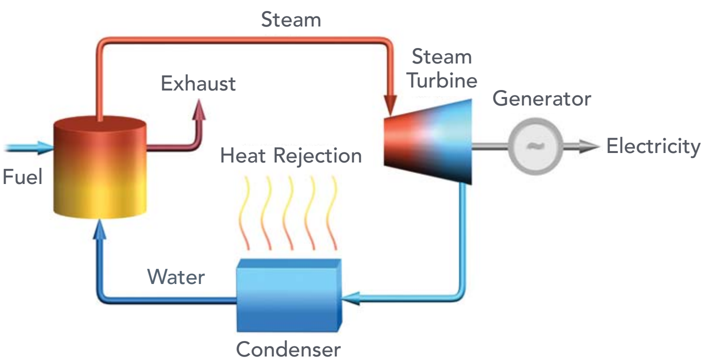
Envergent
TECHNOLOGIES
A Honeywell Company

THE PRODUCTION OF ELECTRICITY FROM WOOD AND OTHER SOLID BIOMASS

RTP™/ADVANCED CYCLE VS. COMBUSTION STEAM CYCLES OR WHY NOT SIMPLY COMBUST?

For decades, the only commercial option available for the production of electricity from wood, wood residues and other solid biomass has been direct combustion coupled to a steam turbine – that is, burning biomass in a boiler to produce hot gases, producing steam from the hot gases via a heat exchanger, and then generating power from the steam using a steam turbine. The application of advanced cycle technology, using the RTP process, now offers the opportunity to provide a much more efficient and economical way to utilize biomass for the production of renewable electricity. This is possible since the RTP technology converts solid biomass, which cannot be used directly in an advanced cycle, into a liquid that is compatible with high-efficiency advanced power production engine-generator sets.

STEAM CYCLE



Conventional biomass power plants are classic examples of the steam cycle, which in turn is the most common industrial application of the basic “heat engine” or *Carnot cycle.*

Although proven in hundreds of installations, in principle there is a very significant limitation associated with a steam cycle:

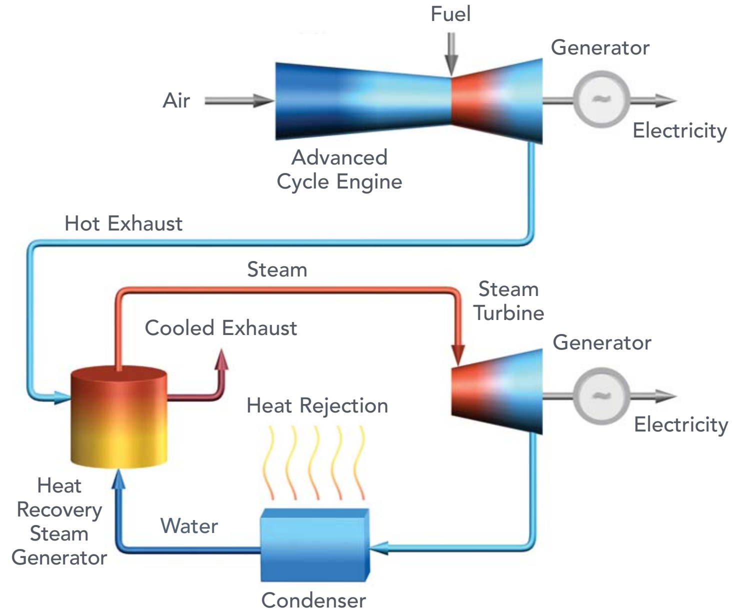
- A steam cycle is restricted to a relatively low efficiency for the conversion of fuel to power, by its inherent nature (i.e., fundamental thermodynamic limitations associated with operating pressures and temperatures)

Furthermore, there is a second significant limitation that is evident when power is produced by first combusting biomass in a boiler and coupling it to a steam cycle:

- By definition, when biomass is combusted to produce power from steam, the option of achieving higher conversion efficiencies via a combined cycle is lost

Typically a *combined cycle* is characterized by a high-efficiency advanced cycle (that is, a gas turbine or diesel engine) followed by a lower-efficiency steam cycle. The two cycles are coupled sequentially and are known collectively as a combined cycle.

