HYDROGEN SYSTEM OPTIMIZATION STUDY FOR BP CARSON REFINERY (LOS ANGELES)

CONSULTANT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

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July 2001
500-03-061C

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Hydrogen System Optimization Study for BP Carson Refinery (Los Angeles)

1006164

Final Report, July 2001

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CITATIONS

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This report describes research jointly sponsored by EPRI and the California Energy Commission.

The report is a corporate document that should be cited in the literature in the following manner:

Hydrogen System Optimization Study for BP Carson Refinery (Los Angeles), EPRI, Palo Alto, CA, California Energy Commission, Sacramento, CA: 2001. 1006164.

REPORT SUMMARY

New product specifications and the increased processing of heavier crudes mean that refiners are seeing a rise in hydrogen consumption per barrel of crude oil. Economic incentives for optimising the hydrogen system lie not only in reduced operating costs of hydrogen plant, but are particularly strong when optimised hydrogen usage can eliminate or postpone investment in new hydrogen plant. This project evaluated the scope for hydrogen savings at BP's Carson facility in Los Angeles, California.

Background

The effective management and efficient integration of hydrogen and off-gases are becoming increasingly important tasks for many of the world's oil refiners and petrochemicals producers. Legislation to reduce global emissions of greenhouse gases is enforcing the production of low-sulphur fuels with the result that hydrogen is in increasing demand in refineries. New product specifications and the increased processing of heavier crudes mean that BP, like other refiners, is seeing a rise in hydrogen consumption per barrel of crude oil. This trend is set to continue and, as a result, improving hydrogen management at refineries is becoming increasingly important.

Objectives

- To reduce refinery hydrogen system costs
- To improve hydrogen management in refinery processes
- To achieve capacity debottlenecking
- To improve energy efficiency and environmental impact.

Approach

The project team developed an investment strategy using HydrogenPinch™ Analysis techniques to identify and rank projects to improve refinery hydrogen system costs and increase efficiency at the BP Carson Refinery in Los Angeles, California. The method is based on Pinch Technology, which seeks to determine the minimum, or "target," hydrogen make-up to meet the demands of all process units in a network by matching hydrogen sources with appropriate sinks. Optimization software determines the hydrogen system routings that minimize the operating cost of the system. These techniques are complemented by a sensitivity analysis, which identifies both the process units where a decrease in hydrogen purity offers potential for operating cost savings and the units where an increase in hydrogen purity can be achieved at lowest cost. This is particularly important for achieving production and yield benefits.

Results

Only minimal scope for "easy win" projects was identified at the Carson Refinery, since existing integration and recovery measures at the site were already reasonably extensive. The amount of H_2 burned as fuel is small; and the existing production and regeneration facilities are operating at, or close to, their limits. Therefore, only small savings can be expected if these existing constraints are accepted as given. Significant potential for improvement was identified in relation to three key areas:

- Operation of an existing Membrane Recovery Unit (MRU) and the availability of a second, currently unused, MRU. Project combinations were identified that utilize existing equipment with some additional piping. These options could achieve savings of up to $1.0 million per year. More complex modifications could increase this saving to $1.3million per year.
- Increasing capacity of No. 1 H_2 plant. Iincreasing the capacity of the plant to its nameplate level opens up significant potential to replace purchased hydrogen.
- Reducing feed purity to a number of processes including hydrodesulfurization**,** isomerization and benzene saturation units in the South plant. Feed purity can reportedly be reduced to 85% without adversely affecting the operation of the process. Projects were identified to exploit the full capacity of the No. 1 H_2 plant and lower feed quality to the identified unit, resulting in savings of up to $3.4million per year.

Comment: Alan/Doug, can you pls expand this? For ex: Membrane separation equipment called PRISM (it will be good to expand this also……

Comment: Alan/Doug, pls expand this also….

The maximum saving achievable by combining projects is $4.5million per year. To realise this saving, a new H_2 compressor would be required. However, it is expected that a slightly smaller saving of $3.8million per year would be achievable by making extensive use of existing pipework and available capacity in two existing compressors. This second option also offers significant production benefits by increasing hydrogen purity to key refinery processes. The project incentives have been determined using a model of the hydrogen supply system. Capital cost estimates were not carried out for this report. However, local contractors can carry out detailed engineering for the packages described in the report.

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EPRI Perspective

Hydrogen Pinch evaluation is applicable across all refineries and other hydrogen users, resulting in energy savings and environmental mitigation. In this study, a global energy balance has shown that the proposed projects result in a net fuel saving and a corresponding reduction in CO_2 emissions. In general, however, a net increase in power consumption is predicted. The project combination corresponding to the maximum saving will reduce fuel consumption by 33 MMBtu/h and CO_2 emissions by 36 MMlb per year. Power consumption for this case would rise by 920 kW.

Keywords

Pinch technology
Energy efficiency
Oil refineries
Hydrogen
Global warming

ABSTRACT

The HydrogenPinch Analysis carried out by Linnhoff March for the BP Carson refinery in Los Angeles, California, resulted in the development of an investment strategy RoadMap detailing opportunities for:

- Reducing refinery hydrogen system operating costs
- Improving hydrogen management in refinery processes
- Capacity debottlenecking
- Improving energy efficiency and environmental impact.

