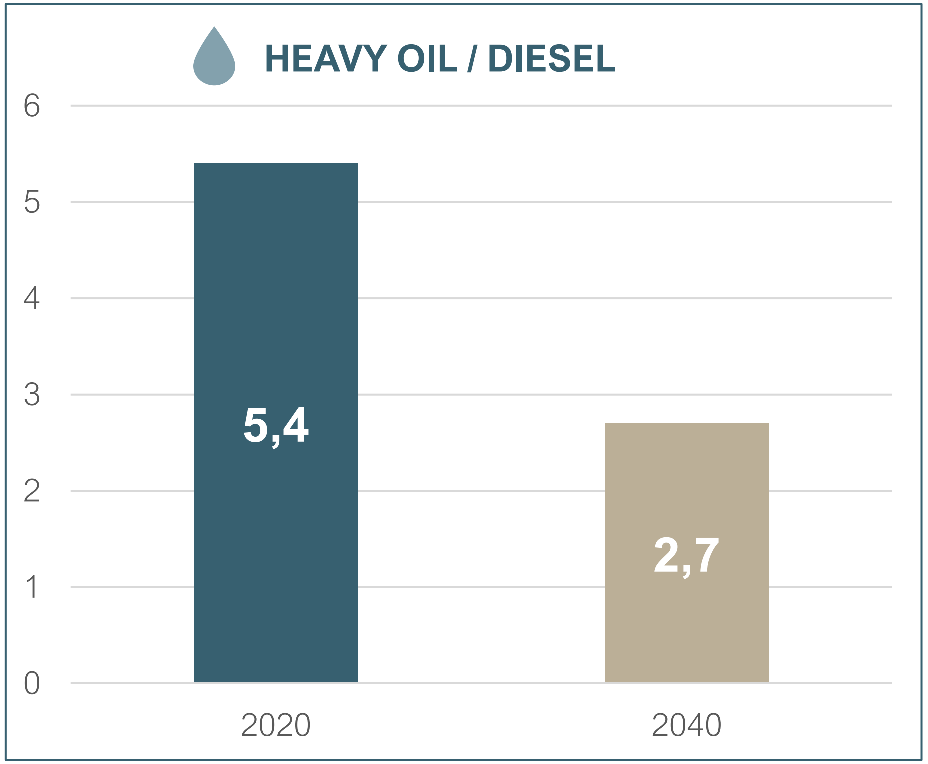
NATURAL GAS

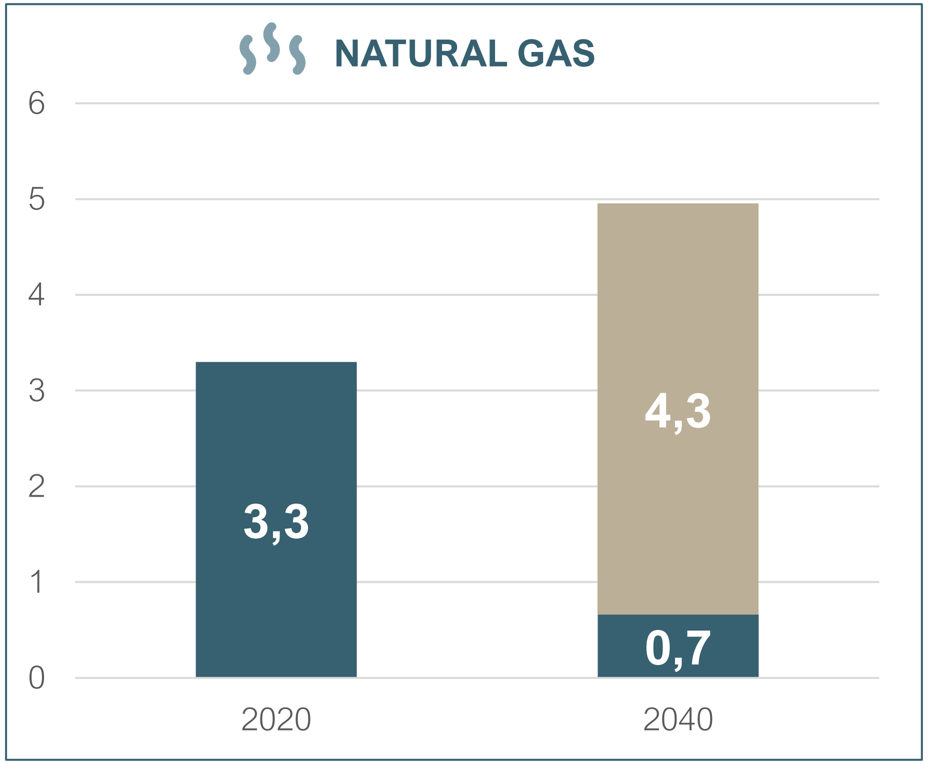
It should be noted that the **number of already installed ORCs on this type of units is currently very low** compared to its potential. Rare examples of 3 engine power plants (total capacity of 90 MW) are equipped with Turboden ORC modules in Italy and in Turkey.

1. We assumed an average life of 30 years for the engine power plants

Current status of power plant fleets, along with expected evolution of market conditions, lead us to envisage an additional potential of about 7 GW for installation of ORC systems by 2040

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE





■ Installed Capacity (GW)

■ New capacity to be installed (GW)

Forecasts over the period of 2020-2040:
- Reduction of installed capacity by half[1]
- Decommissioning of almost all the current fleet[2] (scenario for Europe)

Forecasts over the period of 2020-2040:
- 50% increase in the installed capacity[1]
- Decommissioning of about 80% of the current fleet[2] (scenario for Europe)

Sources: 1. Installed power generation capacity by source in the Stated Policies Scenario, 2000-2040 – IEA; 2. SAB Discussion Paper on Investment requirements 2015

Despite this potential, several factors limit the adoption and installation of ORCs on engine power plants

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

LIMITATIONS RELATED TO FUEL

Use of heavy fuel oil as a fuel in most of engine-based power plants, strongly limits the current deployment of ORC systems:

- High sulphur content of heavy fuel oil makes it necessary to keep the flue gases' temperature above 180°C. This prevents **the formation of sulphuric acid, which can damage the heat exchangers**. This threshold does not allow the ORC to fully recover the waste heat.
- The fumes from combustion of heavy fuel oil contain pollutants: SOx, NOx and fine particles. To limit the impact of these pollutants on population, **flue gas treatment equipment is installed in some power plants, which limits the available space for installation of heat exchangers to recover waste heat.**
- As heavy fuel oil is very viscous, it must be heated to 60°C for its use as diesel fuel. **The heat consumed in this process reduces the heat to be recovered by the ORC.** It should also be noted that the surface occupied for the preparation of fuel oil can prevent the installation of an ORC in certain cases.
- **As heavy fuel oil is relatively inexpensive (around € 300 / ton), the limited savings made do not encourage the installation of an ORC unit.**

LIMITATIONS RELATED TO INSTALLATION

The installation of heat exchangers on exhaust stacks can lead to **a decrease in their draft, with a consequent decrease in engine efficiency.**

Installing the heat exchangers also reduces the emitted fumes' temperature. The colder fumes are then dispersed over a smaller area around the plant, which **causes localized pollution and health consequences** for the local population.