COMBINED CYCLE



In a combined cycle, the steam cycle *follows* the high-efficiency advanced cycle, since it is ideally suited to use the exhaust heat from the diesel engine or gas turbine, and thereby generates additional power from the waste heat. The bottom line is that very high conversion efficiencies are possible using a combined cycle – efficiencies that are simply not possible when wood or other solid biomass is directly combusted and coupled to a steam turbine. *(Note: it is therefore impossible to speak of having "combined cycle" when a combustion/boiler system is the primary means of producing power from biomass. This would imply the addition of a steam cycle after a steam cycle!).*

The question then arises - why not use solid biomass in an advanced cycle and then have the option of coupling it to a steam cycle, resulting in a high-efficiency combined cycle? The answer is simply that solid biomass cannot be fed into a gas turbine or diesel engine – a liquid or gaseous fuel is required to operate an advanced cycle. This is where the technical and economic benefits of RTP become acutely apparent.

TECHNICAL ADVANTAGES OF RTP FOR POWER PRODUCTION

Envergent Technologies and Ensyn's RTP technology produces a high yield of liquid fuel from solid biomass. This liquid fuel, known as pyrolysis oil, has two very important technical (and economic) benefits when compared to a direct combustion option:

- It can be used in an advanced cycle for high-efficiency production of electricity
- The advanced cycle can then be coupled to a steam turbine (or other heat engine) in a combined cycle to utilize waste heat for maximum power production.

Furthermore, the inherent properties of a liquid fuel provide significant technical and economic advantages over direct combustion products (i.e. hot gases) and gasification fuel gas products:

- the pyrolysis oil liquid can be produced in one location and used at another, thereby decoupling the production of the fuel from its end-use (as is the case in the petroleum industry) – i.e., the separation of fuel production and fuel use in space or location
- the pyrolysis oil liquid can be produced continuously (which is technically and economically ideal for a thermal process), and then stored and used at an optimal time (for example, peaking) – i.e., the separation of fuel production and fuel use in time

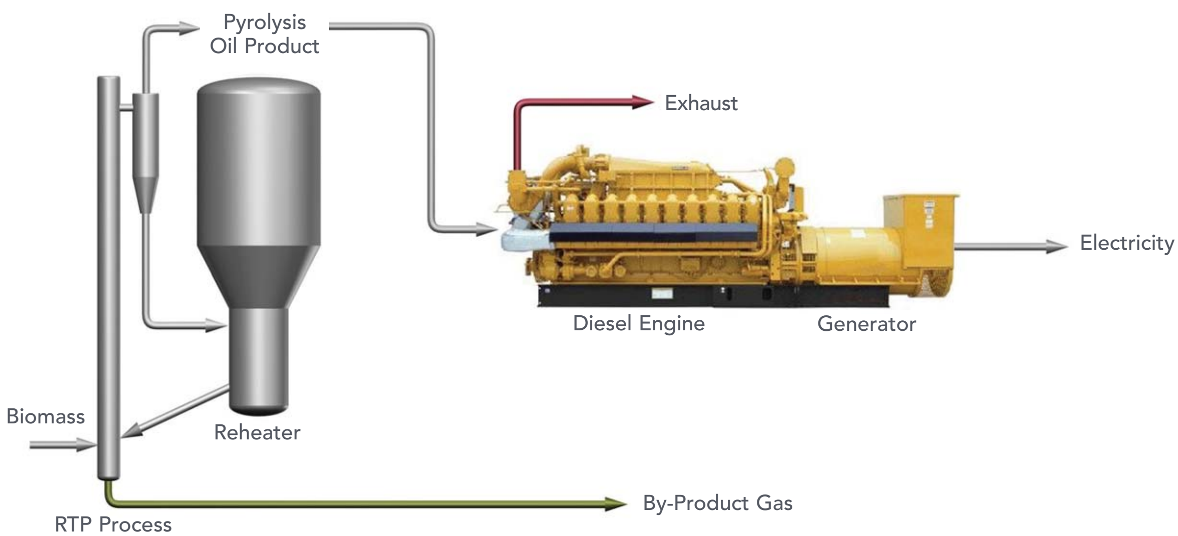
These benefits are further supported by the more consistent quality and reduction in transportation cost of energy-densified liquid pyrolysis oil relative to solid biomass.