The RoadMap highlights compatible project combinations with the potential to save up to $4.5 million per year. In terms of the global energy balance, investment routes can be selected that will reduce consumption of fuel by 11-39 MMBtu/h resulting in a reduction in CO2 emissions of 12-42 MMlb per year. In general, however, power consumption for these combinations will rise (860-1800 kW).

The HydrogenPinch approach demonstrated the ability to identify non-obvious project solutions in a systematic, step-wise way. Projects can thus be ranked from zero/low cost opportunities to sizeable investment alternatives.

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1 INTRODUCTION

BP operates a major full-conversion refinery at its Carson facility in Los Angeles, California. New product specifications and the increased processing of heavier crudes mean that BP, like other refiners, is seeing a rise in hydrogen consumption per barrel of crude oil. This trend is set to continue and, as a result, improving the refinery's hydrogen management is becoming increasingly important.

With the support of EPRI, BP commissioned Linnhoff March to carry out a HydrogenPinch project to evaluate the scope for hydrogen savings and to generate alternative flowsheets that would realise those savings.

Economic incentives for optimising the hydrogen system lie not only in reduced operating costs of hydrogen plant, but are particularly strong when optimised hydrogen usage can eliminate or postpone investment in new hydrogen plant. With rising refinery demands, this scenario is becoming increasingly relevant. Additionally, improvements in gas quality reaching the processing units can increase production and/or yield with the associated economic benefits that this brings.

The main focus of the work was the hydrogen system rather than the processing units. The results presented in this report are therefore in terms of hydrogen cost. However, where it was identified that proposed modifications would positively impact on the processing units this has been documented.

The Linnhoff March proprietary HydrogenPinch technology and software formed the basis of the study. The tools were used to:

- Aid in collecting data and developing the hydrogen balance
- Generate and simulate ideas for modifications to the complex hydrogen network taking into account the availability of spare equipment and spare capacity in existing equipment
- Structure the analysis into systematic targeting stages.

2 OBJECTIVES

The effective management and efficient integration of hydrogen and off-gases are becoming increasingly important tasks for many of the world's oil refiners and petrochemical producers. Legislation to reduce global emissions of greenhouse gases is enforcing the production of low-sulphur fuels and this means that hydrogen is in increasing demand in refineries. It is estimated that between 50% and 70% of existing refineries are either already short of hydrogen or will be in the next few years.

Linnhoff March was contracted by EPRI to carry out an analysis of the BP Carson Refinery using HydrogenPinch technology with the objective of developing decision support information in the form of an investment strategy RoadMap. This RoadMap details opportunities for:

- Reducing refinery hydrogen system costs
- Improving hydrogen management in refinery processes
- Highlighting potential for capacity debottlenecking
- Improving energy efficiency and environmental impact.

The RoadMap puts BP in a position to select the most economical route that best meets its criteria for future H2 supply.

The work was divided into two phases:

- Phase 1: for initial targeting, to quantify the potential for improving H2 utilization;
- Phase 2: for project development, to turn the identified potential into feasible projects that will achieve the targets in the most cost-effective manner.

2.1 Targeting Phase

The targeting phase is a systematic review of the refinery hydrogen system to establish its limitations and flexibilities and the potential improvements that can be achieved.

The basis for this review and subsequent project development is a consistent H2 balance for the site. This consists of a model that incorporates all hydrogen producers and consumers with their associated conditions of supply/production (flow, purity, pressure) and connectivity. The model includes existing levels of supply and demand as well as predicted future levels. In the particular case of the BP Carson refinery, the model was required to include the No.2 Light Hydro unit, which is being considered for the future.

The potential for improvement in the system, or “target”, is determined in a series of steps corresponding to increasing degree of modification to the H2 system. Initially, only simple piping modifications are considered, while ultimately, the analysis considers installation of new compressors plus changes to the process conditions (e.g. H2 purity in process feeds). In this way, “easy wins” requiring little or no modification can be identified first, while more complex projects follow at later stages, when more and more constraints are relaxed. This procedure also identifies the key decisions that form the basis of the investment RoadMap.

Specific objectives of the targeting phase at the BP Carson refinery were to:

- Understand limitations and flexibilities of H2 usage
- Develop H2 balance models for future H2 demand levels
- Identify short-term “easy win” projects
- Quantify the potential to improve H2 utilization in a series of stepped targets, incorporating different degrees of system modification.

2.2 Project Development Phase

This phase involves a detailed review of the targets to develop the most cost-effective projects that will achieve, as closely as is technically and economically feasible, the theoretical level of savings that were identified in Phase 1. The procedure invariably identifies a number of alternatives that have an impact on, or are dependent on, strategic site development issues. These alternatives thus determine the final form of the RoadMap.

