PINCH ANALYSIS :
For the Efficient Use of Energy, Water & Hydrogen

NITROGEN-BASED FERTILIZER INDUSTRY
Energy Recovery at an Ammonia Plant

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PINCH ANALYSIS APPLICATION EXAMPLE

Nitrogen-Based Fertilizer Industry
Energy Recovery at an Ammonia Plant

This document describes a Pinch study of an Ammonia plant typical of that found in a facility that manufactures nitrogen-based fertilizers. The objective of this document is to illustrate in more concrete terms how Pinch analysis can be used to analyze and improve this industrial process in a retrofit situation. It is one of the step-by-step examples that support the technical guide entitled *Pinch Analysis for the Efficient Use of Energy, Water and Hydrogen* produced by Natural Resources Canada. The Pinch concepts used in this example are presented in more details in this guide.

Pinch techniques were initially developed to address energy efficiency issues in new plant design situations. The techniques need to be modified for retrofit studies like the one described here. The key distinction is that in retrofit situations the analysis must take into account equipment that is already installed, whereas in a new design situation the designer has the flexibility to add or delete equipment at will. This difference makes the retrofit problem inherently more constrained.

Broadly speaking, modifications identified by a Pinch analysis may be categorized as changes to the process configuration itself (primarily in the unit heat recovery network) and changes to the process-utility interface. The latter category may also include changes to the unit heat recovery network, but focuses on improving the manner in which hot and cold utilities (flue gas, steam, cooling water, refrigeration, etc.) are utilized to serve the needs of the process. In retrofit situations, the constraints imposed by existing equipment can compromise the practicality and economic viability of changes to the process; under such circumstances, improvements to the process-utility interface may be more feasible and economically rewarding.

Although different approaches are possible for Pinch studies in retrofit situations, the approach taken in this example can be summarized in the following steps:

❶ Obtain data on existing process configuration relevant to Pinch study

❷ Generate targets for each relevant utility using the Composite Curves and the Grand Composite Curve

❸ Identify major inefficiencies in the existing heat exchanger network

❹ Identify possible process modifications to reduce the energy use

❺ Consider alternative retrofit strategies and select the most promising one

❻ Define and economically evaluate projects related to the selected strategy

The objective in the Pinch study is to make changes that reduce the net cost of utilities for the process, taking overall site impacts into account. All costs mentioned in this text are given in Canadian dollars (CAN$)

Process Description

The ammonia process consists of:

- Feed gas treatment (primarily sulfur removal)

- Primary and secondary reforming to produce synthesis gas (primarily hydrogen plus carbon monoxide)

- High and low temperature shift reactors (to maximize hydrogen yield)

- CO_2 removal and recovery

- Methanation to convert residual CO and CO_2 to methane

- Ammonia synthesis

- Product separation via refrigeration

- Compression (feed gas, air, process gas, refrigerant)

The process areas listed above are fully integrated and include an associated heat recovery network and ammonia refrigeration system.

This example is based on a moderate-size ammonia plant having a production rate of approximately 1,000 st/d[1].

The process is illustrated as a simplified process flow diagram (PFD) in Figure 1, which shows the main process streams and their respective heating or cooling loads. To simplify the schematic and aid understanding of energy flows, individual exchangers are not shown, but the locations of energy addition and removal are shown. Accordingly, the heat loads shown are aggregated duties that may represent more than one heat exchanger and/or furnace heating coil and thus may involve

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[1] 1,000 st/d: 1,000 short tonnes per day (1 short tonne = 0.9 metric tonne)

both process-to-process heat exchange and utility heating or cooling. Clarification of that portion of the utility heating supplied by primary reformer flue gas is provided in Figure 2, which illustrates the configuration of the primary reformer convection section for the base case. Disaggregation of the heating and cooling requirements also is indicated below in the Heat Exchanger Network Summary (Table 1), where the duties and temperatures of individual heat exchangers are provided.
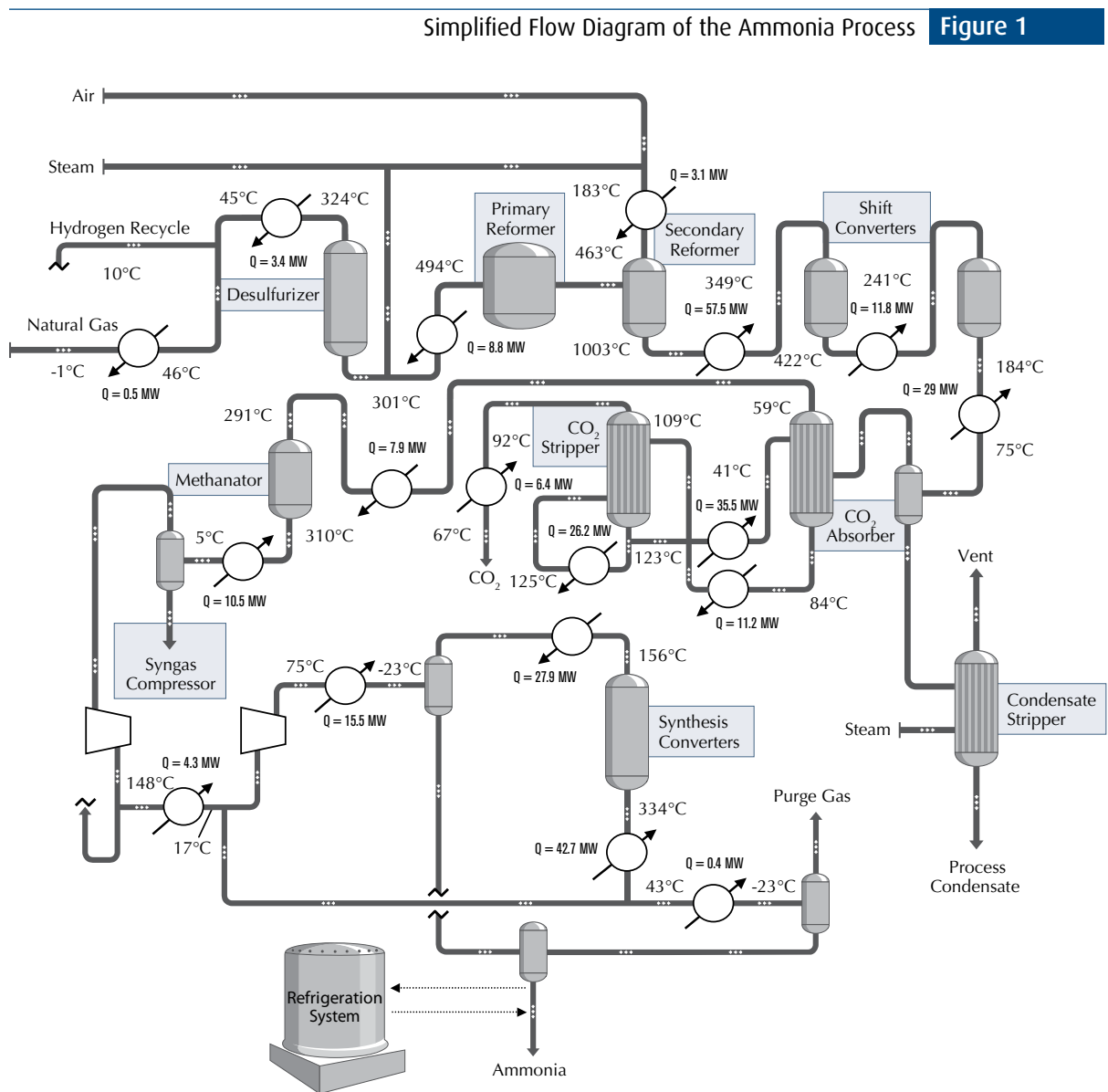
Simplified Flow Diagram of the Ammonia Process **Figure 1**

