The Economic Justification of Investing in Energy Efficiency

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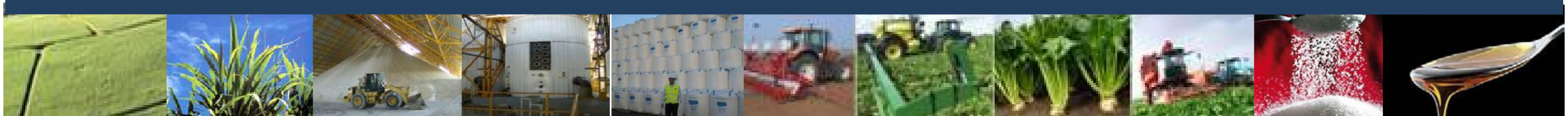
Introduction

This presentation looks at a historical sugar factory and compares it to the new generation factories in terms of cogen energy that can be sold to the grid.

We ignore the sugar produced in this presentation as it can be viewed as unchanging in the various scenarios examined.

A cane rate of 10,000 tons per day is chosen and the results can be extrapolated to suit other cane rates.



Introduction

There are 2 main variables, the rest being largely fixed for a given factory size:

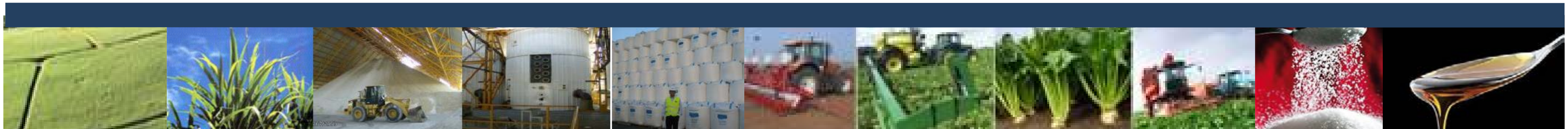
1. Steam % cane (process steam requirements)
2. Boiler steam pressure and temperature

Turboalternator specific steam consumption, (kg/kw.h), is not an independent variable as it is related to boiler steam pressure and temperature.

These give rise to 4 combinations that are of interest to us.

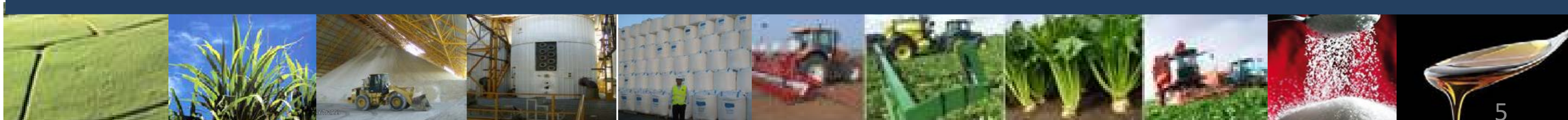
Introduction: 4 options

Case	Boiler Pressure	Steam % Cane	Comment
	bara	%	
1	High	Low	New factory design - maximises cogen
2	High	High	New boilers and cogen but with process unchanged
3	Low	Low	Historical boilers and cogen but with process improvements
4	Low	High	Historical factory design - can implement very limited cogen



What do we mean by Specific Steam Consumption ?

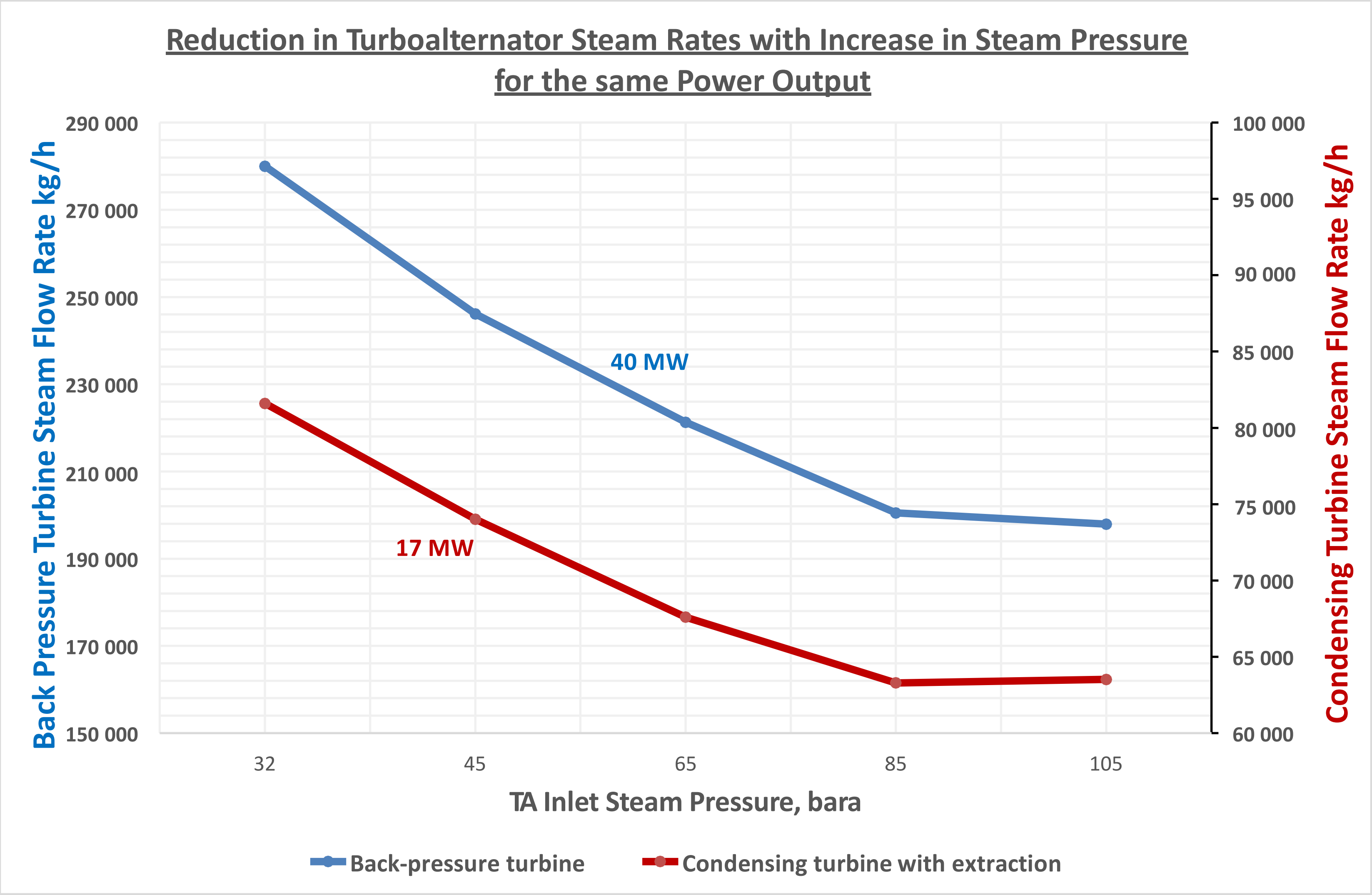
	Design Power	Inlet Steam Pressure	Inlet Steam Temp	Back Pressure Turbine Inlet Steam Rate	Power Efficiency	Sp. Steam con-sumption
	MWe	Bara	C	kg/h	%	kg/kW.h
PG5	5	29	371	45 830	94	9,17
PG4	5	32	380	41 400	91	8,28
1	39,05	32	400	280 000	96	7,17
2	40	45	450	246 130	96	6,15
3	40	65	480	221 280	96	5,53
4	40	85	520	200 480	96	5,01
5	40	105	520	197 915	96	4,95



What do we mean by Specific Steam Consumption ?

	Design Power	Inlet Steam Pressure	Inlet Steam Temp	Condensing Turbine Inlet Steam Rate	Power Efficiency	Sp. Steam consumption
	MWe	Bara	C	kg/h	%	kg/kW.h
6	17	32	400	81 600	95	4,80
7	17	45	450	74 010	95	4,35
8	17	65	480	67 595	95	3,98
9	17	85	520	63 290	95	3,72
10	17	105	520	63 513	95	3,74

What do we mean by Specific Steam Consumption ?