Specific objectives of the project development phase at the BP Carson refinery are:

- Systematic identification of key inefficiencies and bottlenecks in the system
- Evaluation of all integration opportunities and alternatives for H2 re-use and regeneration that lead to improved plant operability and higher system efficiency
- Conceptual design and economic evaluation of projects to meet the targets and overcome bottlenecks
- Development of an investment RoadMap highlighting benefits of alternative strategies in terms of operating cost, capital avoidance, environmental impact, operability, and debottlenecking.

3
DATA BASIS

BP supplied the base-case data used for the analysis of the hydrogen system. The balance corresponds to a case where all refinery units (including the planned No.2 Light Hydro unit) are fully operational and running in steady state.

The supplied data formed a very good basis for the preparation of the overall site H_2 balance. Additional information was only required to establish the internal flows within certain process units. Linnhoff March's proprietary software was used to finalise the balance.

3.1 Hydrogen Producers and Consumers

The BP Carson refinery site is divided geographically into North and South plants with process units in both areas. The non-utility refinery process units can be divided into hydrogen producers and consumers as follows:

Producers

- No. 1 reformer (North)
- No. 2 reformer (North)
- No. 3 reformer (North)

Consumers

- FFHDS (North)
- HCK (North)
- Jet (North)
- Mid Barrel (North)
- No. 1 Light Hydro (North)
- No. 2 Light Hydro (South -planned)
- NHDS/Isom/Bensat (South)

For the purposes of the analysis, the hydrogen consumers were defined as closely as possible according to the scheme shown in Figure 3-1.

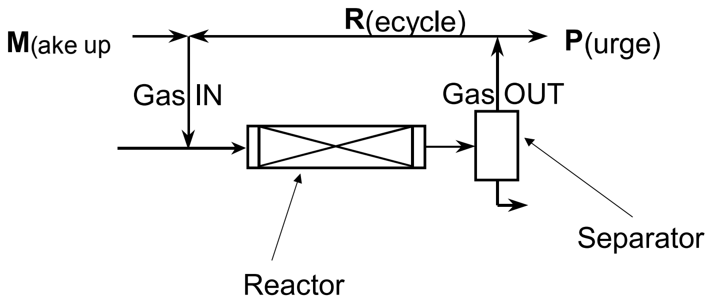

Figure 3-1
General Definition of Process Unit Hydrogen Balance

The main part of the process, where H_2 is only present in a mixture with feeds and products (i.e. in reactors and separators), is modelled as a black box. Once hydrogen is removed from the process streams for recycle, purge or re-use, it is effectively available for integration with other processes. Only then is it represented as a hydrogen stream in the balance.

The data required to describe base-case (normal) operation of the plant is:

- Flow (**M**ake up, **R**ecycle and **P**urge)
- Pressure
- Composition at the inlet (IN) and outlet (OUT) (molar/volume basis)
  - H_2
  - C_1 - C_3 etc.

In most cases, model development is iterative, with the software indicating where additional measurements are needed. However, in this case, the initial data was good, requiring no additional data gathering. This saved a large amount of time during the study.

Note that the NHDS, Bensat, and Isom units have been combined in a simplified black box representation. Because the interconnecting streams within this unit must remain unchanged, the analysis considers only the main inlet and outlet streams.

3.2 Hydrogen System Utilities

The HydrogenPinch approach minimises operating cost within the constraints of the system. The cost of hydrogen supply, treatment of off-gas and H_2 regeneration are a key part of this.

Hydrogen is supplied to the processes from two hydrogen plants plus imported purchased hydrogen.

- No.1 H_2 plant is located in and supplies to the North area. The plant is fed with natural gas as well as concentrated waste gas from the PRISM regeneration unit. The plant is currently operating ten percent below its name-plate capacity, producing hydrogen at 95% purity.
- No. 2 plant is located in the South area but supplies mainly the North area. The plant is currently operating at its maximum capacity and produces H_2 with a purity of 99.9%
- At present, purchased H_2 is imported to the South area, where its high pressure means that it can be used to supply the units there without additional compression. Gas is supplied at 800psig and 99.9% purity.

Outlet streams from the processes that cannot be used as feedstock to other processes have three possible uses:

- Feedstock for the hydrogen plants
- Fuel gas
- Feed for the PRISM unit, which produces a hydrogen-rich permeate stream and a concentrated waste stream. The waste stream can itself be supplied to the hydrogen plants as feedstock.

In the existing H2 system a single PRISM membrane regeneration unit is currently in operation. A second PRISM unit is available but unused. This second unit is known as the “Idle PRISM”.

PRISM performance has been modelled to reflect existing operation. This relates hydrogen recovery and removal ratio to the feed. It is recognised, however, that higher impurity levels in the feed will result in condensation of C3+ components in the gas stream. This limits both the existing PRISM unit and utilisation of the idle unit.

3.3 Base-Case Operating Costs

In addition to costs of utilities, such as hydrogen make-up, costs are associated with the fuel gas sink, gas regeneration and compression. It has been assumed here that regeneration costs can be represented entirely by the cost of compressing the feed.