Figure 2 Primary Reformer Furnace: Convection Section Configuration
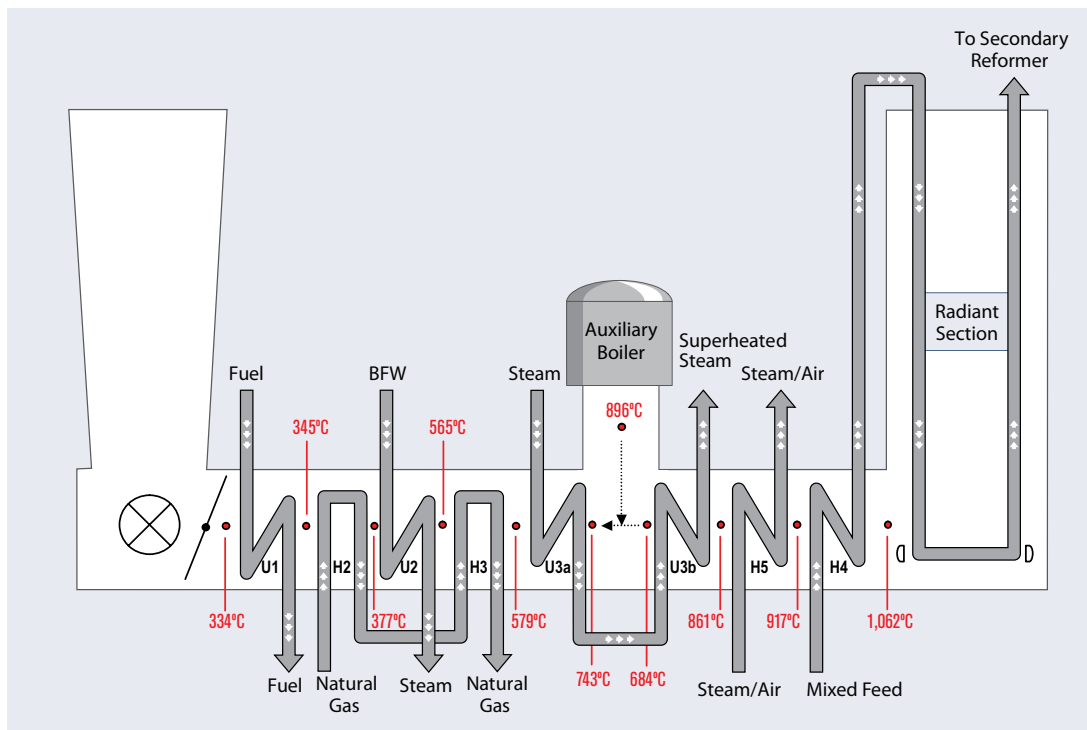
Step 1: Obtain Data on Existing Process Configuration Relevant to Pinch Study

Operating Data

Data needed for the Pinch study includes heat loads and temperatures for all of the utilities and process streams. In most cases this is obtained from a combination of test data, measured plant data and simulation, often supported by original design data. These data can be divided into two categories: process data and utility data.

Economic Data

The other type of data required is economic data. In the early stages of a study, the most important economic data relates to the cost of energy. Later capital costs become important; this is discussed under Step 6.

Energy prices generally depend on which utility is being considered, and in the present example fuel gas, steam generation, and purchased power costs must be considered. The applicable values for this study were as follows:

❒ Fuel: 6.00 CAN$/GJ

❒ 100 barg steam (HP): 19.00 CAN$/1000 kg

❒ 38 barg steam (MP): 15.30 CAN$/1000 kg

❒ Purchased Power: 47.00 CAN$/MWh

Notwithstanding the values shown above, it should be noted that utility pricing - especially steam pricing - can be a complex issue. In this study, as in many Pinch studies, a site-wide steam system model was developed to arrive at an appropriate price structure and to verify the value of anticipated steam savings.

Note: *The value of cooling water is generally a small fraction (typically ˜10%) of that for hot utilities and thus is ignored in this example. It should be kept in mind that reduction in cooling water usage can take on greater importance where plant operation or throughput is constrained by existing cooling system limitations.*

Annualized energy costs and savings are calculated based on an assumed "on-stream factor" of 97%, or 8,500 hours/year.

Once collected, the required data must be put it in the proper format for the Pinch study. This is often referred as the data extraction phase. The main rules for data extraction are presented in the *Pinch Analysis for the Efficient Use of Energy, Water and Hydrogen* guide of Natural Resources Canada.

Heat loads and temperatures for all streams in the process are required for the study. Not included in the process stream data, however, is the radiant section process heat duty for the primary reformer, since it is a "given" that this duty cannot be supplied to the process in any other way. Hence this portion of the process is not available for reintegration in some other manner.

Heat exchanger matches in the existing heat recovery network (including those in the primary reformer convection section) and the base stream data set used for the study are shown in Table 1. Note existing utility duties are shown for completeness.

For the purposes of targeting existing utility loads are ignored, since they reflect the existing heat integration scheme, which may not be optimal. The only exceptions are utility streams closely related to process operation and are not considered changeable. An example of this is process steam injection which is a process requirement unchanged by the heat integration scheme. Also, the primary reformer is a large fired heater. The radiant duty of the primary reformer, and hence its fuel firing rate, is set by feedstock conversion requirements. Subject to this constraint, the design objective is to make best use of the convective heat remaining in the flue gas leaving the radiant section of the reformer.