RTP pyrolysis oil can be used to fuel advanced cycle power producers, including a diesel engine generator set (GenSet) and a power turbine GenSet. This briefing document is focused on the diesel engine GenSet, since it presently represents the highest single cycle and combined cycle efficiencies

Table 1 illustrates the technical advantages of three RTP power generation options at a scale of about 25 MWe, when compared with typical biomass combustion systems at the same scale. The three RTP options can be characterized as follows:

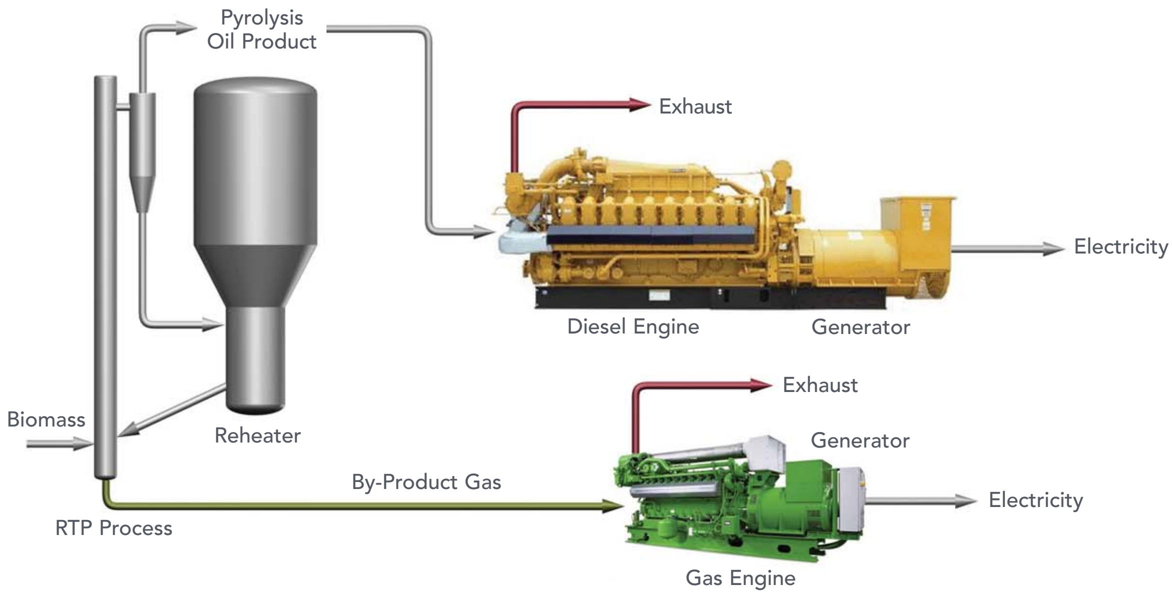
1. RTP plus Single Cycle Diesel Engine Option

This assumes that only a medium-speed diesel engine GenSet (i.e. a single advanced cycle) is used, and there is no coupling to a steam cycle or other secondary power generation cycle. This option would only be used when there is both a high price and a high demand for most or all of the engine waste heat for some useful industrial purpose. This option is not optimal when maximum electricity production is the commercial objective.



2. RTP plus Dual Engine Option

This assumes that two advanced cycles are used in the RTP pyrolysis oil facility – primary power production using pyrolysis oil in medium-speed diesel engines, and secondary power production using the RTP by-product gas in a high-speed gas engine. A combustible gas is a natural by-product of RTP facilities. Where maximum power production is the commercial objective, this is one of the best RTP options.



3. RTP plus Diesel ORC Combined Cycle

This assumes that the primary power production GenSet (i.e., the diesel engine) is followed by an Organic Rankine Cycle ("ORC") heat engine in a *combined cycle* configuration. This combined cycle configuration uses an ORC rather than a classic steam cycle to produce additional power, and represents the highest power conversion efficiency. *(There are sound technical and operational reasons for employing an ORC vs. a steam cycle in the RTP combined cycle configuration, but these are beyond the scope of this briefing document)*