In the evaluation, a value was assigned to fuel gas corresponding to the heat of combustion of H_2 ($825/MMSCF). Thus, if less H_2 is fed to the fuel gas system, more natural gas must be used to provide the equivalent heating duty. For example, a fuel gas stream of 1.5 MMSCFD and 17% H_2 has a value of:

$$1.5 * 0.17 * 823 = 210 \text{ \$/day}$$

The hydrogen that is fed to the H_2 plants could be expected to have some value as a feedstock. However, within the refinery it is regarded as economically beneficial to reduce the hydrogen in this stream (i.e. the hydrogen has a negative value in this context). Any H_2 in the feed flows straight through the units and only uses up valuable capacity and requires unnecessary heating/cooling. Because of the difficulty of assigning a value to this gas, a conservative approach was adopted assuming a nominal small negative value. The targets thus produced still aim to reduce this H_2 flow, but no economic significance is attached to it.

To fully account for compression costs, a variable cost is assigned to the link between each source and sink of hydrogen. This not only accounts for existing compressors but also allows the HydrogenPinch optimisation procedure to determine where an additional compressor could be installed cost effectively. These costs are calculated based on the following equation:

$$Power = P_1 * V_1 * \ln(P_2/P_1) * C$$

Where: V_1 = actual volume of 1SCF in CF
P_1 = inlet pressure (psia)
P_2 = outlet pressure (psia)
C = site-specific derived constant = 3.51
Power = compressor power (kW/MMSCFD throughput)

The constant C was derived from a best-fit calculation based on reference data provided for five key compressors on the site. The calculated powers do not exactly match real-life powers because the use of a single constant does not allow for properties such as changing efficiency. However, the approach works well as it allows for the possibilities of connecting new streams to existing compressors and exploiting available pressure to avoid the need for compression.

Utility	Cost $/MMSCF
No. 1 H2 Plant	Base
No. 2 H2 Plant	1.1 x Base
Purchased H2	2 x Base
Fuel gas (H2 content)	823
Compression power	0.04 $/kWhr

3.4 Base-Case Hydrogen Balance

Figure 3-2 shows the balance that was developed from the base-case data. The figure shows the connectivity of the process units and the use of H_2 headers. The main headers are:

- High pressure – 1760psig-1570psig feeding the FFHDS and HCK units
- Medium pressure – 735psig feeding the South plant units
- Low pressure – 200psig fed by the Jet, Nos.1-3 reformers, PRISM and No. 2 Light Hydro, and feeding the Tail Gas, Mid Barrel and A/B compressors
- Very Low pressure – 100psig feeding the PRISM and fuel gas.

This balance is a snapshot of operation, assuming that all units are running at steady state. It serves as the basis for calculating the savings. The operating costs (incl. compression cost) for this case is **$54.7 million per year**.

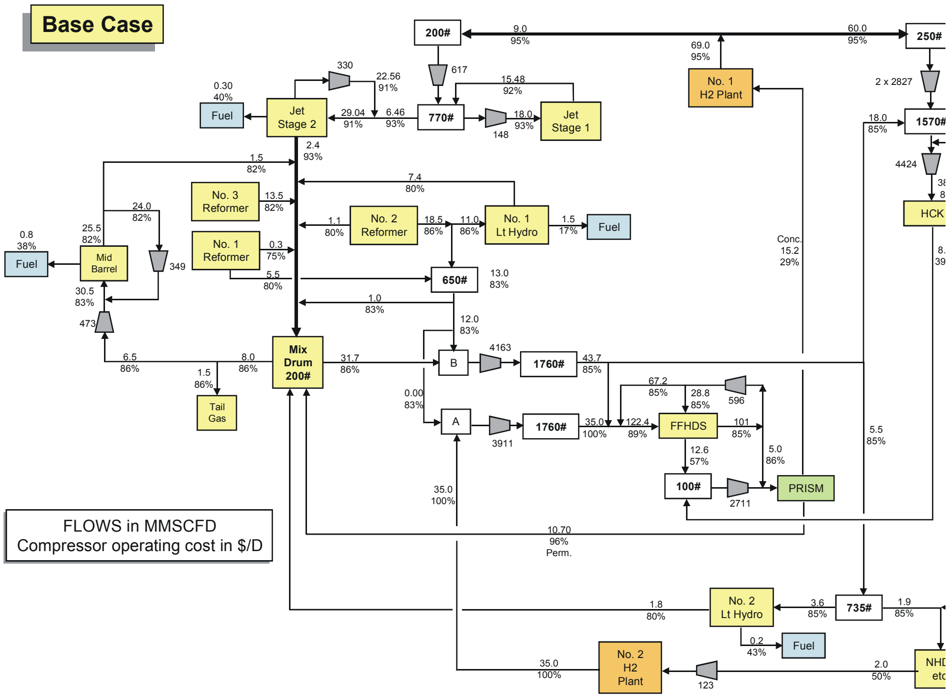

Figure 3-2
Base Case Hydrogen Balance

3.5 Limitations and Opportunities

Figure 3-3 shows a schematic drawing of the refinery, which illustrates a number of the constraints that were identified during this project.