Heat Exchanger			Hot Side			Cold Side		
N°	Type [1]	Duty (MW)	Stream	T_s [2] (°C)	T_t [2] (°C)	Stream	T_s [2] (°C)	T_t [2] (°C)
P1	P-P	5.91	Low Temp Shift Converter Feed	332	241	Methanator Feed	118	291
P2	P-P	17.24	Gas to CO_2 Absorber	184	137	CO_2 Striper Reboiler	124	125
P3	P-P	11.23	CO_2 Stripper Bottoms	123	97	CO_2 Stripper Feed	84	109
P4	P-P	2.02	Syngas Compressor Intercooler	148	88	Methanator Feed	59	118
P5	P-P	7.34	Syngas Compressor Discharge	32	-11	Syngas Feed to Converters	-23	23
P6	P-P	20.55	Converter Effluent	183	43	Syngas Feed to Converters	23	156
H1	P-HU	0.48	LP Steam	148	147	Natural Gas Feed	-1	46
H2	P-P	2.40	Combined Flue Gas	377	345	Natural Gas and H_2 Recycle	45	244
H3	P-P	0.97	Combined Flue Gas	579	565	Natural Gas and H_2 Recycle	244	324
H4	P-HU	7.78	Primary Reformer Flue Gas	1062	917	Mixed Feed to Primary Ref.	301	494
H5	P-HU	3.11	Primary Reformer Flue Gas	917	861	Steam/Air to Secondary Reformer	183	463
H6	P-HU	8.95	LP Steam	148	147	CO_2 Stripper Reboiler	123	124
C1	P-CU	57.52	High Temp Shift Converter Feed	1003	349	HP Steam Generation	317	318
C2	P-CU	5.84	Low Temp Shift Converter Feed	422	332	HP Steam Generation	317	318
C3	P-CU	11.76	Gas to CO_2 Absorber	137	75	BFW Preheat	44	112
C4	P-CU	24.26	CO_2 Stripper Bottoms	97	41	Surface Condenser Water	35	46
C5	P-CU	6.37	CO_2 from Stripper	92	67	Surface Condenser Water	35	46
C6	P-CU	5.16	Methanator Effluent	310	158	BFW Preheat	112	292
C7	P-CU	4.82	Methanator Effluent	158	28	Cooling Water	20	35
C8	P-CU	0.51	Methanator Effluent	28	13	10° Refrigeration	9	10
C9	P-CU	1.52	Syngas Compressor Intercooler	88	39	Cooling Water	20	35
C10	P-CU	0.75	Syngas Compressor Intercooler	39	17	10° Refrigeration	9	10
C11	P-CU	2.06	Syngas Compressor Discharge	75	32	Cooling Water	20	35
C12	P-CU	4.78	Syngas Compressor Discharge	32	13	10° Refrigeration	9	10
C13	P-CU	3.36	Syngas Compressor Discharge	13	-3	-7° Refrigeration	-8	-7
C14	P-CU	5.28	Syngas Compressor Discharge	-3	-23	-33° Refrigeration	-34	-33
C15	P-CU	10.81	Converter Effluent	334	261	BFW Preheat	212	293
C16	P-CU	11.37	Converter Effluent	261	183	BFW Preheat	112	212

Heat Exchanger			Hot Side			Cold Side		
N°	Type [1]	Duty (MW)	Stream	T_s [2] (°C)	T_t [2] (°C)	Stream	T_s [2] (°C)	T_t [2] (°C)
C17	P-CU	0.43	Purge Gas	43	-23	-33° Refrigeration	-34	-33
C18	U-U	18.53	Refrigerant Condenser	109	25	Cooling Water	20	35
LSI	LSI		MP Steam	254	253	Process Steam	112	253
LSI	LSI		MP Steam	254	253	Process Steam	253	254
U1	P-HU	0.78	Combined Flue Gas	345	334	Fuel Gas	17	163
U2	U-U	14.08	Combined Flue Gas	565	377	BFW Preheat	112	297
U3b	U-U	12.85	Primary Reformer Flue Gas	861	684	Steam Superheat	373	441
U3a	U-U	10.34	Combined Flue Gas	743	579	Steam Superheat	318	373

☐ **Process Data**   ☐ **Utility Data**

[1] "P-P" indicates process-to-process heat exchanger; "P-CU" indicates utility cooling; "P-HU" indicates utility heating; "U-U" indicates hot utility/cold utility heat exchange; LSI indicates live steam injection (0 approach temp required)

[2] T_s = supply temperature; T_t = target temperature

Table 1: Heat Exchanger Network Summary ΔT_{min} values

Process Stream or Utility?

The Composite Curves generally represent the heating and cooling needs of process streams. The Grand Composite Curve is then used to select the appropriate mix of hot and cold utilities to satisfy these needs. In the Ammonia process, however, the distinction between process and utility streams must be considered carefully. For example, flue gas typically is regarded as a hot utility. However, the Primary Reformer flue gas is an unalterable process feature, in effect making the flue gas a process stream. For purposes of stream data extraction, it is assumed that flue gas heat is available down to the temperature at which acid gas condensation would make further heat recovery economically impractical due to metallurgical considerations.

Step 2: Generate targets for each relevant utility using the Composite Curves and the Grand Composite Curve

Set ΔT_{min} values

In order to generate the Composite and Grand Composite Curves used for Pinch Analysis, it is first necessary to set ΔT_{min} values for the problem. ΔT_{min}, or minimum temperature approach, is the smallest temperature difference to be allowed in any heat exchange match between hot and cold streams. This parameter reflects the trade-off between energy consumption (which decreases as the ΔT_{min} value gets smaller) and the required capital investment for heat recovery equipment (which increases as the ΔT_{min} value gets smaller).

It is possible to explore this trade-off quantitatively (for example, by using Pinch area targeting and capital cost targeting tools as presented in the *Pinch Analysis for the Efficient Use of Energy, Water and Hydrogen* guide), but in practice this is rarely done. Rather, there are typical ranges of ΔT_{min} values that have been found to represent a reasonable trade-off between capital and energy that generally can be applied with a high level of confidence.

In this pinch example, a ΔT_{min} value of 20°C, has been applied to all process-to-process heat exchange matches. However, different capital-energy trade-offs apply for heat transfer between process streams and utilities; therefore, different ΔT_{min} values typically are applied to heat exchange matches for each utility.

The following utility ΔT_{min} values were selected:

- ❐ Flue gas: 40°C
- ❐ Steam: 10°C
- ❐ Cooling Water: 10°C
- ❐ Refrigeration   5°C

The ΔT_{min} value for flue gas is somewhat arbitrary given its high-temperature characteristic. As discussed below, the minimum temperature approach for the flue gas is, in practice, set by the minimum temperature to which the flue gas may be practically cooled, taking possible corrosion problems (from condensable) into account. The lower ΔT_{min} value for refrigeration reflects the higher energy cost associated with power-intensive refrigeration systems (as compared to cooling utilities such as cooling water and air).