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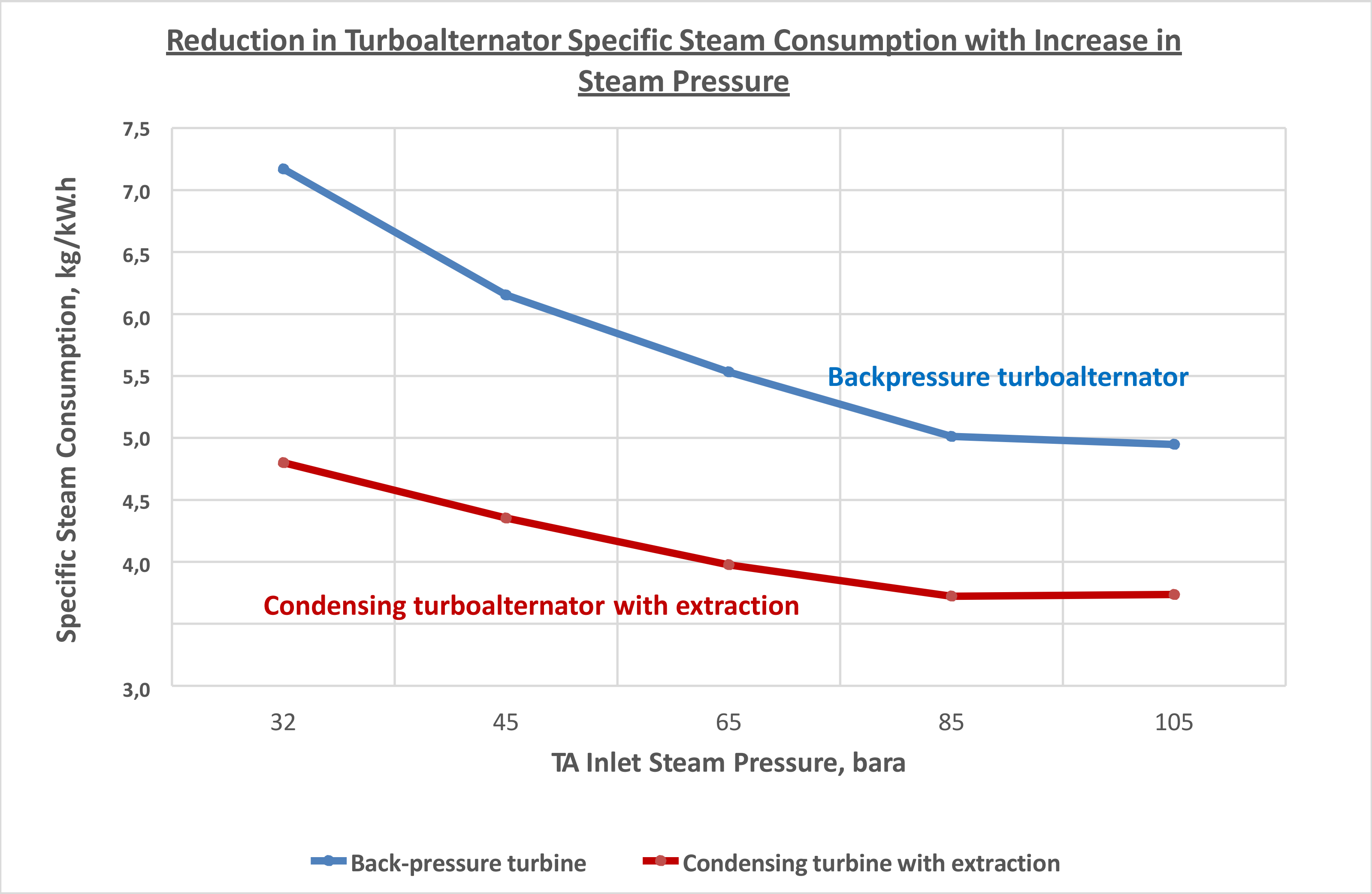
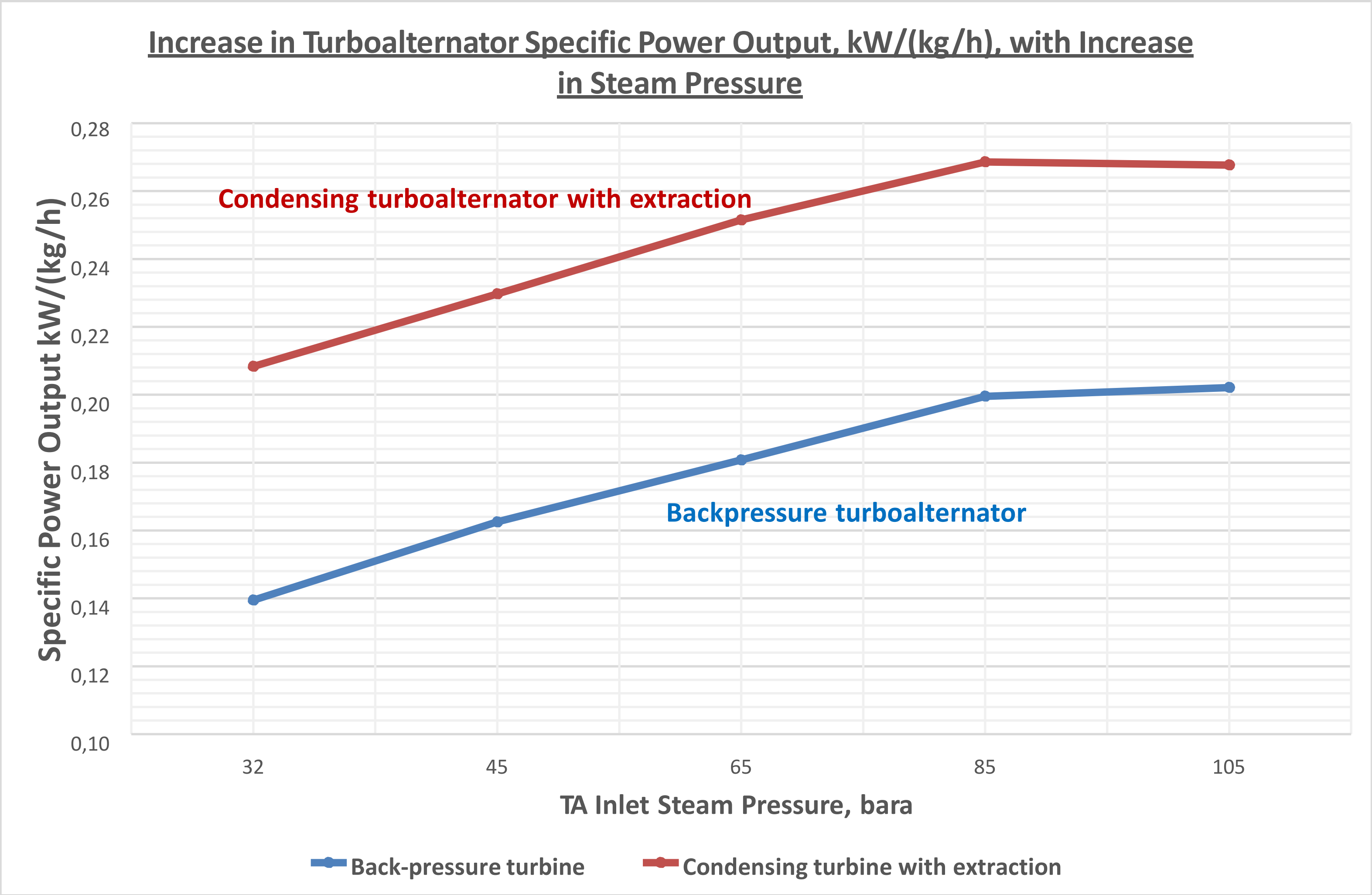


What do we mean by Specific Power Output ?