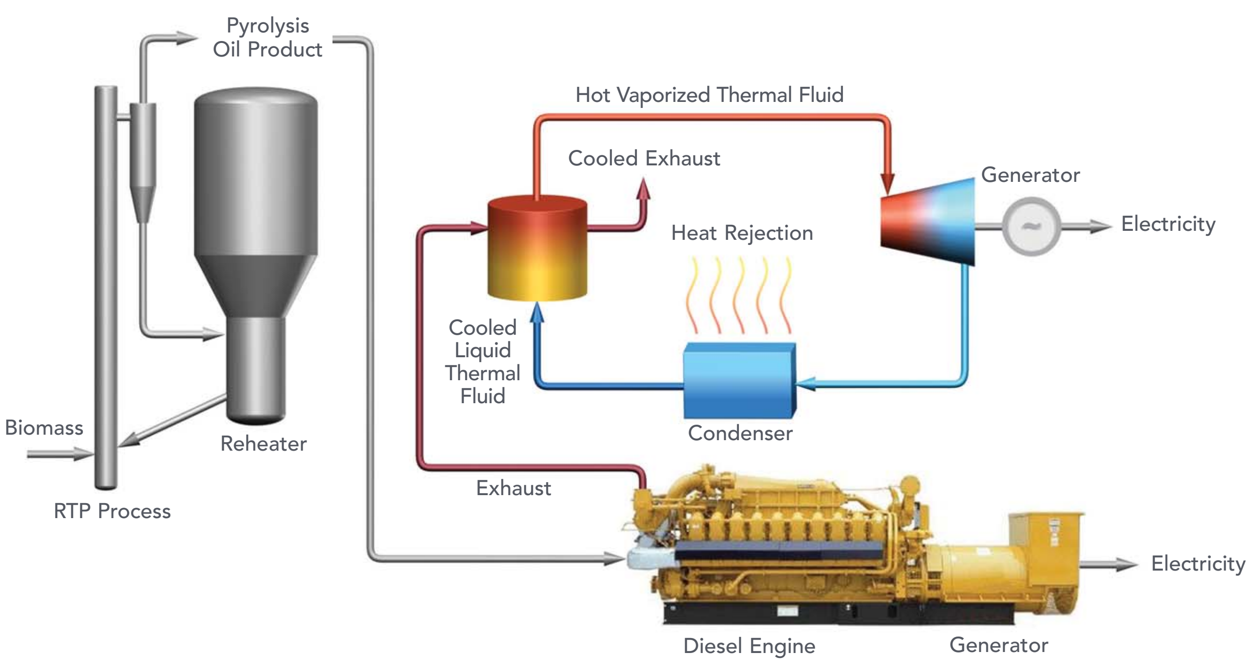


Table 1 – **A Comparison of the Efficiencies of Direct Combustion and RTP Power Production Facilities** NOMINAL WOOD/BIOMASS PLANT CAPACITY: 400 dry tonnes per day (or 84 MWth – LHV basis)					
	Direct Combustion/Steam Cycle		**RTP Diesel Advanced Cycles**		
	Industry Range	**Reference Plant**	**RTP/Diesel (Single Cycle)**	**RTP Dual Engine**	**RTP/ORC (Combined Cycle)**
Conversion Efficiency % (biomass to power)	16 to 26	21	33	36	40
Heat Rate BTUth/kWe (biomass to power)	21,330 to 13,120	16,250	10,340	9,480	8,530
Power Output MWe	13 to 22	18	28	30	34

The above table clearly illustrates the technical advantages that the RTP power production options exhibit when compared to power production via direct combustion/steam cycle. The "Reference Plant" values are based on real data from current direct combustion/steam cycle operations, and are derived from the average efficiencies of more than 60 biomass combustion/steam cycle plants in the United States that operate in the range of 15 to 35 MWe. The RTP/Diesel efficiencies are based on average values that are anticipated for pyrolysis oil use in diesel engines, as provided by the engine generator set (GenSet) suppliers. As is the case for commercial direct combustion/steam cycle systems, guaranteed pyrolysis oil performance may be lower than the actual expected operational performance. It is important to note that although the RTP/ORC option is the most favorable from a technical perspective, its economics are complex and very site-specific. For this reason, the RTP Dual Engine GenSet is used as the representative RTP power option for the basis of comparison with the direct combustion/steam cycle Reference Plant.

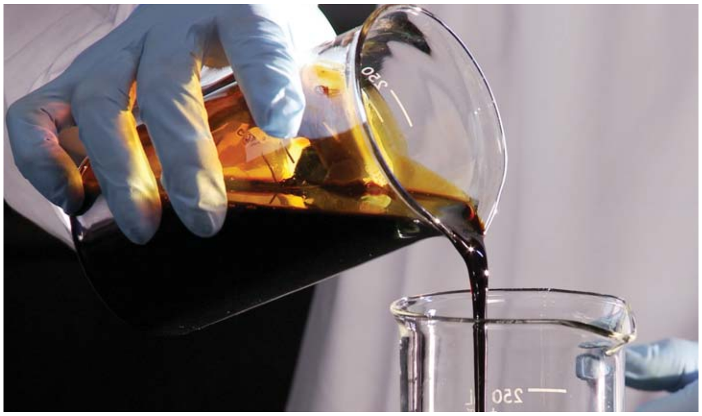
The following technical conclusions are apparent from the data in **Table 1**:

- For all three RTP power production cases, the biomass-to-electricity conversion efficiency is higher and the heat rate is lower, when compared to direct combustion-steam cycle efficiencies and heat rates
- From the same quantity of input biomass (in this case, 400 dry tonnes per day) a RTP power plant can produce 55 to 90% more electricity than a direct combustion-steam cycle
- Stated another way, it would take an additional 55% to 90% of biomass material to produce the same amount of power from a direct combustion/ steam cycle

ECONOMIC ADVANTAGES OF RTP FOR POWER PRODUCTION

As illustrated in **Table 2**, there are significant economic advantages associated with a RTP/Advanced Cycle compared to a direct combustion/steam cycle. The economics are directly comparative, and assume the fully installed cost at a given location (i.e., all inclusive except land purchase and civil infrastructure). Note that the prior installation of wood/biomass handling systems, dryers, etc. at the site can reduce the installed capital cost of both systems.

Table 2 – **A General Economic Comparison of Direct Combustion and RTP Power Production Facilities** NOMINAL BIOMASS PLANT CAPACITY: 400 dry tonnes per day (tpd) (or 85 MWth – LHV basis)		
	Direct Combustion/ Steam Cycle	**RTP Dual Engine Advanced Cycle**
Conversion Efficiency % (biomass to power)	21	36
Power Plant Output MWe	18	30
Additional Power from RTP % (from identical biomass input)	n/a	70
Installed Capital Cost ($ per kWe)	3,700	3,300



Installed capital cost is expressed as $/per unit of power production, which is standard for the industry. This allows the biomass-to-power conversion efficiency to be reflected in a single economic index, enabling a quick, meaningful capital cost comparison of various power facilities. By way of example, a 30 MWe RTP/Dual Engine power plant would consume 400 dry tonnes per day (tpd) of biomass and would cost about $99 million (i.e., 30,000 kWe x $3,300 per kWe). On the other hand, a 30MWe direct combustion/steam plant would cost over $110 million (i.e., 30,000 kWe x $3,700 per kWe) and would consume about 690 dry tonnes of biomass per day.

It is clear from **Table 2** that the capital cost unit of power production is about 10% lower for a RTP facility than for a direct combustion/steam cycle facility. This is a direct result of the significantly higher RTP power conversion efficiencies. It is important to note, however, that the operating expense which is a function of conversion efficiency, feedstock cost and electricity price, has a much greater effect on the overall power production economics than the capital cost.

For equivalent power production, the biomass consumption of a RTP facility (and therefore its corresponding biomass cost), would be 70% lower for the RTP power facility. Expressed in other terms, for equivalent wood/biomass input to the plant, the electricity revenues would be at least 70% higher for the RTP power facility. These advantages are expressed quantitatively in **Table 3**, on the basis of a 400 dry tpd RTP case study.

Table 3 – **A Quantitative Economic Comparison of Direct Combustion-Steam Cycle and RTP-Engine Power Production Facilities** (400 dry tonnes per day RTP Plant Reference Case)

	Direct Combustion/Steam Cycle (M$)	RTP Dual Engine (M$)	Annual RTP Advantage (M$)
Case 1: Constant Biomass Input of 400 dry tpd (30 MWe RTP and 18 MWe Combustion)			
Annual Power Revenue (At $0.10/kWe)	14.0	24.0	10.0
Case 2: Constant Power Output of 30 MWe (400 dry tpd RTP and 690 tpd direct combustion)			
Annual Biomass Costs (At $50/dry tonne)	11.1	6.5	4.6

CONCLUSIONS

When compared to a direct combustion/steam power plant, a RTP advanced cycle power plant is expected to:

1. Produce approximately **70%** more power from the same amount of input biomass (vastly increased revenue per unit of biomass converted to electricity)
2. Use about **70%** less biomass for every kWe produced (vastly reduced operating costs)
3. Have a capital cost (Capex) that is about **10%** lower per unit of electricity produced

Using a 400 dry tpd RTP plant producing 30 MWe as the reference case:

1. For an identical consumption of biomass (400 dry tpd), the annual increase in electricity revenue would be **10 M$** for the RTP power plant (30 MWe) when compared to a direct combustion/steam facility (18 MWe), assuming a power price of $0.10/kWe.
2. For identical power production (30 MWe), the annual savings in biomass costs would be approximately **4.6 M$** for the RTP power plant (400 tpd) when compared to a direct combustion/steam facility (685 tpd), assuming a biomass cost of $50/dry tonne.

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