The installation of heat exchangers requires the shutdown of the engines. It therefore takes place during maintenance shutdowns of plant. In event of a delay in installation, **prolonging the maintenance shutdown results in significant economic losses.**

The integration of an ORC into the plant's control system requires an **increase in the expertise and resources** of the operators and maintenance teams.

ECONOMIC LIMITATIONS

For an operator whose engine power plants cover a small share of the production mix, **the economic gain from installing ORCs is perceived as marginal.**

In addition, **the investments related to installation of ORCs compete with other investments that are easier to sell** to public opinion, such as "green" electricity (wind, solar) or hydrogen.

Sources: Interviews; Pagamon analysis

In France, certain island-located engine powerplants, mainly diesel, are excellent candidates for the installations of an ORC

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

EDF	Saint-Pierre (cogeneration)	**21 MW**

EDF	Vazzio	132 MW
	Lucciana	**112 MW**

EDF	Pointe-Jarry	**220 MW**
	Bellefontaine B	**211 MW**
	Pointe de Carrières	81 MW
	Saint-Martin	**39 MW**
ContourGlobal	Énergies Saint-Martin	20 MW

EDF	Livarot Project	**120 MW**

EDM	Longoni	**40 MW**
	Badamiers	39 MW

EDF	Port-Est	**220 MW**

ENERCAL	Népoui	55 MW

EDT ENGIE	Punaruu	122 MW

RECENT INSTALLED CAPACITY

~ 970 MW

In black: recent capacities; In grey: older power plants (> 20 years) likely to be renovated or decommissioned soon (and are not suitable for the ORC installations)

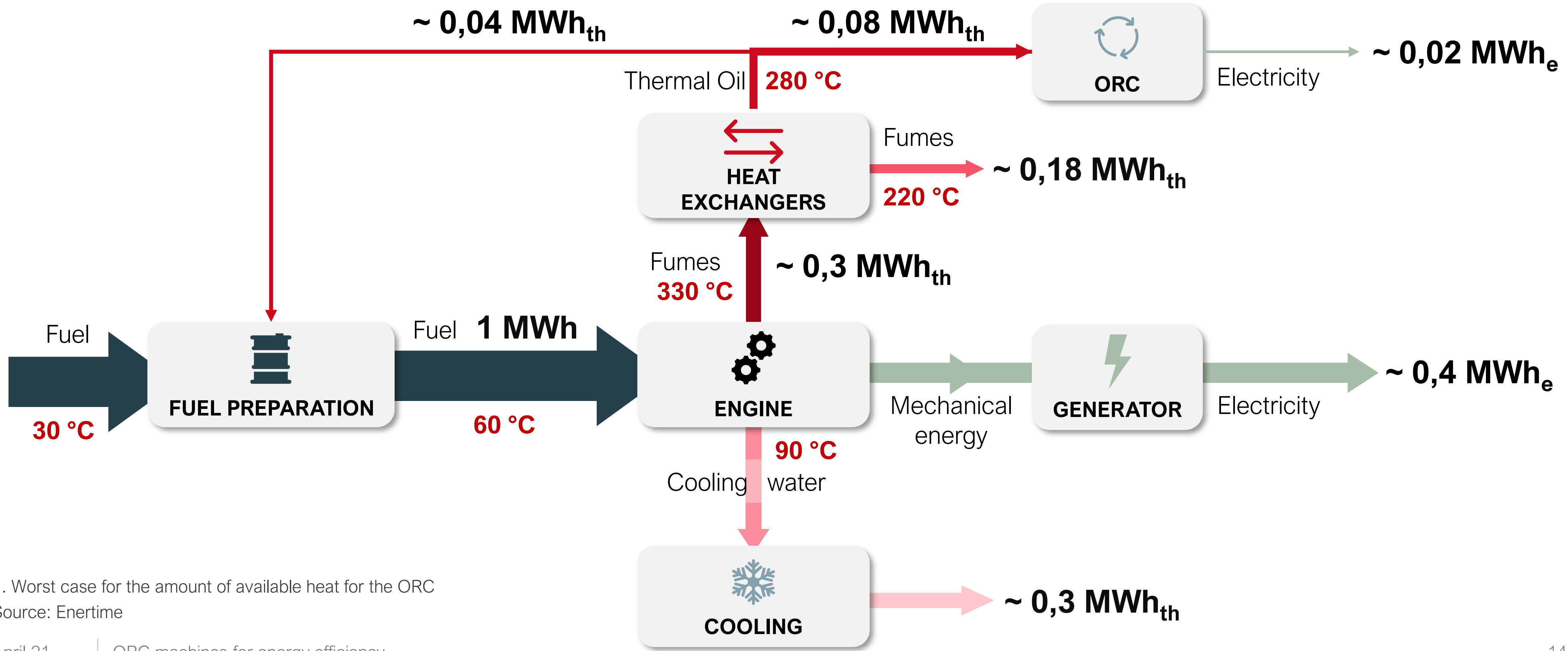
Economic and environmental aspects

A favorable change in macro-economic and regulatory contexts that will further reinforce applicability of ORC systems

Waste heat from a power plant accounts for about 60% of energy from the fuel. One half is distributed via the exhaust fumes, the other half via water for cooling of the engines

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

ENERGY FLOW FROM OF A HEAVY FUEL OIL DIESEL PLANT[1]



1. Worst case for the amount of available heat for the ORC

Source: Enertime

Due to the carbon content of fuel, the operation of a power plant emits 418 to 730 g of CO2 per kWh of electricity produced