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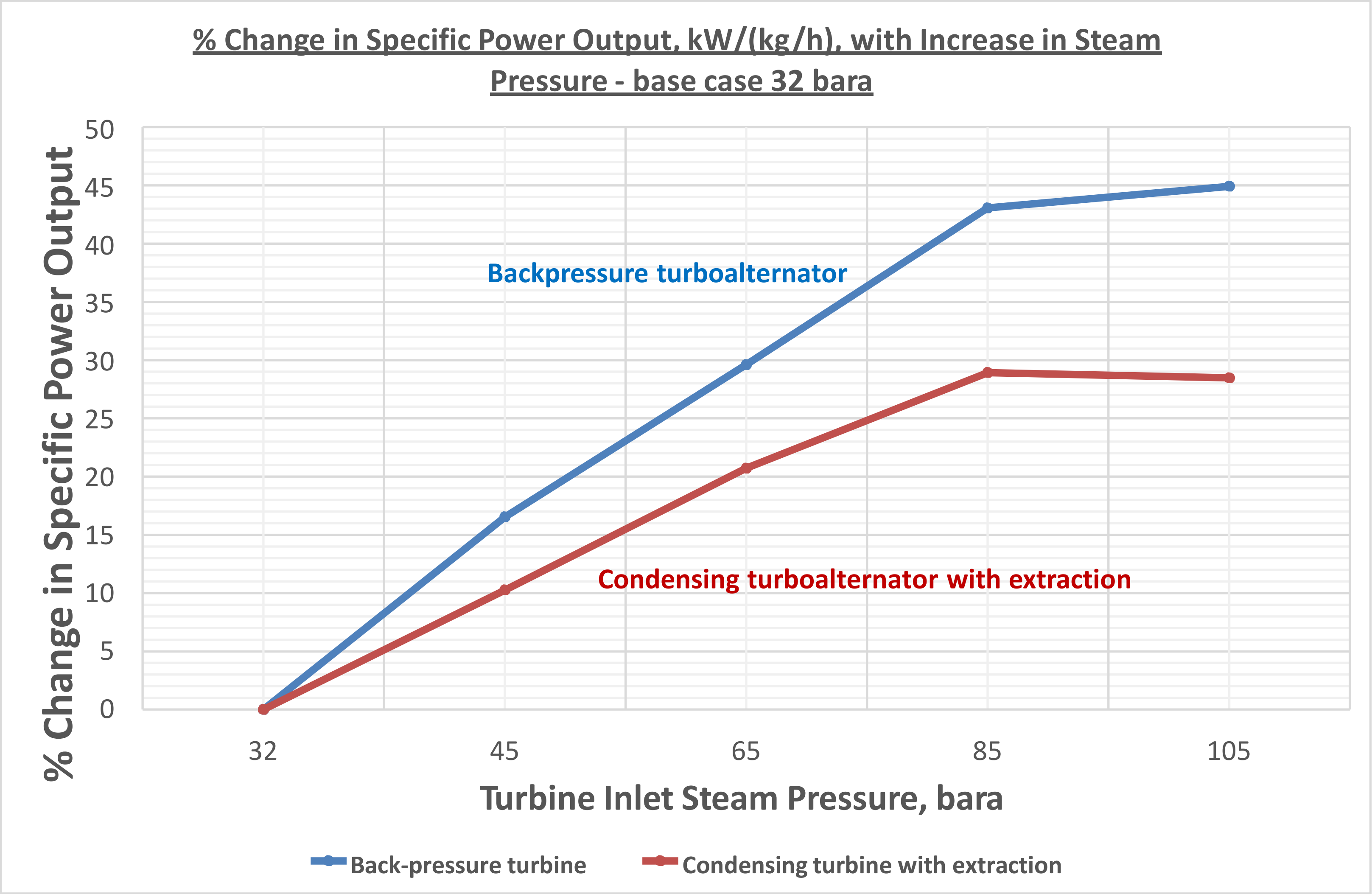
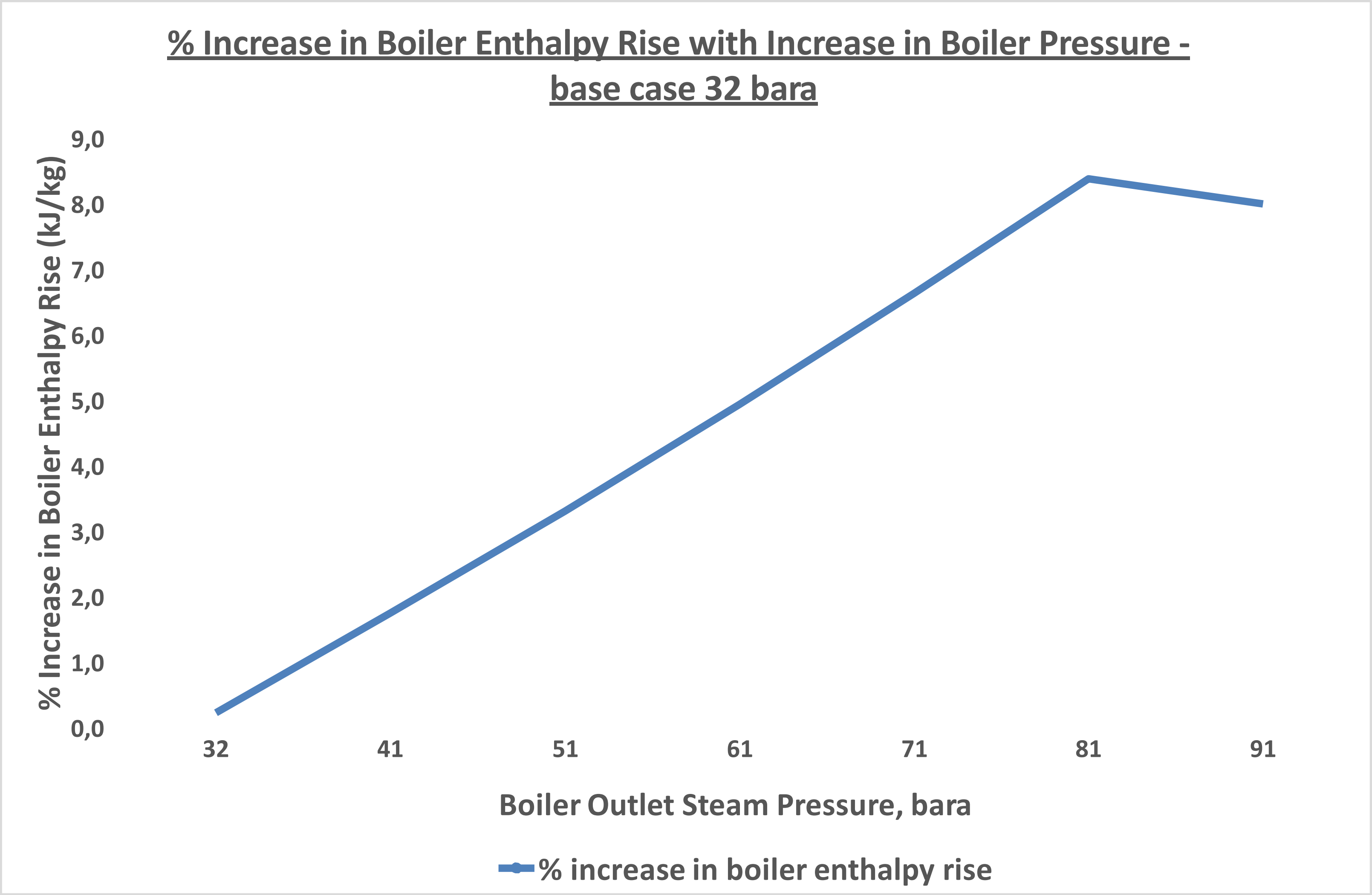


Boiler Characteristics

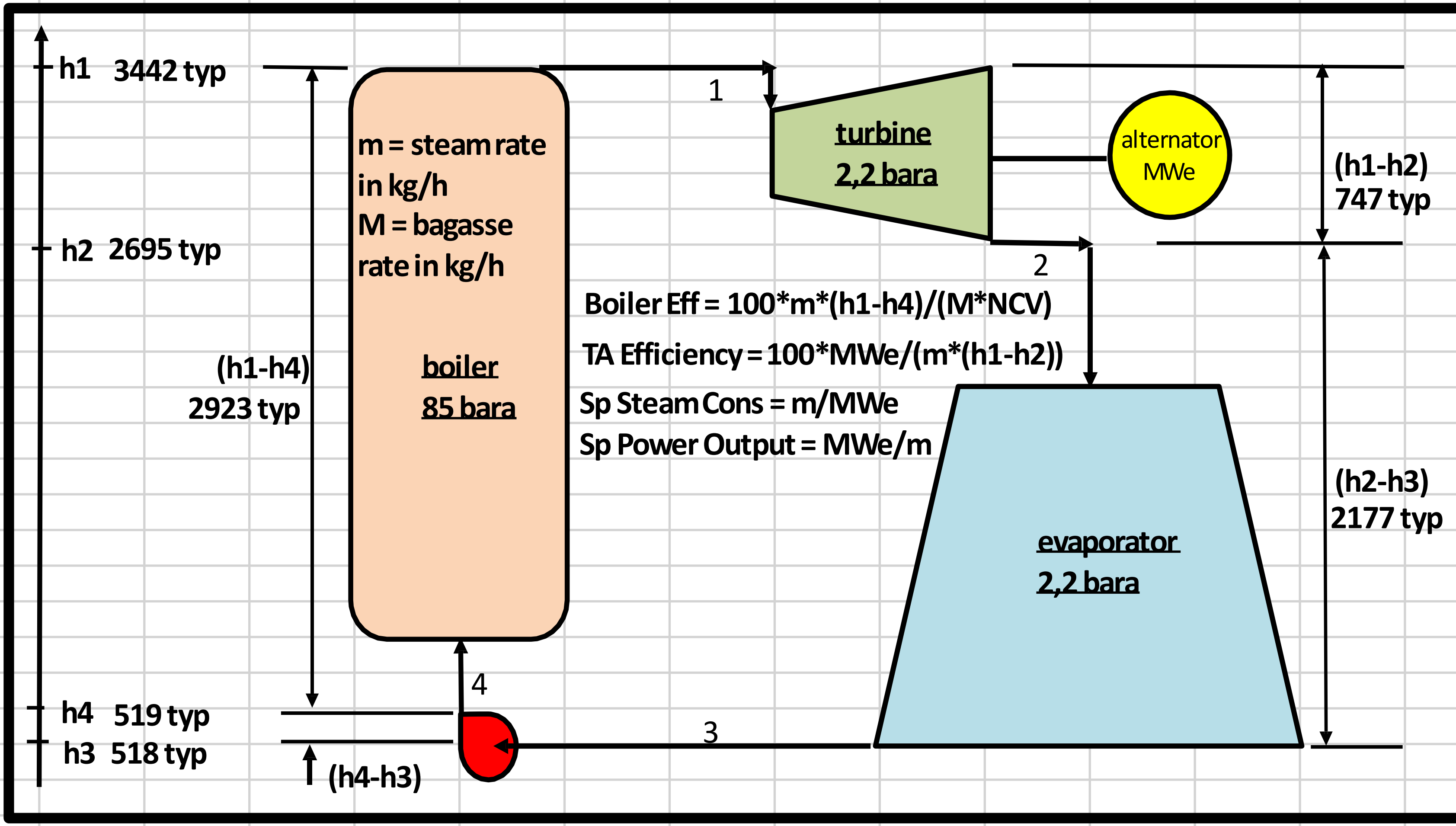
- boiler is a dumb servant to the turboalternator
- boiler is an “enabler” for the TA to generate more power per unit steam rate
- boiler efficiency constant at all pressures