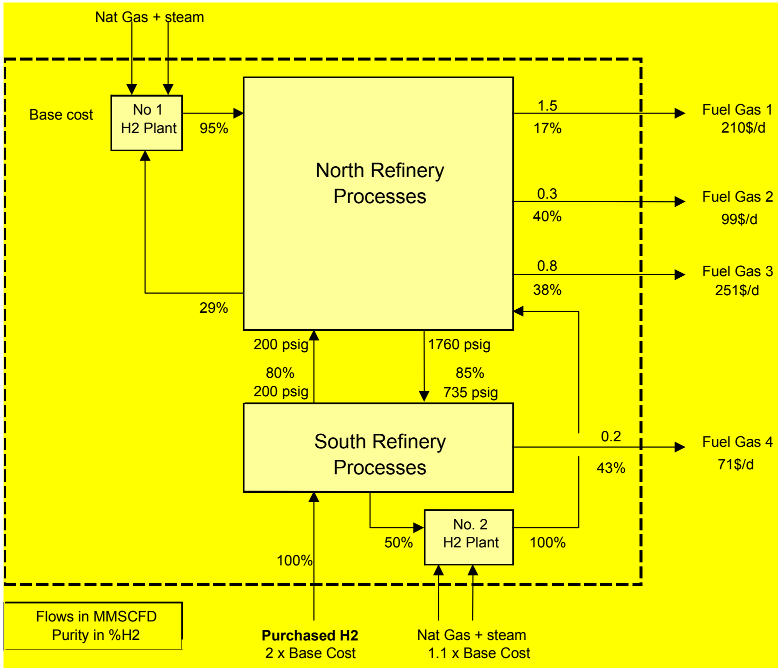

Figure 3-3
Schematic Hydrogen Balance

The diagram shows that the value of H_2 going to fuel gas is very small. Therefore, any absolute H_2 savings will, by balance, be equally small. In fact, if all of it can be recovered, there would only be a saving of $630 per day or $223,000 p.a.

The diagram also shows the three sources of make-up hydrogen - two H_2 plants and purchased hydrogen. The internal make-up sources are considerably cheaper than purchased H_2. However, as the two H_2 plants are operating at or near maximum capacity, there is also little or no scope to switch between utility levels (between the different sources).

There is one stream that might be exploited to give savings. The PRISM concentrate that is returned to the No. 1 H_2 plant has no value, so recovery of this stream does not represent a saving in itself. However, if hydrogen can be recovered from this stream at a purity that can be used within the refinery, this will reduce the amount of make-up that is required.

This stream carries only 29% H_2 and can therefore not be used directly in any other unit. To realise a saving by recovering its hydrogen, the capacity of the PRISM must be improved. At present, performance is limited by the level of impurity in the unit feed. Higher hydrocarbon concentrations than in current operation would lead to condensation on the membrane, reducing its effectiveness. Since recovering more hydrogen from the concentrate means that, by default, the concentration of impurity increases, it can be seen that the problem of condensation must be addressed if the existing or idle PRISM units are to be used for this purpose. This can be achieved in a number of ways:

- Operate the idle PRISM unit at low pressure downstream of the existing unit, thereby avoiding the hydrocarbon dew point
- Use chilling to cool the PRISM feed and condense the heavier impurities. When the gas is heated to its normal feed temperature, it will be further from the hydrocarbon dew point.

The total H_2 content of the concentrate stream is 4.4 MMSCFD. The maximum saving corresponds to complete recovery and reducing generation in the No. 1 H_2 plant ($1.6million p.a.) or H_2 import ($3.2million p.a.). However, it will not be possible to recover the entire hydrogen content of the concentrate stream by the means outlined above and any additional recovery will be accompanied by other costs such as refrigeration or compression. The savings will therefore be significantly less than the maximum.

To summarise the above points, if the H_2 system constraints are accepted as given, potential for improvement will be limited.

- Absolute hydrogen savings by recovery from fuel gas will be very small
- Savings are limited from switching between utility levels, since the H_2 plants are currently operated at or near maximum capacity
- Improving the regeneration capability of the PRISM units opens up potential for recovering H_2 from the PRISM concentrate.
- In order to make significant savings, therefore, it will be necessary to identify and exploit any flexibility in the system that can be achieved by changing process conditions. Two key parameters identified during the course of this work are:
- The nameplate capacity of the No. 1 H_2 plant is ten percent higher than the current maximum achievable throughput, but could be increased to the nameplate capacity with some relatively small investment. This additional generation capacity is at the lowest cost level. If it can somehow be exploited to replace imported hydrogen, a maximum saving of $3.9million p.a. is possible
- The feed purity to the NHDS/Isom/Bensat units in the South plant is much higher than required. At present, the feed is 98% H_2, principally from purchased imported H_2. This can potentially be reduced to 85% without adversely affecting the operation of the processes.

A further flexibility identified by BP was the availability of a spare compressor. Without this spare unit, any attempt to increase hydrogen recovery that would require additional compression would incur a significant investment cost. Considering the compressor in the analysis therefore opens up further potential for cost-effective recovery.

The most significant constraint to be incorporated in the analysis is the geographical separation of the North and South plants. The large distance makes the cost of new connections between the areas almost prohibitive. It was therefore important to identify potential for improvement that would require no additional piping links between the North and South plants.