Composite and Grand Composite Curves

The Composite Curves for the base case stream data summarized in Table 1 are shown in Figure 3. These curves are comprised of all the process heating and cooling duties, and targets for utility use and generation can be inferred from these curves. In this case the process has an inherent excess of high temperature energy. This energy can be utilized to generate substantial quantities of superheated high pressure steam as currently done in exchangers U3a and U3b.
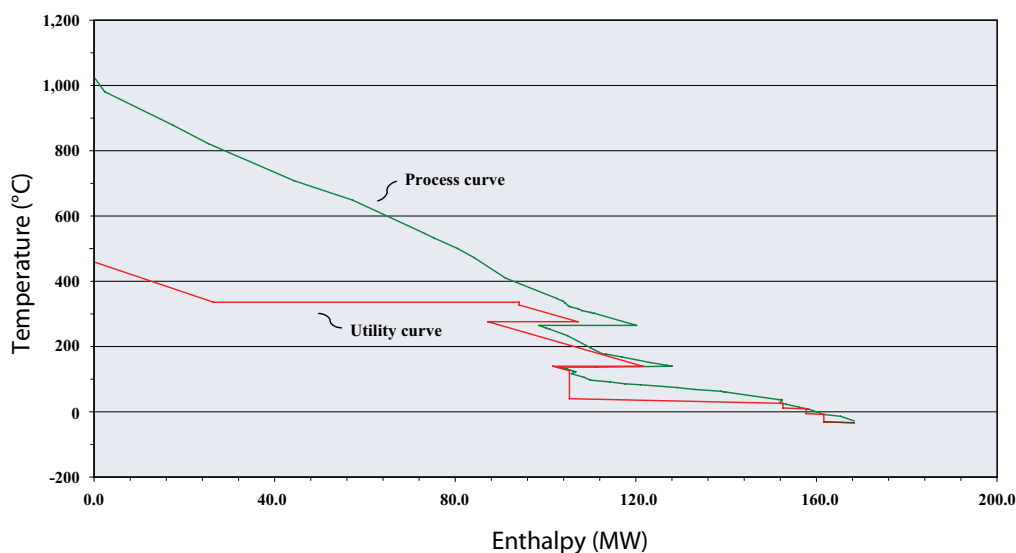
Composite Curves for Ammonia Process (ΔT_{min} = 20°C) - Base Case **Figure 3**
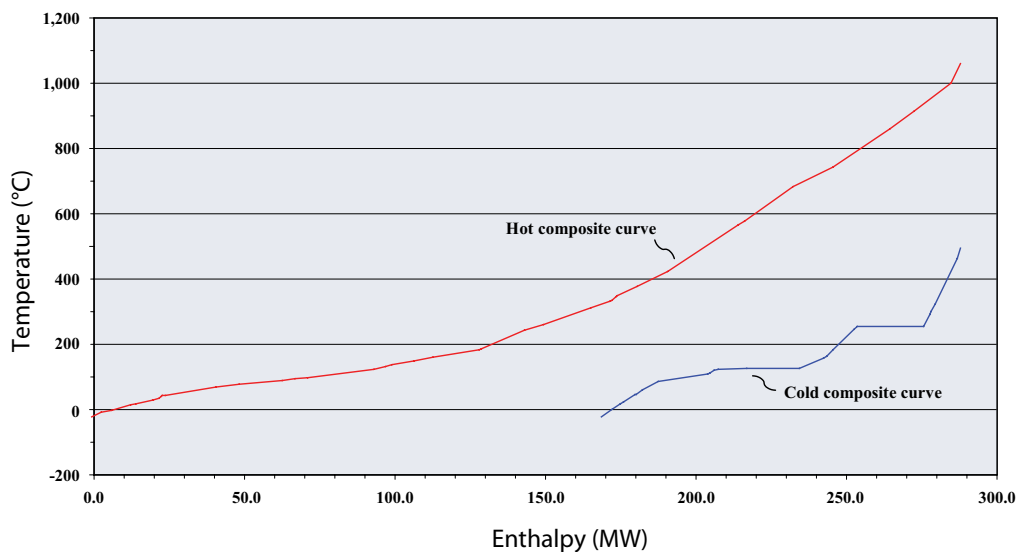
Grand Composite Curve for Ammonia Process (ΔT_{min} = 20°C) - Base Case **Figure 4**

A second representation of the base case data is provided in Figure 4 in the form of the Grand Composite Curve. In this representation, the base case heat rejection profile of the process is matched against the available utilities - HP steam generation, MP steam use, LP steam use, cooling water, and refrigeration.

The composite and grand composite curves show that the Ammonia process is a "Threshold problem" that requires only heat removal. This implies that there should be no net requirement for heating of process streams with hot utility (remember that we have accepted that the reformer firing duty is fixed, so the curves are not implying that the process does not require any external energy supply). Note that despite the excess of energy the grand composite curve shows potential for use of MP and LP steam. In general, it is a good idea to maximize use of lower pressure steam maximizing generation of HP steam, since there is potential for shaft-work (power) generation via let down of HP steam to MP steam via turbines.

Table 2 summarizes the energy targets for utility level as derived from the Grand Composite Curve at the selected values of ΔT_{min}. In the first instance targets are developed on the assumption that there are no practical or economic constraints that would prevent the target energy use from being achieved. This assumption will be reconsidered later.

The scope for changes in utility use through improved integration is the difference between actual and target use/generation of each utility. For example the target MP steam use is 20.0 MW, and the actual use is 30.2 MW suggesting that savings of 10.2 MW of MP steam can be made.

Threshold Problem

The Ammonia Process is, in Pinch terms, a "Threshold problem" (see illustration below). Below a certain ΔT_{min} value, "threshold problems" require only HOT utility or (as in the case of Ammonia) COLD utility, but not both. Such problems do not exhibit a process pinch or the "normal" capital vs. energy tradeoff. They do, however, have utility pinches, as discussed in Step 3.

"Threshold problems"
For $\Delta T_{min} \leq \Delta T_{threshold}$, energy targets do not change as ΔT_{min} changes.
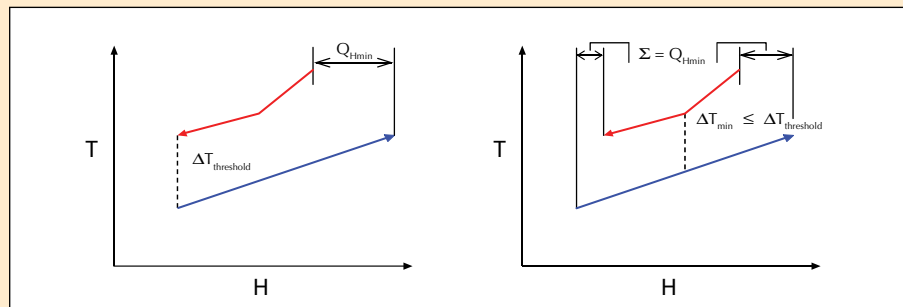
Establish hot and cold utility targets

Table 2 shows that the key deficit in energy performance relates to HP steam generation being below target by 29.5 MW. The implication of this is that with complete freedom to redesign the heat recovery systems, heat recovery into steam generation could be increased by 28.5 MW - more than 25% of the base case.

Steam use for process heating is overall close to target, although the base case consumes more MP steam and less LP steam than targeted. Due to the work production potential from expansion of MP steam to LP in a turbine, LP steam could be cheaper than MP steam and the difference between target and actual use could be associated with a cost penalty. A correct understanding of the site steam balance is required to make this determination.

Total actual refrigeration is shown to be slightly below target. This is due to some exchangers in the cold section of the process operating below the 5°C minimum ΔT selected for targeting. Such an observation is common in a retrofit project.

The primary conclusion to be drawn from the unconstrained targets is that the main opportunity for cost reduction lies with improved integration in the "hot end" of the process.