Outlet steam pressure	bara	32	41	51	61	71	81	91
Outlet steam temperature	C	400	425	450	475	500	525	525
Outlet steam rate	tph	100	100	150	150	200	200	200
Boiler efficiency (NCV)	%	89	89	89,1	89,1	89,2	89,2	89,2
Bagasse consumption rate	tph	41	42	64	61	81	80	79

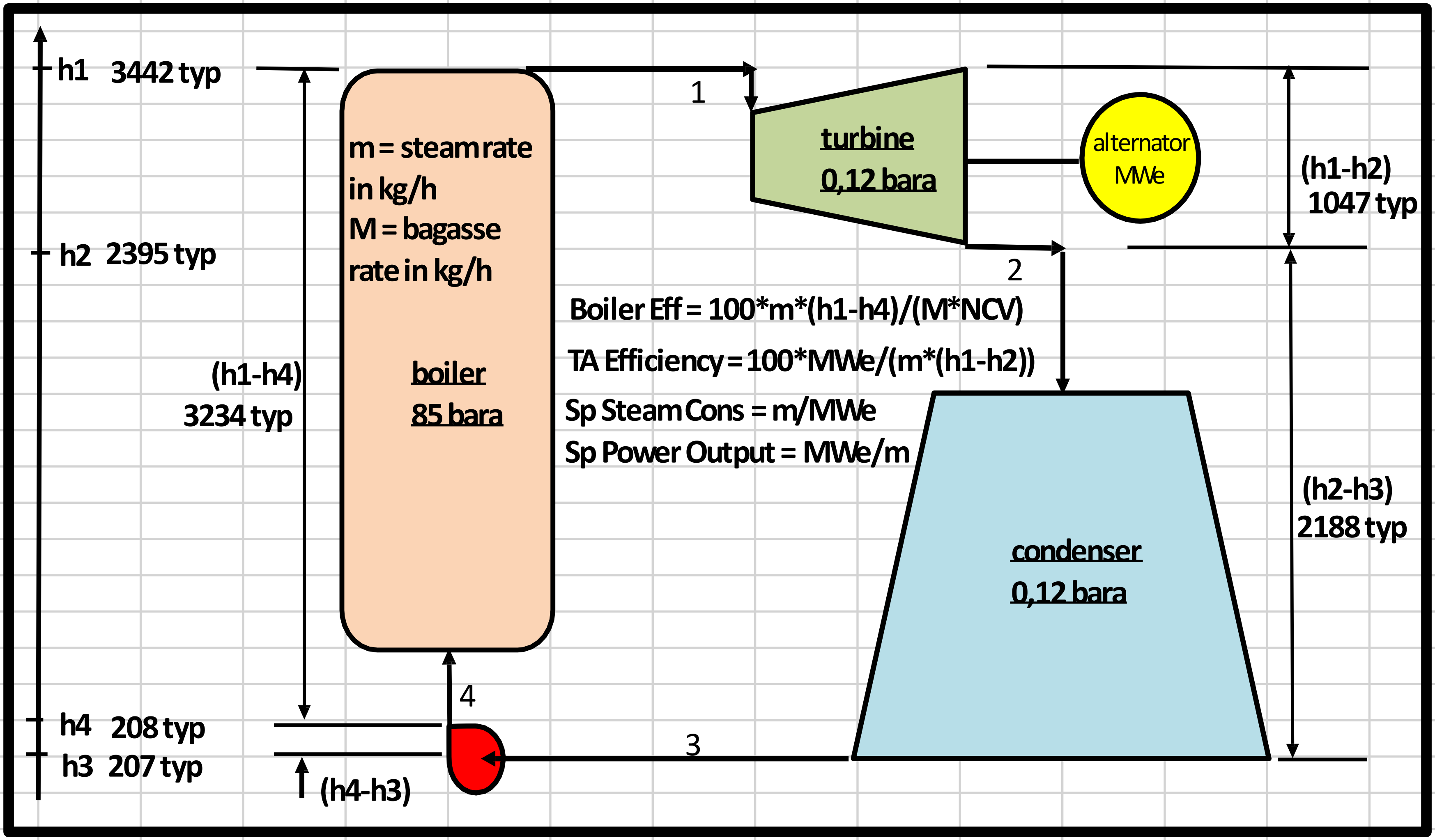
Boiler Options

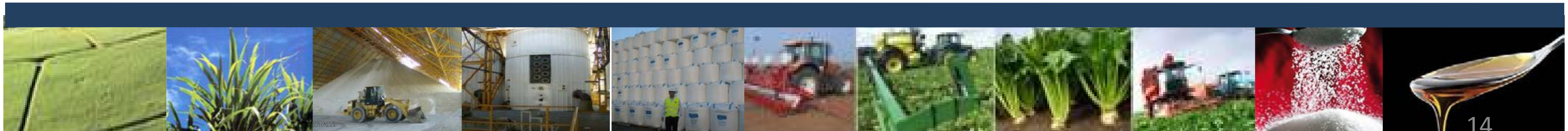


Rankine Cycle with Backpressure Turbine



Rankine Cycle with Condensing Turbine





How then to optimise/maximise cogen ?

1. Boiler & TA efficiencies must be high
2. TA specific power output must be high
3. This requires boiler steam at high pressure & temperature
4. Finally, reduce the amount of steam energy required for process (S%C) so that more energy can be exported as cogen power

In the modelling that follows it will be assumed that the capex cost of improving the S%C requirement is USD 20 million.

It is also assumed that the low-pressure backpressure turbine requirements can be met from existing low-pressure boilers.

Analysis

The factory data selected for calculation is tabled:

INPUTS	%	T/day	T/h
Cane		10 000	417
Brix in cane	15,44		
Fibre in cane	11,00		
Moisture in cane	72,21		
Ash in cane	1,35		
Bagasse		2 366	99
Brix in bagasse	2,00		
Fibre in bagasse	46,50		
Moisture in bagasse	50,00		
Ash in bagasse	1,50		

Slide 4 Case 4: Historical Factory

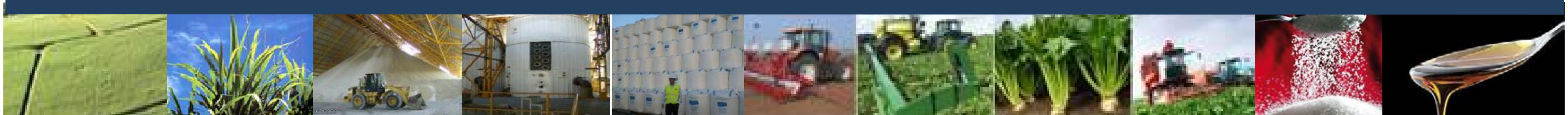
- Low pressure steam
- High TA Sp. Steam rate
- High S%C
- No Cogen
- No Condensing T/A

REQUIREMENTS	MWh/TC	MWh/day	MWh/h
Factory power requirement	0,040	400	17
	S/C	T/day	T/h
Process steam requirement	48	4 800	200
TURBOALTERNATOR BACK PRESSURE		T/day	T/h
Turboalternator MWe	17		
Turboalternator steam pressure bara	32		
Turboalternator steam temp C	380		
Turboalternator efficiency	92		
Process steam requirement via Letdown %	25		50
Steam from desuperheating water			12
LP steam avail ex CE turbine			
Steam required by/available from TA			139
Process steam required from TA			139
TURBOALTERNATOR CONDENSING		T/day	T/h
Turboalternator MWe			
Turboalternator steam pressure bara			
Turboalternator steam temp C			
Turboalternator efficiency			
Turboalternator steam requirement			
Turboalternator steam extracted			
SUPPLY		T/day	T/h
Boiler steam output		4 545	189
Boiler outlet steam pressure bara	32		
Boiler outlet steam temp C	400		
Boiler efficiency (NCV)	80		
Bagasse rate to boiler		2 088	87
Bagasse surplus		278	12

Slide 4 Case 4: Historical Factory with Limited Cogen

- Low pressure steam
- High TA Sp. Steam rate
- High S%C
- Limited Cogen
- Reduce % letdown