4
TARGETING RESULTS

Initially, three targets were defined. However, interactions between projects made the boundaries between phases increasingly unclear, so additional steps were included. The original targets 1, 2 & 3 were re-defined as follows:

- Target 0 – identifying potential for improvement without any additional equipment, e.g. reducing compression costs by adjusting letdown flows
- Target 1 – determining savings potential from simple repiping projects
- Target 2a – determining the benefit of exploiting existing spare equipment (PRISM and compressor)
- Target 2b – identifying scope for improvement by addition of new equipment, e.g. compressors, headers, N/S refinery links
- Target 3 – Assessing the potential benefits of changing process conditions (including specific changes proposed by BP).

In the following sections, the target savings for each step are described and the projects to achieve these savings are listed.

4.1 Target 0

The benefits defined for all projects in this report include not only the benefits from the infrastructure changes described but also the benefits from optimising the letdown flows around the system to fit best with the new set-up.

As a starting point, it is necessary to calculate how much can be saved in the system without any investment in new equipment, so that the incremental benefit resulting from investment can be fully appreciated. It is, of course, necessary to address the impact on the operability of the plant resulting from these changes.

There are three letdowns on the plant:

- 1760 psig to 1570 psig
- 1760 psig to 735 psig
- 650 psig to 200 psig

Using the optimiser to assess these flows shows that the 650 to 200 psig letdown can be eliminated and that this is the major source of the saving. Minor adjustments can be made to the other letdowns.

The saving that results is almost entirely associated with a reduction in compressor power. This has been named Project 1.

Initial Savings Estimate:
$72 per day or $26,000 per year

This can be regarded as a base case for all other savings, since this is the optimal configuration of the letdowns. All other targets should be compared with these small savings to obtain a true picture of the savings resulting from more complex modifications.

4.2 Target 1

The targeting phase of the work determines the theoretical minimum hydrogen system cost, which allows a review of potential at each stage. The project development phase can then be tailored once the size of this potential is known.

Figure 4-1 shows the hydrogen composite curves for the BP Carson refinery. The curves relate hydrogen sources (red) with hydrogen sinks (blue) in the target configuration. The target represents the theoretical best fit of process sources to sinks.

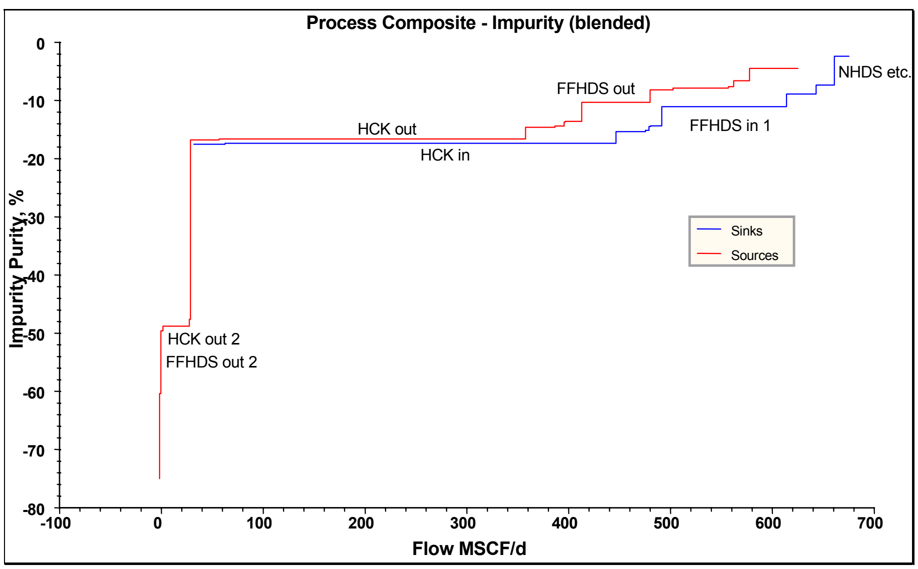

Figure 4-1
Hydrogen Composite Curves

In practice, achieving this target would generally require a high degree of complexity in the piping system and a large number of connections with small flows. In most cases, therefore, achieving the target savings is unlikely, but closely approaching them is possible.

The composite curves show that the HCK unit dictates minimum hydrogen consumption. This minimum, or target, is greater than 99% of existing utility consumption, indicating that the potential for improvement achievable by simple repiping is less than 1% of the current operating cost.

Note that Target 1 was constrained to allow new piping within, but not between, the North and South plants.

Two projects were identified from Target 1:

- Project 2: Feed fuel gas from No. 1 Light Hydro to the PRISM
  Initial Savings Estimate: $390 per day or $138,000 per year
- Project 3: Improve H2 Recovery at the Prism Unit
  Initial Savings Estimate: $633 per day or $224,000 per year

These projects are essentially competing for the same savings opportunity and the incremental benefit from combining the two ideas is negligible. Therefore, the two projects can be considered to be mutually exclusive.

4.3 Target 2

The curves in Figure 4-1 indicate that, to improve savings, streams of low purity must be "upgraded" to at least the concentration of the HCK feed. This can be achieved by increasing regeneration capability, for example by condensing heavies from the PRISM feed, or by utilising the idle PRISM unit (considered mainly as part of Target 2).