Utility	Existing (MW)	Target (MW)	Scope (MW)
Hot utilities			
MP Steam	30.2	20.0	-10.2
LP Steam	9.4	20.0	+10.6
Total Hot	**39.6**	**40.0**	**+0.4**
Cold utilities			
HP Steam Generation	116.5	145.0	+28.5
Refrigeration			
10°C Refrigeration	6.0	5.2	-0.8
-7°C Refrigeration	3.4	4.0	+0.6
-33°C Refrigeration	5.7	6.8	+1.1
Total Refrigeration	**15.1**	**16.0**	**+0.9**

Energy targets: Process ΔT_{min} = 20°C, Steam and Cooling Water ΔT_{min} = 10°C, Refrigeration ΔT_{min} = 5°C

Table 2: Energy Targets Summary

Step 3: Identify major inefficiencies in the heat exchanger network

Previously, it was noted that the Ammonia process is a "Threshold problem", and as such doesn't have a process pinch. However, when utilities are added, they create "utility pinches". The reason for differences between actual and target utility use is cross pinch heat transfer - in this case cross utility pinch transfer.

Table 3 summarizes where cross pinch heat transfer is occurring at the "hot end" of the process and is affecting HP steam generation.

Heat Exchanger	Cross-Pinch Heat Transfer (MW)	Location
LSI	.64	Process steam
H2	.94	Feed gas coil
U1	.57	Fuel gas coil
P2	-2.2	CO_2 stripper reboiler
P1	.17	Methanator feed heating
C6	.44	Methanator effluent vs. BFW
C7	.56	Methanator effluent cooling
P6	.77	Synthesis converter feed heating
H1	.48	Feed heating via LP steam
To stack	12.1	Flue gas to atmosphere
P4	.17	Methanator feed heating

**Table 3:** Cross-Pinch Heat Transfer Summary

As indicated in Table 3, a major portion of the existing cross-pinch heat transfer is associated with the loss of recoverable flue gas heat to ambient air in the stack. The remaining "lost opportunity" is scattered among numerous heat exchange services and thus is likely to be more difficult to capture, particularly in a retrofit situation.

In order to realize savings in purchased energy it is important to understand the mechanisms by which reducing process energy use (or increasing generation) will result in savings. Thus it is necessary to put the target savings in the context of the overall site.

Figure 5 shows a simplified schematic of the steam system structure. Some of the characteristics important to the integration analysis are:

- Almost 50% of steam consumption is associated with work generation in condensing turbines compressor drives.

- 30% of steam consumption is associated with the only 3 large steam consumers: process steam, CO_2 stripper reboiler and process condensate stripper reboiler. Process steam is added to the methane feed ahead of the reformer - it is both a reactant and a diluant that prevents reforming catalyst coking.

- 100 barg HP steam savings can be realized by increasing generation in process waste heat boilers or by improving the thermodynamic efficiency of work production. Such savings result in fuel reductions in the auxiliary boiler.

- 38 barg MP steam savings can be realized via savings in the use of 38 barg steam and 3 barg LP steam. Note that some letdown occurs between the 38 barg and 3 barg headers. Consequently, while there is scope to realize MP savings from savings of 3 barg LP steam, it is limited to the extent of letdown, after which further modifications to the steam system structure - such as elimination of a 38 barg to 3 barg turbine - would be required to keep the system in balance.

Simplified Schematic of Site Steam System **Figure 5**
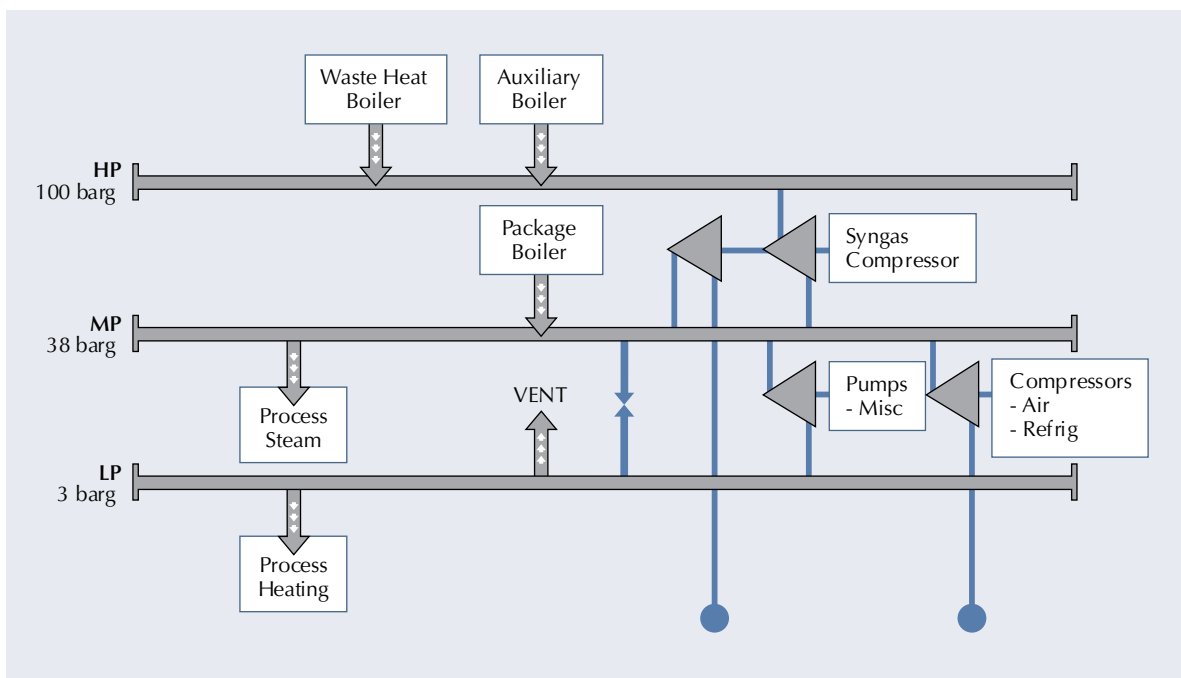
> ### Site Steam Balance Considerations
>
> The targets show that it is possible to making steam savings, but will they correspond to $ savings? A critical step in answering this question is to examine the project sitewide steam system impact to verify that the reduced steam consumption will, in fact, lower fuel consumption in the site auxiliary and/or package boilers. Consequently, the Pinch analysis must be accompanied by a "before and after" assessment of sitewide steam generation and use at all pressure levels to verify actual savings.

Step 4: Identify possible process modifications to reduce the energy use

The site steam balance situation indicates that fired steam production can be reduced by:

❖ Improving the thermodynamic efficiency of work production in turbines to increase work produced per unit mass of steam, and by

❖ Reducing steam demand for process uses on the 38 barg or 3 barg headers.

The idea of improving work efficiency is simply derived from inspection of the steam balance situation. Several modifications could be considered, including increased superheat, vacuum improvements, and turbine efficiency improvements. In this case a superheat temperature increase was selected as the appropriate route. Simulation of the steam system shows that raising superheat temperature from the current value of 440°C, to 482°C, will reduce HP steam demand for work production by approximately 7 T/h[2], the work delivered to compressors being the same.