TURBOALTERNATOR	**Cogen 10 000 T Cane/day**		
Turboalternator MWe	6		
Factory operation/annum, hours	4 000	5 000	6 000
Turboalternator GWh	25	32	38
Rate for electricity supplied to grid USD/MWh	50	50	50
Revenue USD x 10	1,3	1,6	1,9
Rate for electricity supplied to grid USD/MWh	100	100	100
Revenue USD x 10	2,5	3,2	3,8

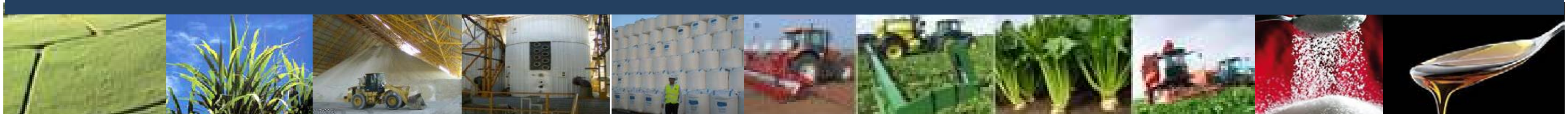


REQUIREMENTS	MWh/TC	MWh/day	MWh/h
Factory power requirement	0,040	400	17
	S/C	T/day	T/h
Process steam requirement	48	4 800	200
TURBOALTERNATOR BACK PRESSURE		**T/day**	**T/h**
Turboalternator MWe	23		
Turboalternator steam pressure bara	32		
Turboalternator steam temp C	380		
Turboalternator efficiency	92		
Process steam requirement via Letdown %	5		10
Steam from desuperheating water			2
LP steam avail ex CE turbine			
Steam required by/available from TA			189
Process steam required from TA			188
TURBOALTERNATOR CONDENSING		**T/day**	**T/h**
Turboalternator MWe			
Turboalternator steam pressure bara			
Turboalternator steam temp C			
Turboalternator efficiency			
Turboalternator steam requirement			
Turboalternator steam extracted			
SUPPLY		**T/day**	**T/h**
Boiler steam output		4 765	199
Boiler outlet steam pressure bara	32		
Boiler outlet steam temp C	400		
Boiler efficiency (NCV)	80		
Bagasse rate to boiler		2 208	92
Bagasse surplus		158	7

Slide 4 Case 1: New Factory Design

- High pressure steam
- Low TA Sp. Steam rate
- Low S%C
- Max Cogen
- Condensing T/A

TURBOALTERNATOR	Cogen 10 000 T Cane/day		
Turboalternator MWe	34		
Factory operation/annum, hours	4 000	5 000	6 000
Turboalternator GWh	136	170	204
Rate for electricity supplied to grid USD/MWh	50	50	50
Revenue USD x 10	6,8	8,5	10,2
Rate for electricity supplied to grid USD/MWh	100	100	100
Revenue USD x 10	13,6	17,0	20,4



REQUIREMENTS	MWh/TC	MWh/day	MWh/h
Factory power requirement	0,040	400	17
	S/C	T/day	T/h
Process steam requirement	29	2 900	121
TURBOALTERNATOR BACK PRESSURE		**T/day**	**T/h**
Turboalternator MWe	17		
Turboalternator steam pressure bara	85		
Turboalternator steam temp C	520		
Turboalternator efficiency	95		
Process steam requirement via Letdown %	16		19
Steam from desuperheating water			4
LP steam avail ex CE turbine			12
Steam required by/available from TA			85
Process steam required from TA			85
TURBOALTERNATOR CONDENSING		**T/day**	**T/h**
Turboalternator MWe	34		
Turboalternator steam pressure bara	85		
Turboalternator steam temp C	520		
Turboalternator efficiency	95		
Turboalternator steam requirement			127
Turboalternator steam extracted			12
SUPPLY		**T/day**	**T/h**
Boiler steam output		5 547	231
Boiler outlet steam pressure bara	91		
Boiler outlet steam temp C	525		
Boiler efficiency (NCV)	89		
Bagasse rate to boiler		2 208	92
Bagasse surplus		158	7

Slide 4 Case 2: New Boilers + Cogen but Process Unchanged

- High pressure steam
- Low TA Sp. Steam rate
- High S%C
- Intermediate Cogen
- Condensing T/A

TURBOALTERNATOR	Cogen 10 000 T Cane/day		
Turboalternator MWe	27		
Factory operation/annum, hours	4 000	5 000	6 000
Turboalternator GWh	109	137	164
USD/MWH for electricity supplied to grid	50	50	50
Revenue USD x 10	5,5	6,8	8,2
USD/MWH for electricity supplied to grid	100	100	100
Revenue USD x 10	10,9	13,7	16,4

REQUIREMENTS	MWh/TC	MWh/day	MWh/h
Factory power requirement	0,040	400	17
	S%C	T/day	T/h
Process steam requirement	48	4 800	200
TURBOALTERNATOR BACK PRESSURE		T/day	T/h
Turboalternator MWe	28		
Turboalternator steam pressure bara	85		
Turboalternator steam temp C	520		
Turboalternator efficiency	95		
Process steam requirement via Letdown %	22		43
Steam from desuperheating water			10
LP steam avail ex CE turbine			6
Steam required by/available from TA			140
Process steam required from TA			141
TURBOALTERNATOR CONDENSING		T/day	T/h
Turboalternator MWe	16		
Turboalternator steam pressure bara	85		
Turboalternator steam temp C	520		
Turboalternator efficiency	95		
Turboalternator steam requirement			60
Turboalternator steam extracted			6
SUPPLY		T/day	T/h
Boiler steam output		5 834	243
Boiler outlet steam pressure bara	91		
Boiler outlet steam temp C	525		
Boiler efficiency (NCV)	89		
Bagasse rate to boiler		2 304	96
Bagasse surplus		62	3

Slide 4 Case 3: Historical Boilers + Cogen + S%C Reduced

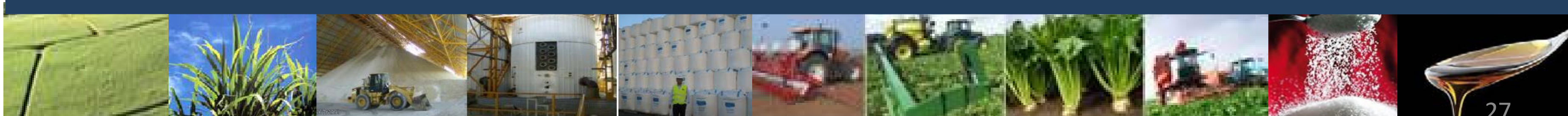
- Low pressure steam
- High TA Sp. Steam rate
- Low S%C
- Intermediate Cogen
- Condensing T/A

TURBOALTERNATOR	Cogen 10 000 T Cane/day		
Turboalternator MWe	21		
Factory operation/annum, hours	4 000	5 000	6 000
Turboalternator GWh	84	105	127
USD/MWH for electricity supplied to grid	50	50	50
Revenue USD x 10	4,2	5,3	6,3
USD/MWH for electricity supplied to grid	100	100	100
Revenue USD x 10	8,4	10,5	12,7

REQUIREMENTS	MWh/TC	MWh/day	MWh/h
Factory power requirement	0,040	400	17
	S%C	T/day	T/h
Process steam requirement	29	2 900	121
TURBOALTERNATOR BACK PRESSURE		T/day	T/h
Turboalternator MWe	12		
Turboalternator steam pressure bara	32		
Turboalternator steam temp C	400		
Turboalternator efficiency	95		
Process steam requirement via Letdown %	17		20
Steam from desuperheating water			5
LP steam avail ex CE turbine			12
Steam required by/available from TA			84
Process steam required from TA			84
TURBOALTERNATOR CONDENSING		T/day	T/h
Turboalternator MWe	26		
Turboalternator steam pressure bara	32		
Turboalternator steam temp C	400		
Turboalternator efficiency	95		
Turboalternator steam requirement			125
Turboalternator steam extracted			12
SUPPLY		T/day	T/h
Boiler steam output		5 496	229
Boiler outlet steam pressure bara	32		
Boiler outlet steam temp C	400		
Boiler efficiency (NCV)	89		
Bagasse rate to boiler		2 280	95
Bagasse surplus		86	4

Summary

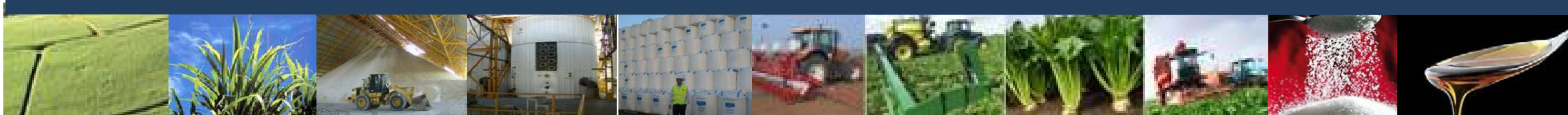
	Case 1			Case 2			Case 3		
	- High pressure steam			- High pressure steam			- Low pressure steam		
	- Low TA Sp. Steam rate			- Low TA Sp. Steam rate			- High TA Sp. Steam rate		
	- Low S%C			- High S%C			- Low S%C		
	- Max Cogen			- Intermediate Cogen			- Intermediate Cogen		
	- Condensing T/A			- Condensing T/A			- Condensing T/A		
TURBOALTERNATOR	Cogen 10 000 T Cane/day			Cogen 10 000 T Cane/day			Cogen 10 000 T Cane/day		
Turboalternator MWe	34			27			21		
Factory operation/annum, hours	4 000	5 000	6 000	4 000	5 000	6 000	4 000	5 000	6 000
Turboalternator GWh	136	170	204	109	137	164	84	105	127
USD/MWH for electricity supplied to grid	50	50	50	50	50	50	50	50	50
Revenue USD x 10	6,8	8,5	10,2	5,5	6,8	8,2	4,2	5,3	6,3
USD/MWH for electricity supplied to grid	100	100	100	100	100	100	100	100	100
Revenue USD x 10	13,6	17,0	20,4	10,9	13,7	16,4	8,4	10,5	12,7



What enables these changes?