Target 2 was subdivided to consider use of existing spare equipment (2a) and installation of new equipment (2b).

Three projects were identified from **Target 2a**:

- Project 4: Idle PRISM fed with PRISM conc.
  Initial Savings Estimate: $2026 per day or $717,000 per year
- Project 5: Use Spare Compressor
  Initial Savings Estimate: $88 per day or $31,000 per year
- Project 6: Idle PRISM operating at lower pressure
  Initial Savings Estimate: $844 per day or $299,000 per year

The best project in terms of financial savings is clearly Project 4, which brings the Idle PRISM on-line. Thus, when considering combinations of projects, this project should be included, although it is also worth further investigating the alternative low-pressure operation of the Idle

PRISM (Project 6). The operational changes described in Project 1 are also included as a matter of course.

Projects 2 and 3 both involve addition of a low-purity stream into the PRISM unit, which means that the purity of the PRISM concentrate stream drops by about 4%. This dramatically affects Project 4, as it increases the amount of dilution gas required to increase the inlet purity to the Idle PRISM to its limit of 52%. Following this through the system, the difference between the Idle PRISM permeate and the dilution gas flowrates reduces and the overall combined project saving drops to a value below that achievable by Project 4 alone. Project 4 can therefore be considered mutually exclusive to Projects 2 and 3.

Projects 2 and 3 also have a negative impact on Project 6 for similar reasons in that they drive down the purities in the PRISM/Idle PRISM units and ultimately eliminate any benefit.

Project 5, on the other hand, appeared unattractive due to the low savings that could be achieved as a result of the purity constraints in the system. However, implementing Project 4 or Project 6 changes this situation because these projects increases the amount of purer H_2 available by the introduction of additional permeate flow.

The most attractive combinations have been defined as two separate projects:

- Project 7: Projects 5 and 6 Combined
  Initial Savings Estimate: $2121 per day or $751,000 per year
- Project 8: Projects 4 and 5 Combined
  Initial Savings Estimate: $3170 per day or $1.1million per year

In Project 4, the No.2 H_2 plant production is reduced by 1.4 MMSCFD. An additional consideration at this point would be to fully utilise of this plant to reduce the amount of purchased H_2. This would require installation of a new compressor to feed the additional gas into the 735# header. In conjunction with Project 4 this would be worth $1230 per day in purchased hydrogen, or $500,000 per year.

For **Target 2b**, a single project was identified:

- Project 9: Upgrade Mix Drum and use Idle PRISM
  Initial Savings Estimate: $3670 per day or $1.3million per year

While this project would result in comparatively large savings, it is a relatively complex design. It would therefore be expected to have a correspondingly high investment cost.

The most significant result is the benefit of increasing hydrogen purity in the existing 200psig mix drum to 91.6% purity. Apart from allowing increased use of this gas in the South plant, this results in higher purity hydrogen being fed to the No.2 Light Hydro, Mid Barrel and Tail Gas units. Potentially, this could result in benefits to production and yield in these units. This has not been included in the estimated savings.

Considerations that could add to the attractiveness of Project 9 are:

- It would use the Idle PRISM in a location near the HCK unit. This is where it was located in the past and where a footprint for the equipment still exists.
- Sending the stream from Reformer 1 to the HCK feed compressor inlet, instead of to the 650psig header, implies less need for compression inside the Reformer 1 black box.

Project 9 includes some of the elements of projects 2-6 so can be considered mutually exclusive to all of them.

4.4 Target 3

Target 3 investigates the potential for improving the hydrogen system by modifying key process parameters, e.g. unit feed purities. A sensitivity analysis was used to identify the key units. Figure 4-2 shows the results of this analysis.

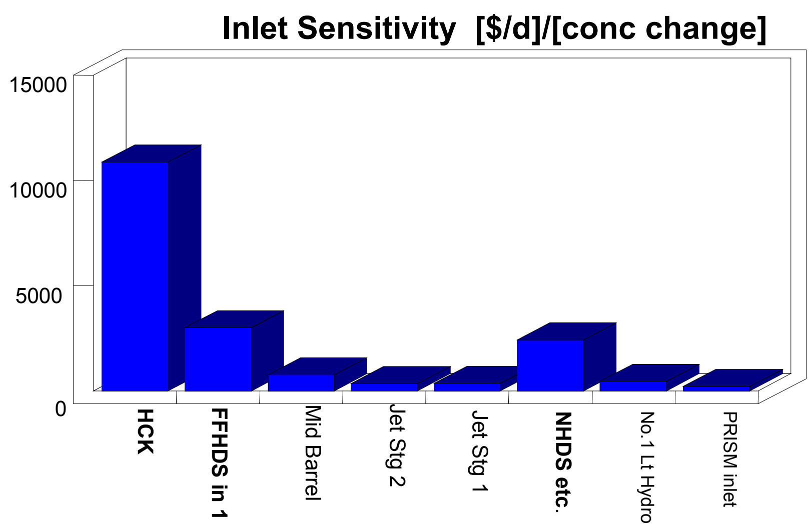

Figure 4-2
Results of Sensitivity Analysis

The bar graph shows the effect on hydrogen system operating cost of a marginal impurity increase in the feed to each unit. Note that this does not take into account any production/yield effects of the increase in impurity.