With respect to opportunities for heat recovery into HP steam generation, several items come into consideration:

• The HP pressure is high (approximately 100 barg) therefore modifications to the system are expensive.

• Increased steam generation implies addition of vaporization duty. The existing HP steam generators would be extremely difficult and expensive to modify.

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[2] 7 T/h: 7 tonnes per hour

- The most obvious source of waste heat is the reformer flue gas, but not much heat could be recovered into steam generation because the flue gas is available at 334°C and the HP vaporization temperature is about 320°C.

While it is always possible to design a heat exchanger network that meets the energy targets practical considerations come into play, particularly in retrofit situations. In this case it becomes apparent that in order to meet the targets extensive modifications to the existing network would be required. In this example, such modifications were not considered likely to be economically viable. Consequently, it was decided to accept the existing steam generation configuration as a constraint and develop new targets. This is done by removing from the analysis all the stream segments associated with heat exchangers that are to be accepted as "unchangeable" features of the process.
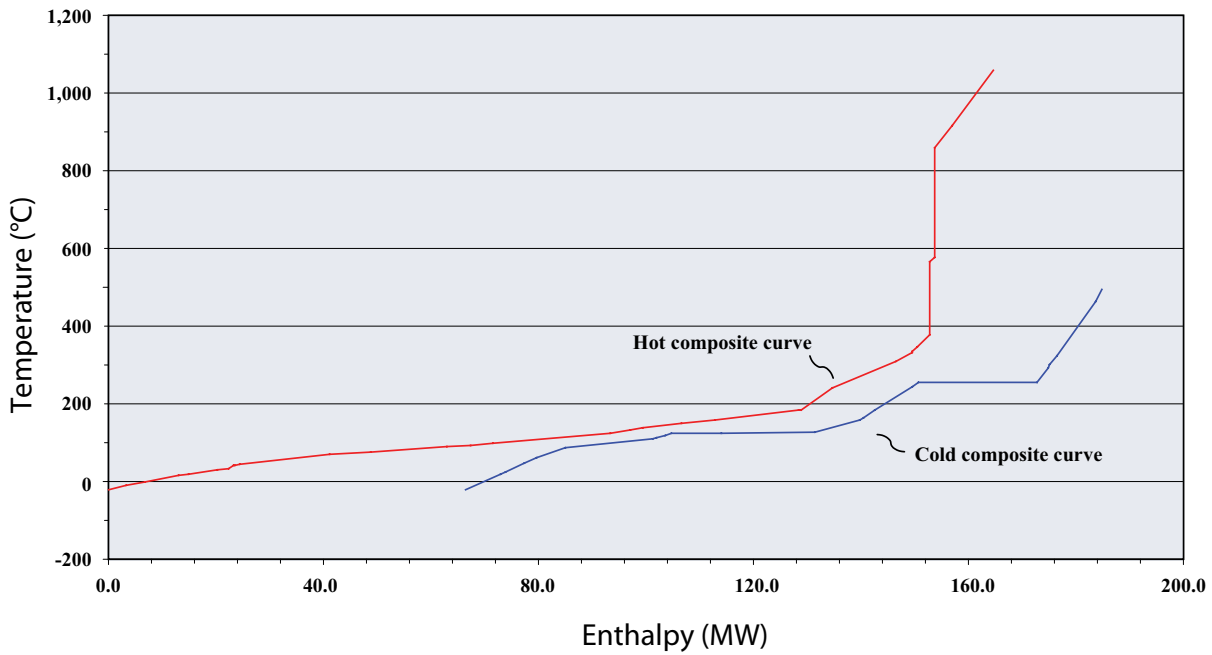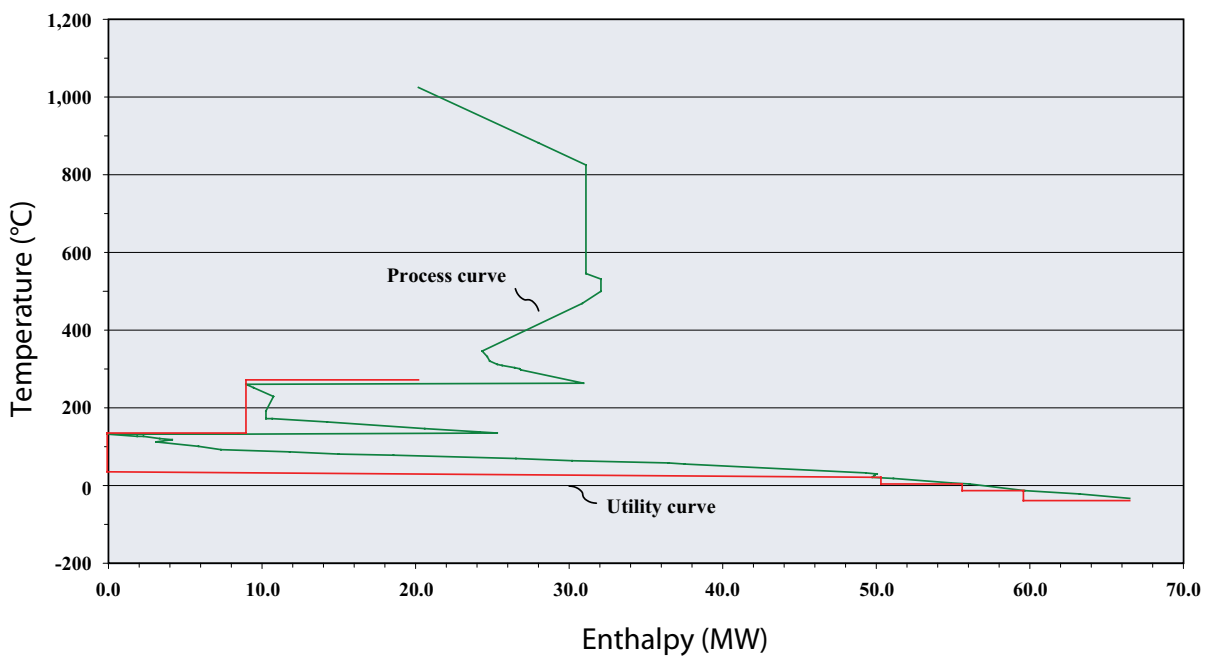
The revised composite and grand composite curves reflecting the constrained situation are shown in Figures 5 and 6. With the constraints in place, the target picture is quite different, since the problem is now pinched and is a net consumer of MP and LP steam.

Utility	Existing (MW)	Target (MW)	Difference (MW)
MP Steam	30.2	11.2	-20.0
LP Steam	9.4	9.0	-0.4

Table 4: Energy Targets Summary - Constrained Targeting

The revised targets imply that it should be possible to reduce MP steam use by 20 MW via improved heat integration. Further inspection reveals that the only large MP steam user is in fact process steam injection. However, since the process steam must be injected into the gas feed, the target must be interpreted not as scope to "save" MP steam, but as reflecting an opportunity to generate MP steam that can displace MP steam that would otherwise be generated in boilers.