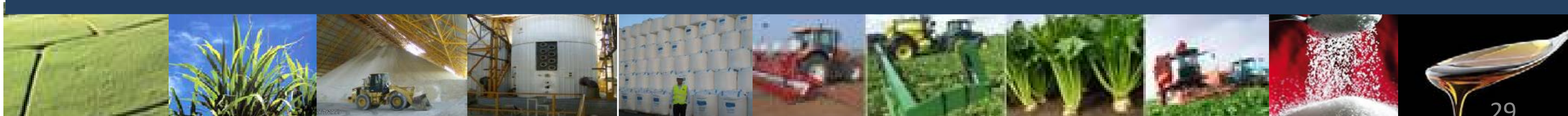
1] Reductions in process steam requirements

2] High pressure boilers which enable turboalternators with low specific steam consumption

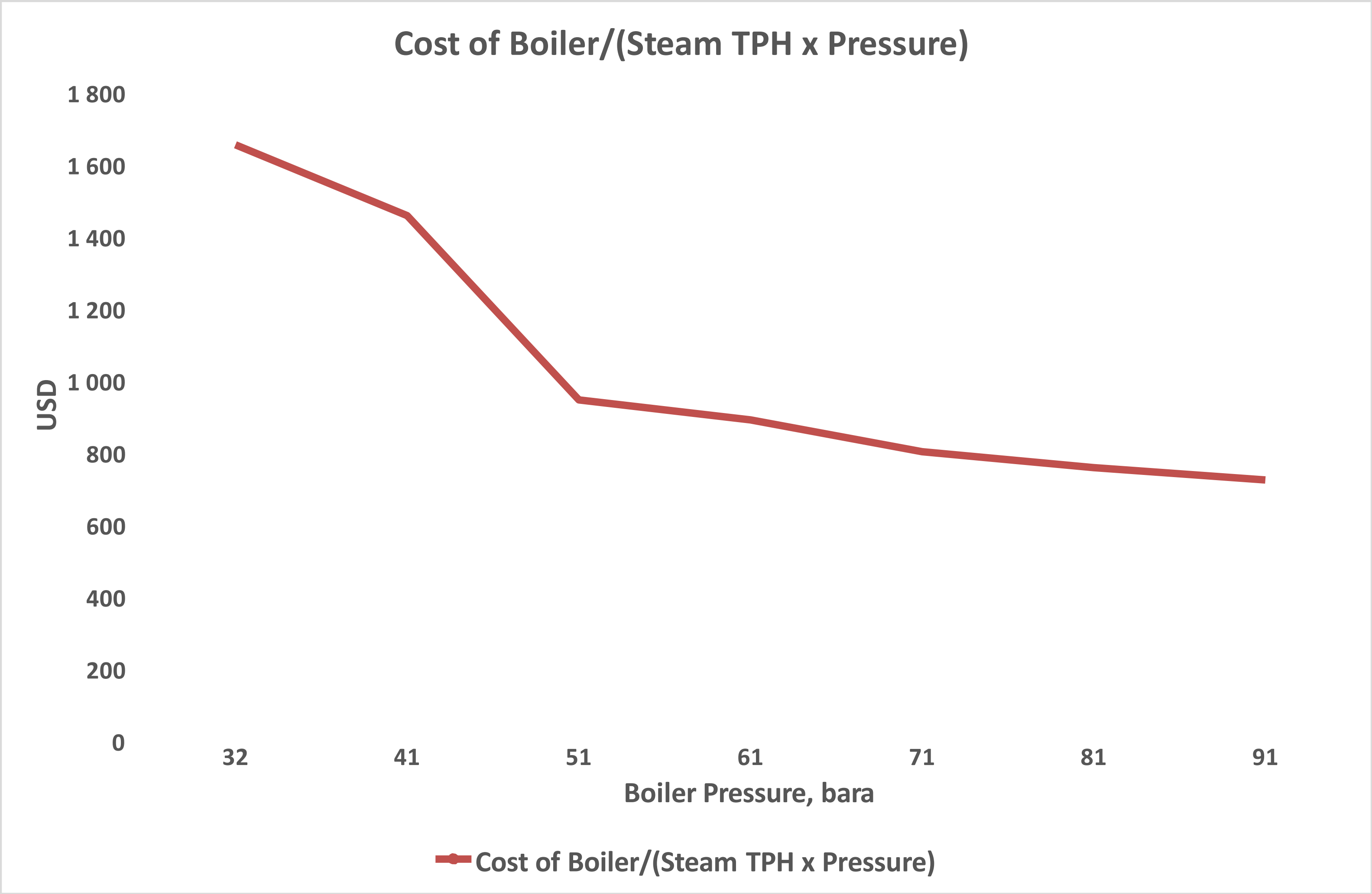


What do they cost?

Boilers								
Outlet steam pressure	bara	32	41	51	61	71	81	91
Outlet steam temperature	C	400	425	450	475	500	525	525
Outlet steam rate	tph	100	100	150	150	200	200	200
Boiler cost (all incl)	USD x 10^6	5,3	5,9	7,0	7,9	10,9	11,7	12,5
Cost of Boiler/(Steam TPH x Pressure)	USD	1641	1439	915	858	768	722	687



What do they cost?



What do they cost?

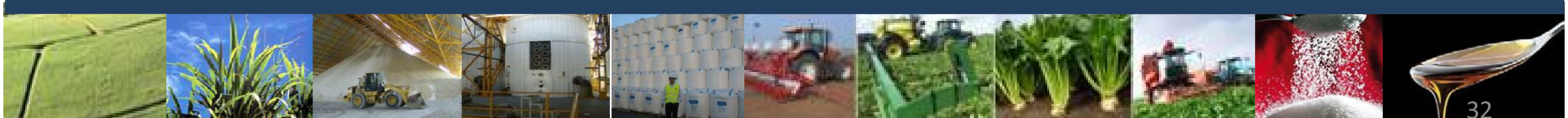
Backpressure Turboalternator				
Power	Total	TA only	Estimated Install Costs	Total
MW	USD x 10	GBP x 10	GBP x 10	GBP x 10
10	6,1	2,0	2,0	4,0
20	7,0	2,3	2,3	4,6
30	8,0	2,6	2,6	5,2

Installed costs are approximately independent of steam pressure (and temperature) and are related more to power output.