OBSERVATION

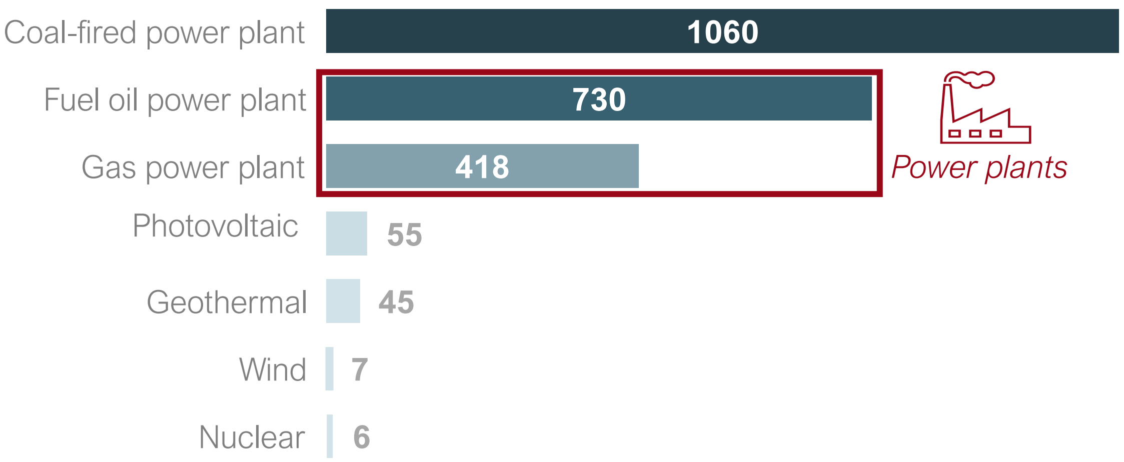
Considering the direct and indirect emissions over their entire life cycle (construction, extraction, fuel supply...), **the oil and gas power plants have significant CO_2 emissions.**

The very nature of the fuels being used explains to a large extent these significant CO_2 emissions. Fuel oil contains more than 85% of carbon and natural gas about 75%.

When indirect emissions over their entire life cycle are included, oil- and gas-fired power plants emit 730 gCO_2/kWh_e and 418 gCO_2/kWh_e respectively. They emit less CO_2 than coal-fired power plants, but much more than wind or nuclear power.

Finally, GHG emissions are not the only problematic emissions. **Gas and oil-fired power plants also emit pollutants** (NOx, SOx and fine particles) that are responsible for a degradation of air quality that can lead to health risks for local populations.

gCO_2 per kWh produced depending on the type of operation[1]



Pollutant emissions from an engine running on heavy fuel oil[2]

SO_2 (g/kWh)	NO_x (g/kWh)	Fine particles (g/kWh)
0,26	0,23	1,28

SOLUTION

The waste heat recovery from these power plants by installing ORCs can generate additional electricity and reduce the amount of fuel needed to produce the same amount of electricity. This **increases energy efficiency and reduces CO_2 and pollutant emissions for each kWh produced**.

Sources: 1 Le contenu en CO_2 du kWh; 2. São Paulo State University - UNESP - FEG - Energy Department, 2004

Within the framework of this study, we have retained three power plant profiles, reflecting the characteristics of installed base

CHARACTERISTICS	Diesel Power plant with heavy fuel oil	Diesel power plant with ULSD fuel oil[1]	Natural gas power plant
Installed electrical power	60 MW_e	55 MW_e	50 MW_e
Operating mode	Intermediate (5 000 EFPH[2])	Intermediate (6 000 EFPH)	Baseline (7 000 EFPH)
Usual location	Mining areas	Coastal or island zone	Gas-producing country
Environnement	High outside temperatures	Access to sea water	Varied
Flue gas temperature drop through heat exchangers [3]	140 °C	160 °C	190 °C
Cold Source Temperature of ORC (°C)	40 °C (air)	20 °C (sea water)	25 °C (air)
Thermal Power to be recovered in the inlet of ORC	16 MW_{th}	20 MW_{th}	22 MW_{th}

1. Ultra-low-sulfur diesel; 2. Equivalent Full-Power Hour; 3. The temperature of the flue gas entering the heat exchangers depends on the size of the engines (between 330 °C to 360 °C)

Source: Enertime

Electrical capacity of an ORC accounts for 3 to 8% of the installed electrical capacity of the plant

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

ORC can be dimensioned based on the characteristics of plant with the following reasoning:

Installed electrical capacity of the plant is the reference point: basis of 100.

Load factor is the ratio between actual energy produced and the energy that would be produced in the same period by the plant at its nominal power. This factor varies from 60% to 85%, depending on operating mode.

Total thermal power to be recovered by ORC (flue gas and possibly the engine's cooling circuit[1]) depends on the load power of plant. In an engine power plant, the **power lost in the flue gases can be estimated to be 75% of power plant load.**

Based on the fuel used and the quality of flue gas, the organic working fluid of ORC **recovers 35% of the thermal power of flue gas in the case of heavy fuel oils, 50% for the ULSD fuel oils or biofuels, and 60% for natural gas.**

Net efficiency of ORC varies between 19% and 23%, depending mainly on the temperature of the cold source. It is less dependent on the temperature variations of the hot source.

	Diesel Power plant with heavy fuel oil	Diesel power plant with ULSD fuel oil	Natural gas power plant
Installed electrical power of plant	100	100	100
Power plant load	62	75	82
Thermal power of the fumes	47	56	62
Thermal power captured by ORC fluid	16	28	37
Electrical power of ORC	3,1	6,2	7,6

Source: Enertime; 1. The differences between the hot and cold temperatures of the engine's cooling circuit is relatively small. Although possible, but it is often not interesting to feed the ORC with this source of waste heat. We mainly consider the flue gas as the source of waste heat.

Depending on the configurations, return of investment for ORC installations varies from 3 to 8 years

		Diesel Power plant with heavy fuel oil	Diesel power plant with ULSD fuel oil	Natural gas power plant
SIZE OF THE ORC	MW_e	1,9	13,6	3,8
ANNUAL ELECTRICITY PRODUCTION BY ORC	GWh	9,3	81,7	26,5
INVESTMENTS				
ORC (including heat exchangers)[1]	M€	6,6	28,3	10,1
Pumping of seawater	M€	-	1,0	-
TOTAL	M€	6,6	29,3	10,1
ANNUAL GAINS				
Fuel	M€	0,9	8,2	1,8
Carbon quotas	M€	0,1	1,1	0,2
ORC operating expenses	M€	-0,1	-0,3	-0,2
TOTAL	M€	0,9	9,0	1,8
RETURN ON INVESTMENT TIME	**Years**	**7,7 Years**	**3,2 Years**	**5,8 Years**
REDUCTION OF EMISSIONS (CO_2, NOx, SOx, fine particles)	**%**	**5,0 %**	**8,3 %**	**9,2 %**

Regulations in certain countries impose a minimum energy efficiency threshold for thermal power plants. The addition of an ORC then allows to comply with these directives and avoid the corresponding penalties.