Further inspection of the heat exchanger network shows that flue gas is still a key heat source, but that it cannot provide all the heat to produce the target savings. Consequently any project to capture the target savings would involve a new steam generation system, and collection of energy from multiple sources. Such a project was considered unlikely to be economic since it would require several exchangers, plus auxiliary equipment such as steam drums and so on.

Figure 6 Composite Curves for Ammonia Process (ΔT_{min} = 20°C) - Constrained Case

**Figure 7** Grand Composite Curve for Ammonia Process (ΔT_{min} = 20°C) - Constrained Case

In order to maximize heat recovery from the major heat source (i.e. flue gas) while keeping the resulting project fairly simple, the composite and grand composite curves can be used as a guide for identifying process modifications using the +/- principle. This principle recognizes that targets are modified when hot or cold streams are shifted relative to the pinch temperature.

The composite curves in Figure 6 show that if the temperature at which process steam is generated could be reduced, then it could be accomplished with a lower grade waste heat.

Inspection of the grand composite curve for the constrained case shows 2 major heat duties just above the pinch temperature, one corresponding to the CO_2 stripper reboiler and the other corresponding to MP Steam associated with process steam injection. If some of either of these 2 duties could be shifted to temperatures below the pinch then the targets would be reduced. The conditions in the CO_2 stripper reboiler cannot be changed.

Exploiting the "+/- Principle"

The process modifications discussed in this section illustrate Pinch Technology's "+/- Principle" (illustrated below), which helps to identify and to direct consideration to process changes that will reduce the net hot and cold utility requirements of the system.
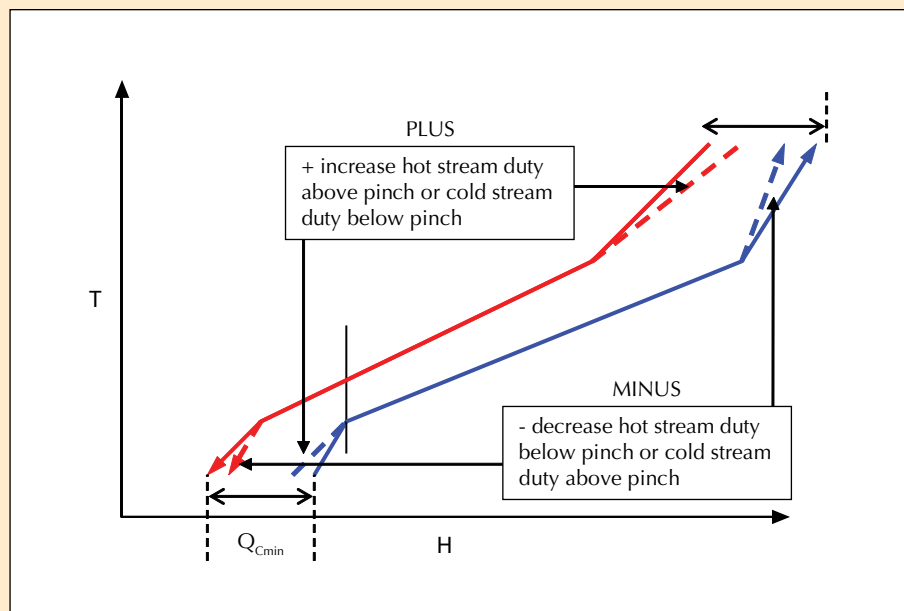
However, it is possible to shift some of the MP process steam duty below the pinch by taking advantage of the fact that water can be vaporized at lower temperatures if added directly to the process feed gas. This process, saturation, occurs because under these circumstances water vaporizes at lower partial pressure than it would as a pure component (i.e. steam). Since the reforming process simply requires the presence of water vapor in the feed gas in a fixed molar ratio, any water not added in the saturation process and still be added by direct steam injection. Further investigation of this opportunity shows that about 35% of the total process steam addition can be accomplished via saturation. Figure 7 shows the grand composite curve for the saturation case.

Figure 8 Grand Composite Curve Showing Impact of Saturator
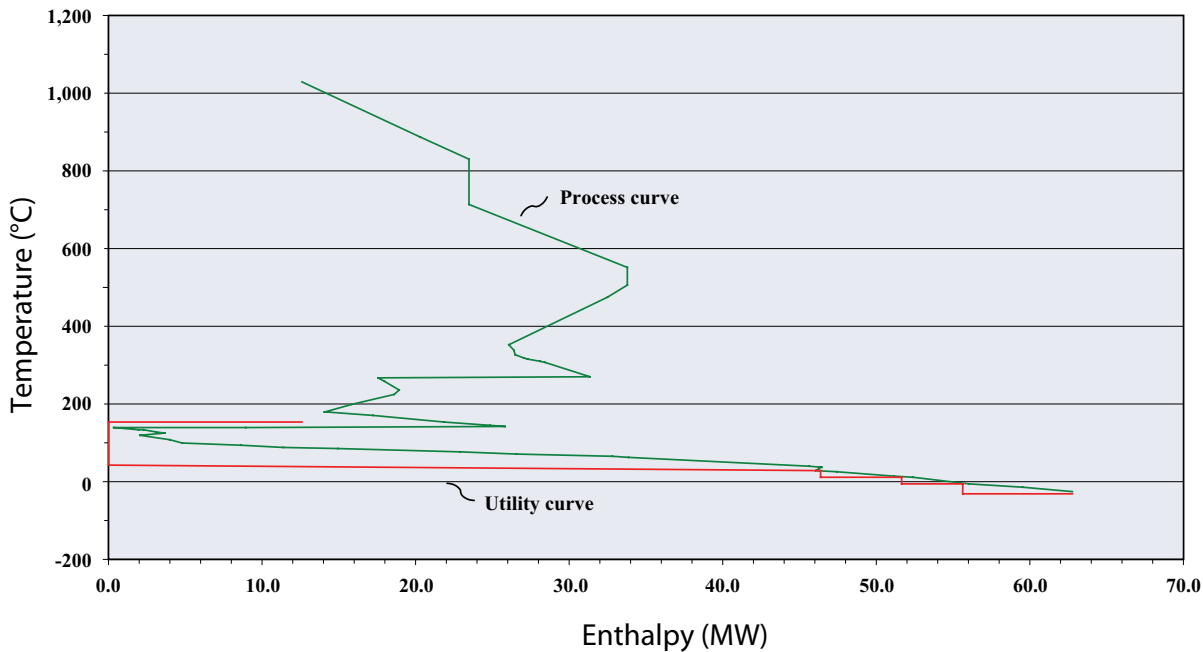
Step 5: Consider alternative retrofit strategies and select the most promising one

Based on the Targeting analysis, the associated identification of cross-pinch heat transfer, and the site context, it was determined that, recovery of additional heat into superheat and feed gas saturation represented good opportunities, and that reformer flue gas was considered the primary heat source.

In this Pinch example, the activity focused on the reformer flue gas, since the remaining cross-pinch heat transfer is in small quantities (<2 MW) in various exchangers throughout the plant. As discussed earlier, its elimination was likely to require numerous equipment and piping changes. In many cases correcting the cross-pinch transfer would require adding surface area to existing services. Such opportunities, while potentially attractive, were considered to be secondary priorities, to be investigated further in subsequent work.