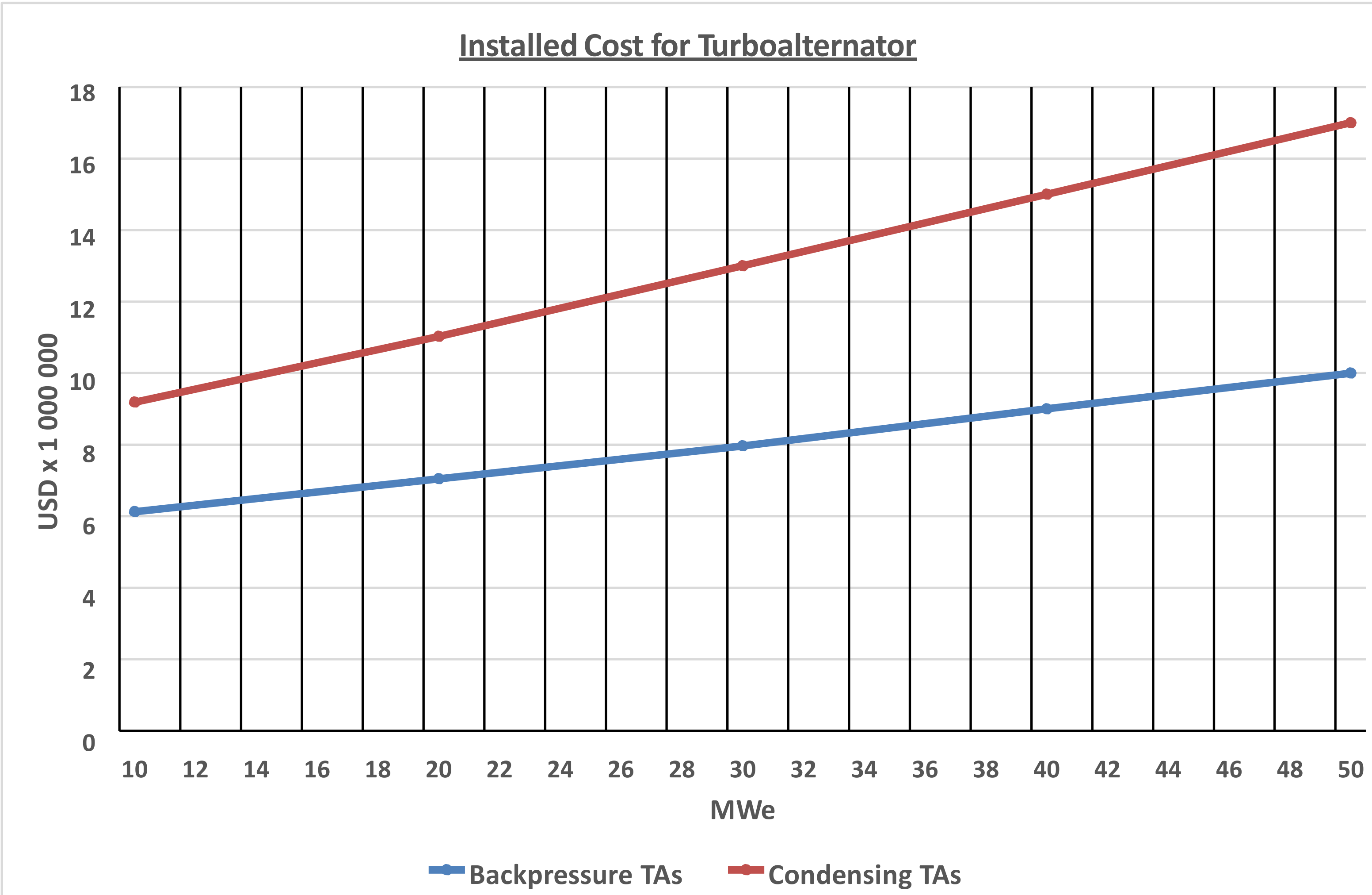
What do they cost?

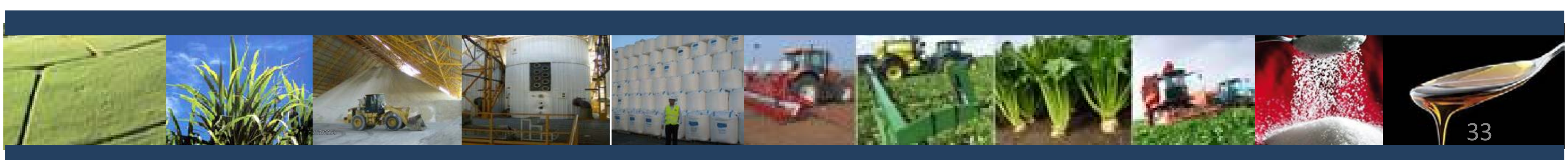
Condensing Turboalternator					
Power	Total	TA only	Condenser	Estimated Install Costs	Total
MW	USD x 10	GBP x 10	GBP x 10	GBP x 10	GBP x 10
10	9,2	2,5	0,5	3,0	6,0
20	11,0	3	0,6	3,6	7,2
25	11,9	3,2	0,7	3,9	7,8

Installed costs are approximately independent of steam pressure (and temperature) and are related more to power output.



What do they cost?





What is the Payback Period?

	Case 1			Case 2			Case 3		
	- High pressure steam			- High pressure steam			- Low pressure steam		
	- Low TA Sp. Steam rate			- Low TA Sp. Steam rate			- High TA Sp. Steam rate		
	- Low S%C			- High S%C			- Low S%C		
	- Max Cogen			- Intermediate Cogen			- Intermediate Cogen		
	- Condensing T/A			- Condensing T/A			- Condensing T/A		
TURBOALTERNATOR	Cogen 10 000 T Cane/day			Cogen 10 000 T Cane/day			Cogen 10 000 T Cane/day		
Turboalternator MWe	34			27			21		
Factory operation/annum, hours	4 000	5 000	6 000	4 000	5 000	6 000	4 000	5 000	6 000
Turboalternator GWh	136	170	204	109	137	164	84	105	127
USD/MWH for electricity supplied to grid	50	50	50	50	50	50	50	50	50
Revenue USD x 10	6,8	8,5	10,2	5,5	6,8	8,2	4,2	5,3	6,3
USD/MWH for electricity supplied to grid	100	100	100	100	100	100	100	100	100
Revenue USD x 10	13,6	17,0	20,4	10,9	13,7	16,4	8,4	10,5	12,7
PAYBACK PERIOD CALCULATIONS									
New boiler steaming rate installed, T/h	250			250			0		
Boiler cost installed USD x 10	15,6			15,6			0		
New TA backpressure installed power, MW	20			30			0		
TA backpressure cost installed USD x 10	7			8			0		
New TA condensing installed power, MW	40			20			40		
TA condensing cost installed USD x 10	15			11			14,5		
S%C improvement costs USD x 10	20			0			20		
Total costs	57,6			34,6			34,5		
Payback period, years (high tariff)	4,2	3,4	2,8	5,3	4,2	3,5	6,8	5,5	4,6
Payback period, years (low tariff)	8,5	6,8	5,6	10,5	8,4	7,0	13,7	10,9	9,1

Fibre % Cane

The higher the amount of fibre in cane, the higher will be the electricity that can be produced. There is a limited amount of fibre available in bagasse, however the amount of bagasse can be increased by adopting new cane varieties with higher fibre content.

Utilization of cane tops and leaves (CTL) and trash is another option which has the potential of optimizing the amount of renewable energy that can be obtained from sugar cane.
It includes the tops, green leaves, stalk and dry leaves of sugar cane.
For every 100 tons of cane harvested, 30 tons of CTL are left in sugar cane fields and also one ton of CTL has the potential to produce around 100 kWh of electricity.

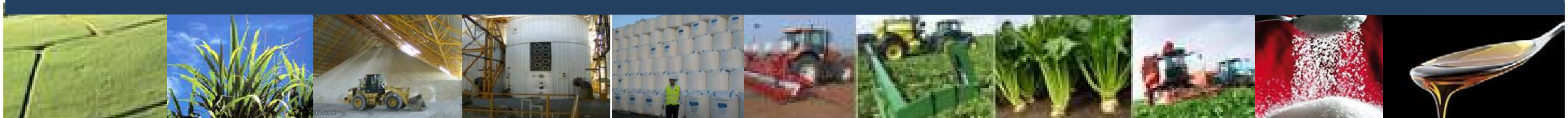
Moisture % Bagasse

Bagasse has a moisture content of about 50% and a calorific value of 7500 kJ/kg (NCV). The presence of water in the bagasse reduces its fuel value.

In order to maximise heat from the bagasse, the moisture can be reduced by drying.

Flue gas is the common source of waste heat used to dry bagasse.

The reduction in moisture can increase boiler efficiencies by 2 to 3 percentage points.



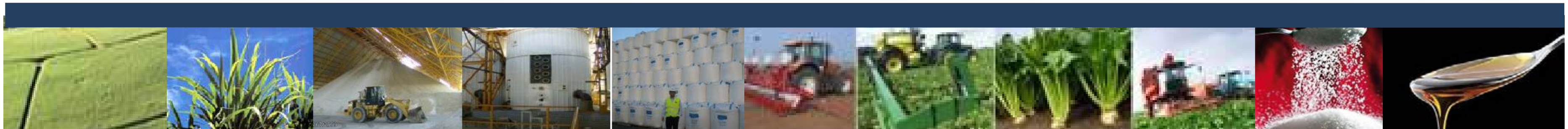
Evaporation

The evaporator station is the biggest consumer of steam in a sugar factory.

There are several designs of evaporators in the sugar industry, from the old Roberts design, to the long tube climbing film to the more recent falling film.

With the Roberts evaporator, the maximum no. of effects seen in industry are five effects.

With the advent of falling film, the higher heat transfer coefficient has made it possible for an additional effect.



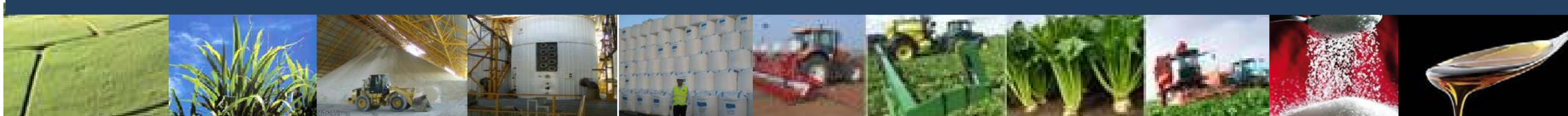
Evaporation

This is due to better heat transfer and no elevation of the boiling point due to hydrostatic pressure.
The other advantage of the falling film design is the short retention time in the vessel.

This allows the option of higher steam pressure in the first effect, without the risk of severe caramelization.