1. The price of the ORC includes the heat exchangers on hot and cold sources, excluding seawater pumping; Source: Enertime.

Transition towards less polluting fuels and increase in the price of carbon quotas will make investment in ORC solutions more attractive

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

For the same amount of produced electricity, an ORC module economizes on fuel. **The more expensive the fuel, the more rapidly the ORC installation is amortized.**

Because of the pollution caused by use of heavy fuel oils, many countries require power plant operators to use **less polluting fuels**, such as **ultra-low sulfur fuel oils or biofuels**.

These regulatory changes **will increase the savings gained from installing an ORC and shorten the payback time of its investment**.

Orders of magnitude: heavy fuel oil: 300 €/ton, low-temperature fuel oil: 400 €/ton, biofuel: 1 000 €/ton.

Impact of fuel change on return time and annual gains

Heavy fuel oil

Regulatory developments: reduction of SOx, NOx and fine particles

	ULSD fuel oil	Biofuels
Impact on the return time	÷ 1.4	÷ 2.8
Impact on cost savings	× 1,9	× 3,8

Changing carbon prices also affect the payback time and annual revenue generated by an ORC.

The price of carbon quotas, which were trading at 31 €/ton in January 2021, could reach 100 €/ton in 2030 and 300 €/ton in 2050.[1] Under these conditions, **the payback period will significantly reduce.**

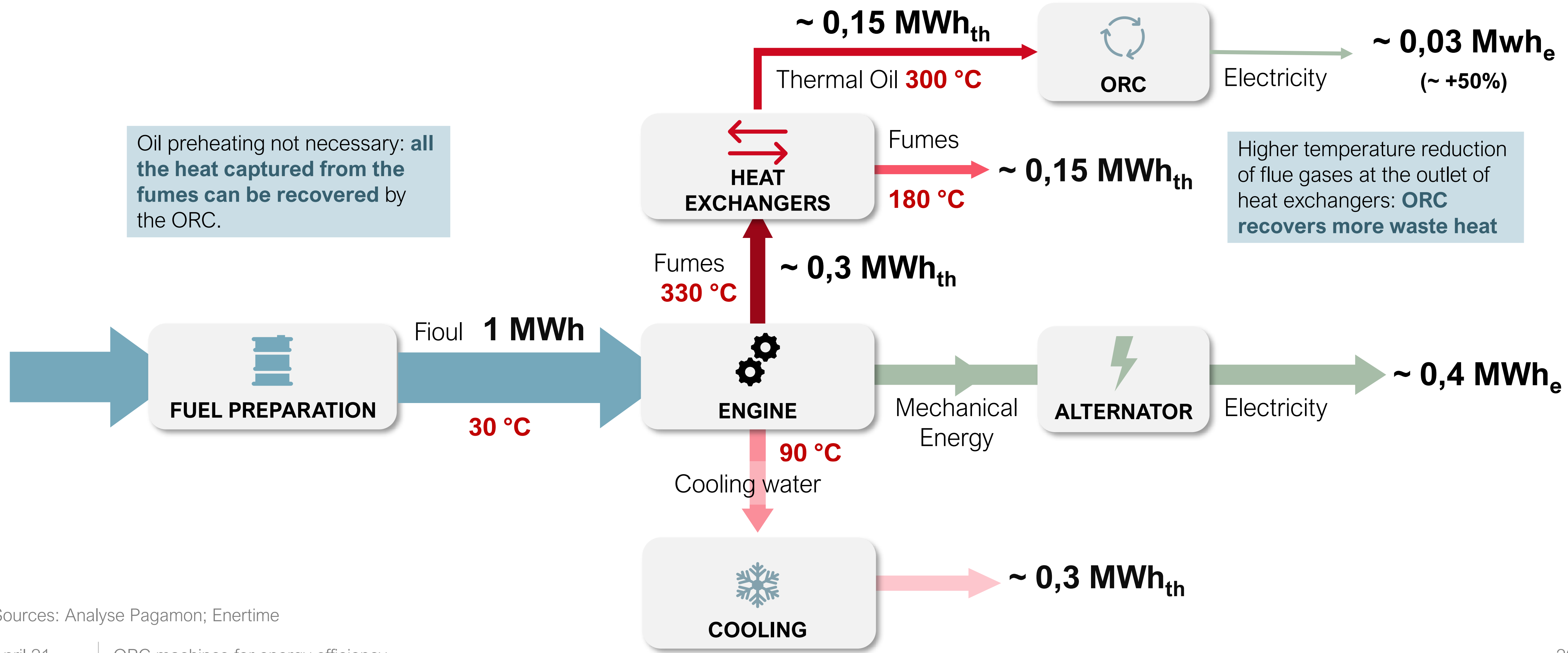
Impact of carbon pricing changes on a heavy fuel oil plant

	2030	*2050*
Carbon quota	100 €/t	300 €/t
Impact on the return time	÷ 1.3	÷ 2.2
Impact on cost savings	× 1,3	× 2,2

Source: 1. Commission 2008, Centre d'Analyse Stratégique (CAS)

In addition to high fuel savings, the configuration of power plants running with ULSD fuel oils or biofuels allows the ORC to recover more heat (+50%), which significantly improves the economic equation

ENERGY FLOW OF A DIESEL PLANT USING ULSD FUEL OILS OR BIOFUELS



Sources: Analyse Pagamon; Enertime

Third-party financing ESCO model for the installation and operation of ORC systems

The attractive solutions for operators and investors

Third party financing ESCO is a powerful tool for the implementation of energy efficiency projects with guaranteed energy savings

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

The **ESCO (Energy Services COmpany)** are the companies that offer to their clients the possibility of financing energy efficiency projects, by adapting contracts for each application.

ESCOs offer an **efficient, flexible and cost-effective method** of improving the energy performance, relying on energy experts and third-party financing entities.