In most instances where energy is available in flue gas, a combustion air preheater can be considered as a project alternative that competes for the same waste heat, and such devices have been incorporated in ammonia plant designs. However, in a retrofit situation, combustion air preheat requires not only a large air – air exchanger, but also significant modifications to the reformer (burner changes, new air ducting).

Further, in this particular case the saturator project offered energy and synergistic environmental benefits including:

- Reduced addition of process steam flow to the feed gas due to the saturator installation.

- Reduced steam flow to the process condensate stripper because a significant portion of the condensate is supplied to the saturator coil.

- Recycle of condensate stripper overheads containing ammonia and methanol.

Overall the expected reduction in steam demand is about 30 T/h. This facilitates shutting down package boilers which currently supply 18 T/h of steam to the ammonia plant, with the balance of the savings coming from backing off auxiliary boiler firing.

	Package Boiler Steam (kg/h)	Auxiliary Boiler Steam (kg/h)	Waste Heat Boiler Steam (kg/h)	Total Steam (kg/h)	Steam to Condensing Turbines (kg/h)
Base Case	Base	Base	Base	Base	Base
Proposed Case	-23,000	-7,000	Base	-30,000	-7,000

Table 5: Impact of Selected Projects on Steam Generation

Other Retrofit Opportunities

Application of Pinch Technology need not (and should not) preclude comprehensive considerations of other energy- and cost-saving retrofit opportunities. Veritech's retrofit analysis of Ammonia Plants has identified (in addition to the Pinch-related opportunities discussed in this example) cost-effective projects in the areas such as:

- Combustion air preheat

- Upgrading compressor and turbine internals to improve efficiency

- Process improvements (Loheat Benfield CO_2 Removal; Make-up gas dehydration)

Step 6: Define and economically evaluate projects to the selected strategy

In this Pinch example, the projects of most interest were:

- Increased HP steam superheat temperature, and

- Installation of a feed gas saturator and associated.

Figure 8 shows a simplified schematic of the overall project.

Increasing the HP steam superheat temperature require replacing the existing superheat coils with larger ones designed for the new, larger duty.

The saturator installation consisted of several key equipment items;

- A new desulfurizer feed-effluent heat exchanger because desulfurization occurs at high temperature (275°C), while the saturator feed must be cold.

- A new saturator coil.

- A knock-out drum to remove carry-over from the saturator coil.

- A pump to supply process condensate to the saturator.

- Associated piping and instrumentation changes.

Note that since the saturator coil is downstream of the superheat coils, the design of the saturator coil is dependent on the design duty of the superheat coils. In an integrated system, this type of interaction is frequently encountered. Process Integration tools allow the designer to understand such interactions and design accordingly.

The resulting primary benefits include:

- Energy use reduction of approximately 2 GJ/st

- Energy cost savings of 3.75 million CAN$/yr

- Total steam demand reduction of 30 T/h

- Shut down package boilers

- An 11% reduction in NO_x, and CO_2 emissions from the site due to fuel savings

The estimated total cost for the project is 5.5 million CAN$, resulting in a simple payback of 1.5 years on the basis of energy savings alone.

Schematic Diagram of Feed Gas Saturator and Superheat Increase Project **Figure 9**
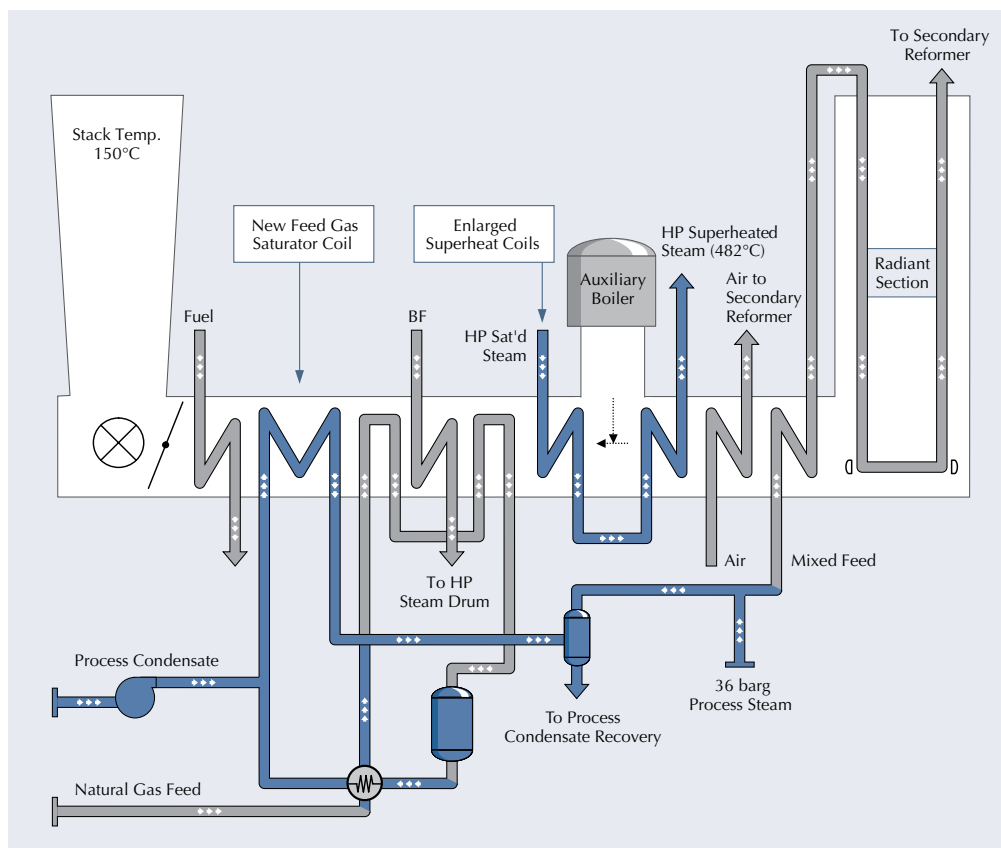
CONCLUSIONS

The application of Pinch analysis can be carried out in a variety of ways and adapted to the specific process and site considerations being investigated. In retrofit applications involving the Ammonia process, examination of the process-utility interactions is a key aspect of the analysis. Good knowledge of the process and its possible alternative configurations - together with the guidance and insights provided by the Composite and Grand Composite Curves - can identify economically attractive retrofit projects. Projects identified through the Pinch aalysis must be carefully evaluated in the context of site steam balance considerations to verify that the expected energy savings will be realized.

The CanmetENERGY research centre in Varennes is one of three research and innovation centres of Natural Resources Canada (NRCan). CanmetENERGY in Varennes designs and implements technological solutions, and disseminates knowledge in order to produce and use energy in ways that are more efficient and sustainable, to reduce greenhouse gas (GHG) and other air emissions, and to improve innovation capabilities of targeted sectors of the Canadian economy.

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