In summary, the advantages of falling film evaporators are:

a. Lower steam consumption due to larger number of effects
b. Higher heat transfer rates due to thin film



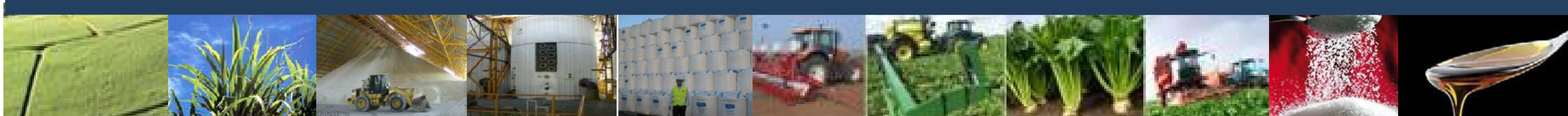
Crystallization

Batch pans suffer from the problem of cyclical operation and the need for high calandria pressure.

The main advantage of continuous pans for energy efficiency is the low calandria pressure required for evaporation.

Typically continuous pans have a low massecuite head and can be boiled with a temperature difference of 30 deg C while batch pans require about 50 – 60 deg C.

This allows the use of sub-atmospheric vapours for heating.

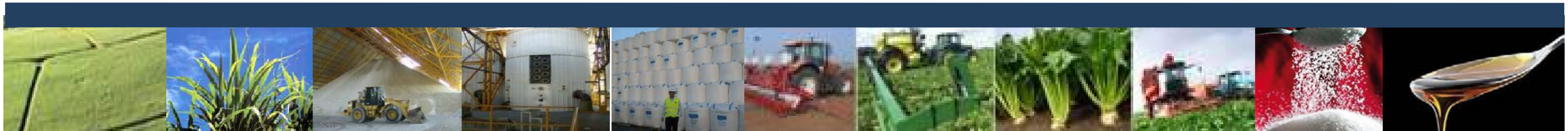


Electric Drives

There are two areas which can be optimised for electrical equipment in a sugar factory:

1. Eliminating low efficiency steam turbines.
2. Use of variable frequency drives.

Sugar factories can replace their inefficient steam turbines with electric motors to reduce the demand for live steam in boilers. Also many electric drives can be replaced by variable frequency drives that match the power consumption with the required capacity.



Vapour Bleeding

For higher energy efficiency, more bleeding is required.

Based on the quin, the following can be done:

Raw Juice Heating: Carried out in 3 Stages.

1st Stage: With 5th Vapour of Quintuple

2nd Stage: With Flashed Condensate

3rd Stage: With Quintuple 4th Vapour

Defecated Juice Heating: Carried out in 3 Stages.

1st Stage: With Quintuple 4th Vapour

2nd Stage: With Quintuple 3rd Vapour

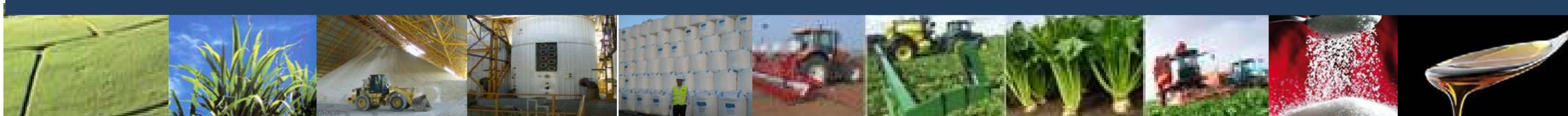
3rd Stage: With Quintuple 2nd Vapour

Clear Juice Heating: Carried out in 3 Stages.

1st Stage: With 3rd Vapour

2nd Stage: With 2nd Vapour

3rd Stage: With 1st Vapour

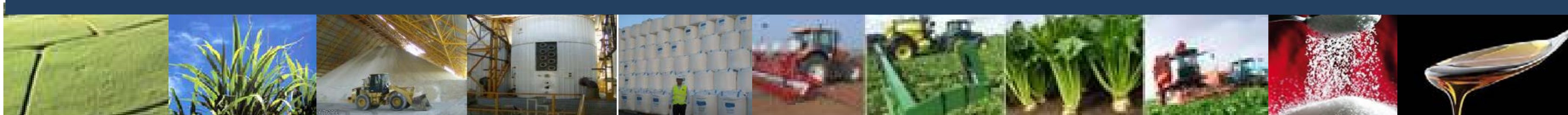


Waste Heat Recovery

There are many areas of waste heat recovery that are both practical and cost justifiable.

a. Heat recovery from pan and evaporator vapour
b. Heat recovery from condensate
c. Heat recovery from juice flash tank
d. Heat recovery from evap condensate flash tank
e. Heat recovery from non-condensable gas (NCG)

Heat recovery from pan and evaporator vapour line heaters has become popular.

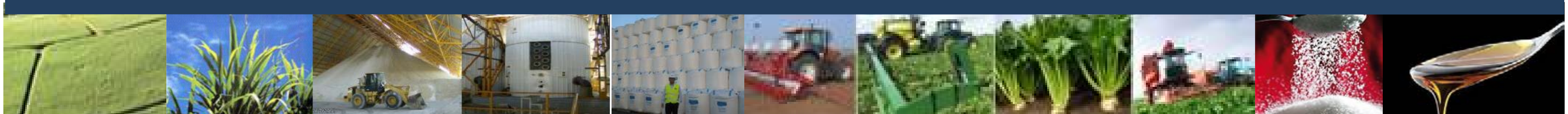


Game Changing Technologies

One such technology is where sub-atmospheric steam from a turbine is sent to the factory directly to continuous vacuum pans (CVPs).

The vapour is exhausted from these CVP to the evaporator.

Calandria steam at 0,75 bara Tsat 91,8°C boils the pan, releasing vapour at 0,25 bara and Tsat 65°C. This delta-T of 27°C is more than enough to boil the CVP.

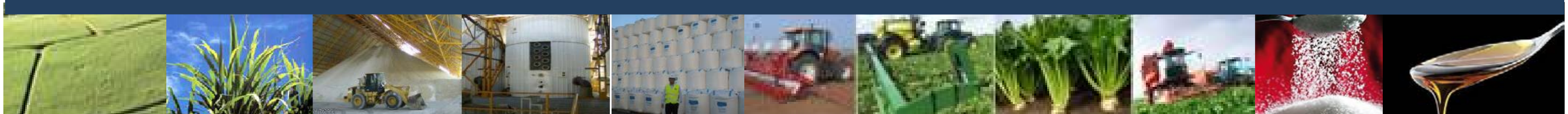


Game Changing Technologies

The resulting vapour can be used to drive a triple effect evaporator, if the vacuum can be deep enough. Here the use of an evaporative condenser is employed.

The evaporative condenser can cool down to a few degrees above the wet bulb temperature, lets say to 0.1 bara Tsat 45ºC.

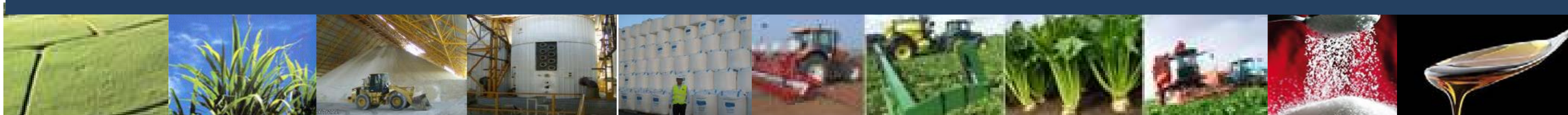
This allows 20 deg to be distributed amongst three effects. Only a specially designed evaporator with falling film design and low pressure drop between effects can perform to expectation.



Conclusion

Critical technologies like Condensing Extraction Turbines, Direct Contact Heaters, Falling Film Evaporators and Evaporative Condensers have allowed factories to push the limits of energy efficiency.

The best steam % cane achievable currently is about 30% but this is a moving target, and it is moving downwards.

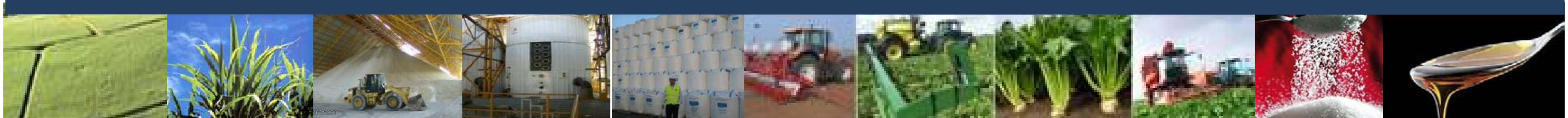


Conclusion

The power house and evaporation systems represent the largest part of the investment and the prices of these units have been improving with time.

The ROI is dependent on the selling price of electricity. It is envisaged that over time, sugar factories will become primarily power stations using bagasse as a renewable energy source.

The cooperation of local government is imperative to make these ideas become a reality.



THANK YOU FOR YOUR ATTENTION!