CHARACTERISTICS OF ESCO

- Energy efficiency improvement services
- Remuneration based on the level of achieved savings
- Investments financed by third parties

TYPES OF CONTRACTS AND USUAL APPLICATIONS

Energy Performance Contract (EPC)	Thermal insulation measures for private or public buildings
Operating equipment lease contract	Implementation of smart metering systems
Power Purchase Agreement (PPA)	Waste heat recovery (energy-intensive industries, engine power plants, etc.)

In the case of ORC installations, ESCOs often use:

- A ***Corporate PPA*** agreement in which the client company provides the space to produce decarbonized energy and agrees to buy back the produced electricity/heat over a defined period.
- A ***Merchant Plant PPA*** agreement in which the electricity production is fed into the general grid via an energy aggregator.

Third party financing model is particularly relevant for the capital-intensive installations such as ORCs

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

ESCO integrates all the **services required for a project and organizes its financing** in one single contract. ESCO bears the associated risks and guarantees the savings over a period, which is defined by the client, to ensure the profitability of the project.

The achieved energy savings allows **the initial investments to be reimbursed** over an agreed period between ESCO and its client to ensure the profitability of the project.

ESCO

- Planning
- Installation & maintenance
- Financing
- Training

Contribution of expertise → *in energy efficiency*

INDUSTRIALIST

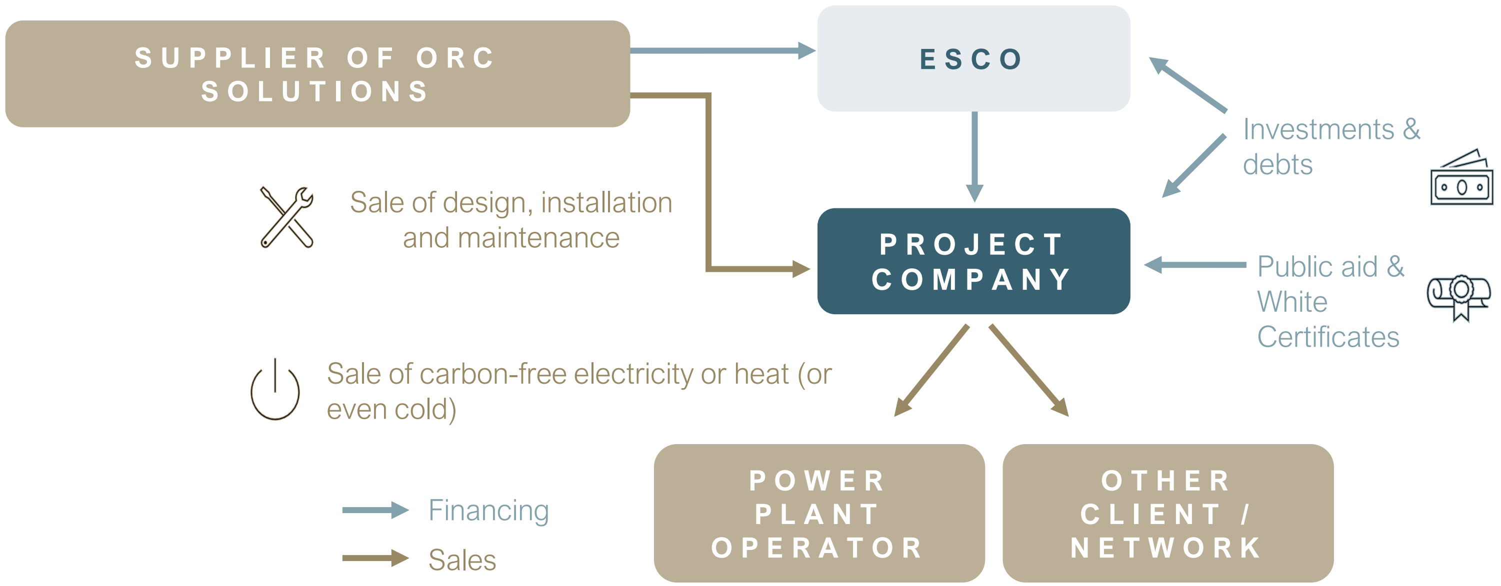
- Saving on energy costs
- No additional asset immobilized
- Integrated services (Engineering)
- Emissions reduction

The installation of an ORC system for the improvement of energy efficiency of a power plant requires an investment of several million euros. This makes **the option of third-party investment model very interesting** for both ESCO and the plant operator.

Third party investment in an energy efficiency project requires a specific financial arrangement between ESCO and a Project Company

For each installation of energy efficiency solution, ESCO initiates a Project Company.[1] The energy efficiency solution provider would sell its services and solutions to this Project Company. To finance these investments, ESCO and its Project Company rely on third parties:

- Equity financing from investment funds, private investors or investments banks
- Debt financing from the EIB, commercial banks or specialized debt funds
- Subsidies and public aid schemes



The Project Company has 4 roles:

- ✓ *Project set-up*
- ✓ *Search for external funding*
- ✓ *Facility management*
- ✓ *Electricity resale*

The advantage of using a separate Project Company for each project is that it reduces the risk of ESCO growing too large. This makes it more difficult to obtain funding and grants, especially the local grants for local objectives.

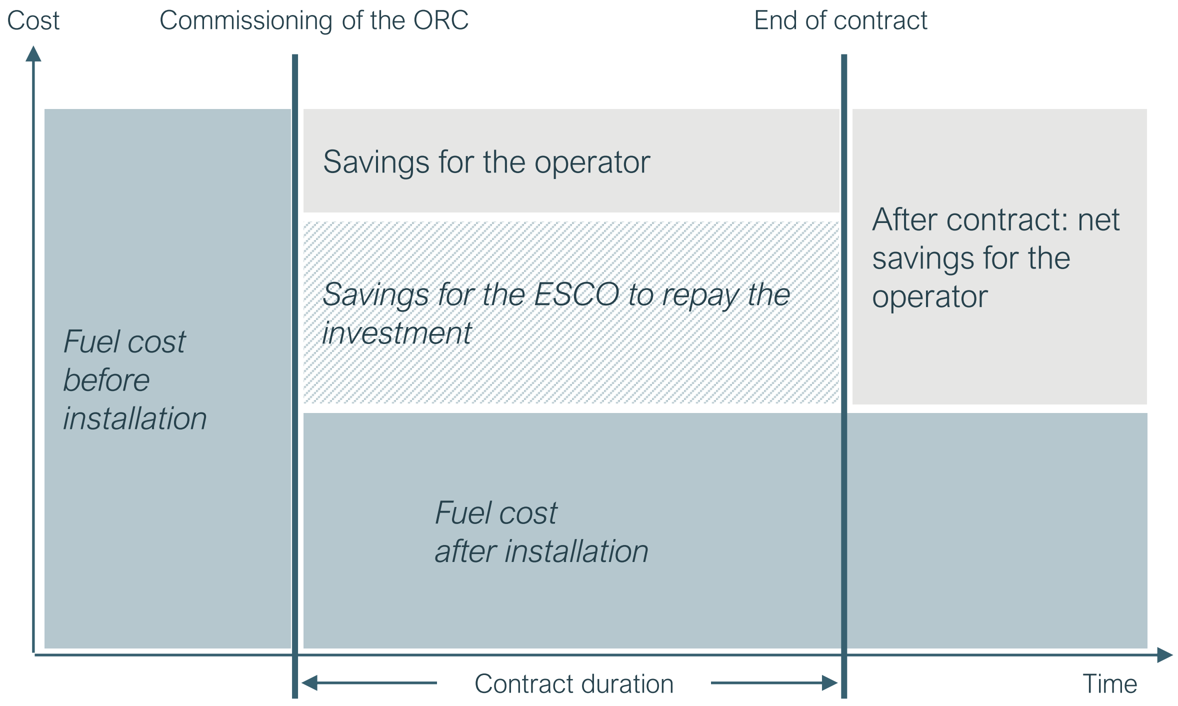
1. Also called SPV as for Special Purpose Vehicle

Third-party financing mechanism ensures savings for the operator, and profitability for ESCO and the Project Company over the contract's duration

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

With ORC installed on an engine power plant, ESCO and the Project Company would pay back the investors by selling electricity to the operator with **an attractive price of about 80-90 €/MWh$_e$, which is less than half the cost of electricity production by the power plant itself.** The energy savings achieved by the operator would allow him to ensure the power plant's electricity self-consumption at a lower cost.

Share of the savings: Schematic diagram



KEY FIGURES
FOR THE INSTALLATION OF AN ORC SYSTEM FOR WASTE HEAT RECOVERY

- ✓ Savings for plant operator: 0,5 to1,5 M€ for the contact duration
- ✓ Payback on investment for the Project Company: 7 to 10 years[1]
- ✓ Internal rate of return for the investors: 10% to 15% per year

MODEL WITH "COMPENSATION TUNNEL"
FOR THE HEAT DELIVERY AT THE INLET OF ORC

If the operator **delivers more heat than the threshold,** a **bonus** is calculated each month

Nominal level of heat delivery, agreed with the operator when designing the ORC (in MWh$_{th}$/month or Nm^3/month)

If the operator **delivers less heat than the threshold**, a **penalty** is calculated each month

1. In this case, the power plant operator does not invest in the ORC installations: this payback period of 7-10 years concerns the Project Company and its third part investors

In France, ESCOs and project companies can obtain considerable subsidies making the investment even more attractive

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

For the ESCOs and the Project Companies, the profitability of energy performance projects must be assessed with respect to **energy prices and CO_2 quotas**.

However, there are numerous **support mechanisms** to improve the payback period. In addition to infrastructure funds, aimed at fulfilling CSR with low interest rates, ESCOs and Project Companies can also use the public support mechanisms or subsidy schemes that take several forms.

SUPPORTS THAT CAN BE USED TO FACILITATE FINANCING

- ADEME grant for CO2-free heat
- Call for Projects IndusEE under the Green Recovery Program

ADEME – Agence de la Transition Écologique · France Relance

- Loan from European Investment Bank (EIB)
- Support from European Regional Development Fund (FEDER)

Banque européenne d'investissement – La banque de l'UE · l'Europe s'engage en France avec le FEDER

- Local or Regional funds

Pôlénergie – Entreprises et territoires des Hauts-de-France · Territoires d'Industrie

- Energy Distributors via White Certificates Mechanism (CEE in France)

CEE – Les certificats d'économies d'énergie – Ministère de la Transition écologique et solidaire

Third party investment model offers many advantages to both plant operators and project investors

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

BENEFITS FOR THE OPERATORS

Increased energy efficiency by **reducing fuel consumption and operating costs**.

High added-value installations with no need for the operator to invest in the project, the operation does not appear as an asset on his balance sheet.

Full-service provision, without requiring internal know-how or external expertise necessary for the project. This allows the operator to focus on its core business.

Contribution to the reduction of environmental impact by reducing GHG and pollutant emissions to meet the operator's CSR objectives, reinforce its image or fulfill its commitments to sustainable development.

BENEFITS FOR THE INVESTORS

Strong and sustainable profitability ensured by the positioning of ORCs on the recovery of waste heat (IRR of 10% to 15%, ROI in 7 to 10 years depending on the project). The "tunnel compensation" guarantees income in the case of variations in the production of waste heat.

Contract terms established to **hedge the financial risk of investors**, especially in the event of termination.

Turnkey solution where ESCO manages the coordination of all the actors involved in the implementation of the project.

Response to social issues, environmental awareness and promotion of energy efficiency.

In the case of French ZNI, the electricity market as a regulated utility implies an adaptation of energy efficiency financing

SPECIFICITY OF THE ELECTRICITY PRODUCTION IN THE ZNI

Non-interconnected zones (ZNI in French), are the French territories not connected to the mainland electricity network. They include Corsica and the French overseas territories. **Contribution to the public service of electricity (CPSE),** collected from (non-industrial) electricity consumers, helps to compensate for the high production costs there. Thus, consumers in the ZNI pay a similar price for electricity as those in mainland France.[1]

Energy efficiency solutions in the ZNI are **an additional lever for reducing the cost borne by the consumer and/or the taxpayer.**

In the ZNI, electricity production follows a regulated utility model. A mechanism managed by **Energy Regulation Board (CRE in French),** supporting power plant operators by financing 7 to 11% of their investments (capex) and by covering their operating costs (opex), including fuel. However, as a result, **electricity producers in the ZNI have limited incentives to save fuel.**

Multi-Year Energy Plan (PEE in French) is the guideline for France's energy transition strategy. In order to benefit from the CRE's schemes, the integration of ORC solutions in the specific PEE plans of the ZNI is a prerequisite.

ADAPTATION OF THE ESCO MODEL TO THE CASE OF REGULATED UTILITIES

To encourage the installation of ORCs for energy efficiency, while considering regulations, an economic model for the waste heat recovery is an appropriate solution. This model is supported by **an obligation to buy back energy from the CRE.**

A comparable example is the equipment of a gas expansion site operated by GRTgaz, a subsidiary of the ENGIE group.[2] The energy of the compressed natural gas is recovered by expansion through a turbine coupled to an generator. The produced electricity is then sold to the grid.

GRTgaz

COMMISSION DE RÉGULATION DE L'ÉNERGIE

Programmation PLURIANNUELLE DE L'ÉNERGIE

Sources: 1. Publication CRE, La transition énergétique dans les ZNI, 2020; 2. Le projet TENORE entre GRTgaz et Enertime, 2018

Resale of electricity on the regulated network, an alternative to third party financing ESCO model, to adapt to the specific characteristics of the ZNI

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

ESCO model for the installation of ORC, entirely financed by third parties, guarantees energy savings to the operator. While it does not consider the specificities of the ZNI regulated utility model. To make ESCO model more attractive to plant operators, one solution is to position ESCO as a regulated grid power supplier.

ESCO AS A POWER PRODUCER

For example, in the case of ZNI where EDF PEI/SEI, EEWF or EDM operate the grid, the plant operator invests in the heat exchangers to recover the waste heat. To pay the costs of heat exchangers' operation, this heat is then sold by the operator or by the CRE to the ESCO. The ORC installed by the ESCO converts this heat into electricity to supply the general network through the relevant aggregator. ESCO negotiates the feed-in tariff with the CRE and positions itself as a producer of carbon-free electricity on the regulated network.

ADVANTAGES FOR THE OPERATOR

- ✓ ***No financial commitment, increase in fixed assets is limited to heat exchangers***
- ✓ ***Sale of heat that offsets the operating costs of heat exchangers***
- ✓ ***An allocation from the CRE for investment in heat exchangers***

Each MWh produced by an ORC must be valued at the marginal cost of producing that MWh by the plant - mainly the fuel cost. As a result, the transition to less GHG-emitting (biofuel) and/or less polluting (ULSD fuels) yet more expensive fuels will increase the level of savings from the ORC. This makes the **ESCO third-party investment model even more attractive** to all the stakeholders.

Support for the installation of ORC in engine power plants would be a strong message for reduction of carbon footprints while maintaining a competitive production cost

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

Recovery of waste heat from engine power plants generates decarbonized electricity in the same way as wind or solar power. In addition, the production cost of the ORC is very competitive compared to these intermittent renewable energy sources.[1,2]

Comparison of production costs between ORC, Wind and Solar in the ZNI:

ORC (non-intermittent) 80-90 €/MWh < **Wind (intermittent) 100-140 €/MWh** < **Solar (intermittent) 110-200 €/MWh** €

3 FACTORS WILL ACCELERATE THE ATTRACTIVENESS OF ORC SOLUTIONS

- Electrification of society, increased carbon “taxation”.
- Fuel switching because of environmental obligations
- Environmental awareness of companies

Soon, the installation of ORC modules for waste heat recovery from power plants will meet the objectives of operators, investors and public authorities on both economic and environmental aspects.

Sources: 1. Rapport sur les coûts des énergies renouvelables, ADEME 2016; 2. Cour des comptes / CRE / Syndicat des énergies renouvelables.

The deployment by public authorities for an industrial green recovery would be an opportunity to accelerate the installation of CROs for energy efficiency

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

PUBLIC INCENTIVES

Energy Transition Act for Green Development in 2015 generated public incentives that favored the wind and solar investments. **Similar mechanisms could be deployed to encourage industrial investments in energy efficiency.**

Public subsidies and grants via calls for projects – such as ADEME's IndusEE – should be encouraged to support the attractiveness of the energy efficiency market.

Finally, although the CEE mechanism does not apply to thermal power plants, they should be involved in the energy efficiency efforts.

REGULATIONS

The European carbon quota mechanism can also encourage manufacturers to implement energy efficiency measures. **The increase in the carbon tax expected in the coming years will make energy efficiency solutions more attractive to the industries.** This will be reinforced by the fact that electricity production is difficult to relocate and is therefore not subject to free carbon allowance allocations.

The transition to less polluting and less GHG-emitting fuels **should be the focus of common environmental obligations** at the European level, rather than being assessed on a case-by-case basis.

ECONOMIC PATRIOTISM

Support of an industrial energy efficiency sector would be greatly enhanced through long-term order commitments. **Certain technologies are currently the focus of recognized know-how and have significant development potential – including export. They deserve to be supported.** By emphasizing their collaboration with the national network of innovative SMEs, the major French energy players will obviously have a key role to play in the development of this sector.

Moreover, as they consume little cement or rare earth materials, ORC technologies seem to contribute to both energy efficiency and the reindustrialization of territories.

APPENDIX

Acknowledgements

Bibliography

Who is Pagamon?

Pagamon would like to sincerely thank all who contributed and shared of expertise and time to carry out this study

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

Bibliography

The ORC technology for the waste heat recovery of the power plants / economic and environmental interests

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

Emissions de GES en 2010: GIEC, 2014, https://archive.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_summary-for-policymakers.pdf

Perspectives des émissions mondiales: Carbone4, 2020, 2019, http://www.carbone4.com/2019-stagnation-emissions-mondiales/

A World Overview of the Organic Rankine Cycle Market: Thomas Tartière, 2017, https://www.sciencedirect.com/science/article/pii/S1876610217340286

La chaleur fatale: ADEME, 2017, https://www.ademe.fr/sites/default/files/assets/documents/chaleur_fatale-8821-2018-06_pdf.pdf

List of the thermal power plants: Global Energy Observatory, 2018, http://globalenergyobservatory.org/list.php?db=PowerPlants&type=Oil

List of the thermal power plants in the USA: EIA, 2021, U.S. Preliminary Monthly Electric Generator Inventory, https://www.eia.gov/electricity/data/eia860m/

Le contenu en CO_2 du kWh: Equilibre des Energies, 2019, https://www.equilibredesenergies.org/12-10-2018-le-contenu-en-co2-du-kwh/

Statistical Review of World Energy: BP, 2020, BP Statistical Review of World Energy 2020, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf

Installed power generation capacity by source in the Stated Policies Scenario: IEA, 2020 Installed power generation capacity by source in the Stated Policies Scenario, 2000-2040 – IEA, https://www.iea.org/data-and-statistics/charts/installed-power-generation-capacity-by-source-in-the-stated-policies-scenario-2000-2040

Investment Requirements In the EU electricity sector up to 2050: VGB, 2015, SAB Discussion Paper on Investment requirements 2015, https://www.vgb.org/en/investment_requirements_EU_2050.html?dfid=73527

Emissions from diesel generation in Small Island Power Systems: Eurelectric, 2011, EURELECTRIC – Emissions from diesel generation in Small Island Power Systems - Recommendations for the revision of the Gothenburg protocol, https://unece.org/fileadmin/DAM/env/documents/2011/eb/wg5/WGSR49/Informal%20docs/EURELECTRIC-disel_engines_and_Gothenburg_protocol-July_2011.pdf

Valeur du carbone à horizon 2030 et 2050: Centre d'Analyse Stratégique n°16, 2009, http://archives.strategie.gouv.fr/cas/system/files/rapp_16_vtc_web.pdf

Marchés du carbone: Ministère de la transition Ecologique, 2021, https://www.ecologie.gouv.fr/marches-du-carbone

Emissions de CO2 en fonction des combustibles: Ademe, 2020, https://www.bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?gaz.htm

L'industrie du raffinage et le devenir des fiouls lourds: Ineris, 2004, INERIS – L'industrie du raffinage et le devenir des fiouls lourds, https://www.ineris.fr/sites/ineris.fr/files/contribution/Documents/fioul.pdf

Bibliography

The third-party financing ESCO model for the installation and operation of the ORC machines

PPA: Où en est-on en france ?: Orygeen, 2019, https://www.orygeen.eu/docs-actus/livres-blancs/ppa-france/

Appel à projets efficacité energétique: France Relance, 2020, https://www.entreprises.gouv.fr/files/files/secteurs-d-activite/industrie/decarbonation/appel-a-projets-efficacite-energetique-procedes-et-utilites-dans-l-industrie.pdf

La chaleur fatale: Ademe, 2017, https://www.ademe.fr/sites/default/files/assets/documents/chaleur_fatale-8821-2018-06_pdf.pdf

Les acteurs, l'offre et le marché de l'efficacité énergétique à destination de l'industrie: Ministère de l'économie et des Finances, 2017, https://www.entreprises.gouv.fr/files/files/directions_services/etudes-et-statistiques/prospective/Industrie/2017-10-Rapport-pipame-efficacite-energetique.pdf

Dispositifs de financement alternatifs pour la rénovation énergétique du bâtiment: Global Chance, 2014, http://www.global-chance.org/IMG/pdf/gc35p12-23.pdf

ORC: Sia Partners, 2015, https://www.sia-partners.com/fr/actualites-et-publications/de-nos-experts/les-modules-orc-avenir-dune-production-renouvelable

Coûts des énergies renouvelables: Ministère de l'environnement, de l'Energie et de la Mer, 2016, https://www.ademe.fr/sites/default/files/assets/documents/couts_energies_renouvelables_en_france_edition_2016.pdf

La modernisation du parc thermique en France: EDF, 2016, https://www.edf.fr/groupe-edf/producteur-industriel/thermique/enjeux/modernisation-du-parc

La contribution au service public de l'électricité (CSPE): Ministère de l'économie et des Finances, 2018, https://www.economie.gouv.fr/entreprises/contribution-service-public-electricite-cspe

Transition énergétique dans les ZNI: CRE, 2020, https://www.cre.fr/Transition-energetique-et-innovation-technologique/soutien-a-la-production/transition-energetique-dans-les-zni

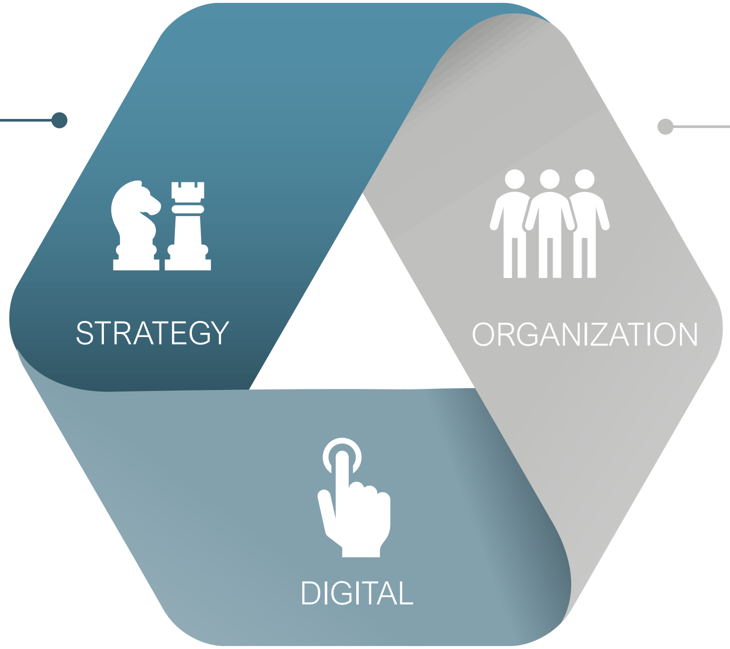
Le projet TENORE entre GRTgaz et Enertime: Communiqué de presse, 2018, https://www.enertime.com/sites/default/files/documents/2018/18_06_21_cp_enertime-grtgaz-projet_tenore_-vdef.pdf

Pagamon helps companies structure their strategic vision, improve their operational performance and sustain change within their organization

PAGAMON
CONSEIL EN STRATÉGIE D'ENTREPRISE

Strategic Consulting

Strategy & Due Diligence
Marketing & Customer Experience
Innovation & Development



Organizational Consulting

Organizational Diagnosis
Agile Transformation
Change Management
Management of complex projects

Digital Consulting

Digital Transformation
Digital Marketing

About
Pagamon

Pagamon is a Strategy and Organization consulting firm founded in 2013.

PAGAMON works on a long-term basis with industry players to help them structure their strategic vision, improve the operational performance of their businesses and sustain change in organizations.

Please visit us on **www.pagamon.com**

For more information, **please contact**

Christophe Bildé – Partner and Founder
christophe.bilde@pagamon.com
+33 (0)6 16 96 12 64

Richard Dumas – Partner and Founder
richard.dumas@pagamon.com
+33 (0)6 60 98 82 48

Romain Friang – Manager Innovation & Development
romain.friang@pagamon.com
+33 (0)6 85 67 73 58

PAGAMON