In this case, the two units where a decrease in hydrogen purity would result in the largest potential savings are the HCK and the FFHDS units. However, BP are more interested in *increasing* hydrogen purity in these units to improve production. In this regard, the plot shows that increasing hydrogen purity to these units is likely to cause the highest operating cost increase of all units on site.

The next most promising unit is the NHDS/Isom/Bensat area in the South plant. As long as reducing feed purity to these units does not adversely affect their operation, it is likely to offer substantial benefits in the operating cost of the hydrogen system.

At present, this (combined) unit is operated with a feed purity of 98% H_2. Discussions with BP indicated that a purity as low as 85% would still be acceptable and not compromise yield/production. Currently, the unit uses a substantial amount of make-up from purchased H_2, which is at the correct pressure to feed the units. The No. 2 H_2 plant product is at a much lower pressure, so is more suited to feed the A/B compressors in the North plant. The results of the sensitivity analysis indicate that this configuration should be reviewed.

Figure 4.3 shows the result of repeating the sensitivity analysis after lowering the inlet purity to the NHDS/Isom/Bensat units. The key effect is that the saving that would be achieved in the HCK and FFHDS units by changing the feed purity is now much reduced. Where Figure 4.2 showed a saving in the order of 10,000 $/day from lowering the HCK feed concentration, lowering the feed purity to the NHDS/Isom/Bensat units reduces the potential savings in the HCK to less than 600 $/day for the same modification.

While this shows the potential saving from reducing feed purity to a unit, it can also be interpreted the other way round – to indicate how much it would cost to *increase* the feed purity, as BP would like to do. The result thus shows that modifying the feed purity to the NHDS/Isom/Bensat units should have the beneficial side effect of reducing the cost associated with increased feed purity to the HCK and FFHDS units. There is therefore a double incentive for reducing the NHDS/Isom/Bensat units feed purity:

- Reducing hydrogen system operating cost
- Reducing the cost of feeding purer H_2 to the HCK and FFHDS units.

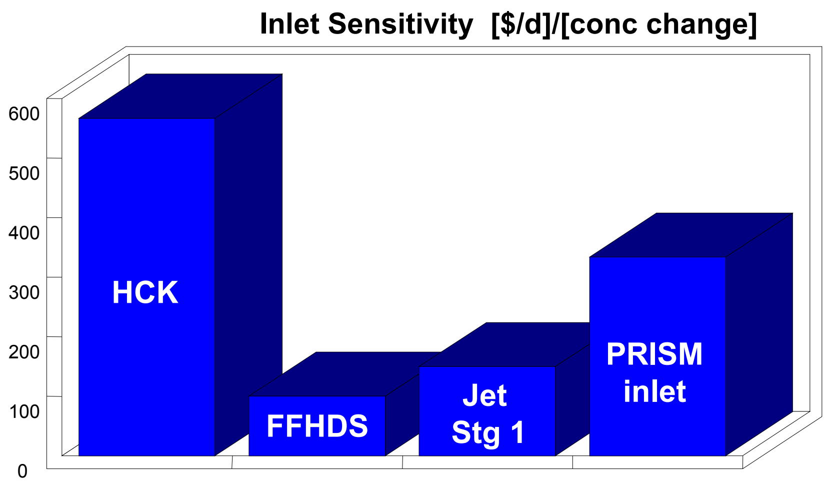

Figure 4-3
Results of Sensitivity Analysis

Three main projects were identified from Target 3:

- Project 10: Feed No. 1 H_2 Plant to 735psig Header
  Initial Savings Estimate: $9493 per day or $3.4million per year
- Project 11: Change "NHDS etc." inlet purity utilising spare compressor
  Initial Savings Estimate: $6426 per day or $2.3million per year
- Project 12: Change "NHDS etc." inlet purity, utilising A/B compressors
  Initial Savings Estimate: $6692 per day or $2.4million per year

All three projects achieve the same end-savings in H_2 make-up by exploiting the additional capacity in No. 1 H_2 plant and a lower feed purity in the NHDS/Isom/Bensat units. They are therefore mutually exclusive.

Project 10 is the most capital intensive, requiring a new compressor and significant new piping from No. 1 H_2 plant to the 735psig header. However, the estimated savings are such that this could be attractive. Also, there appears to be an unused connection from the HCK unit to the 735psig header, which passes by the No.1 H_2 plant and could perhaps be used to transport gas to the South area.

Project 12 has the least capital investment, utilising existing pipework and available capacity in the A/B compressors. The possible disadvantage of this project is that it uses up available capacity, which may impact on required levels of operability and flexibility.

Project 12 in particular has a significant impact on the feed purity to some of the process units. The models used to evaluate savings are conservative and do not evaluate monetary (or other) credits for yield/production improvements. Although, in this case, the feed purity has increased, it has been assumed that the outlet H_2 purity remains unchanged.

An equally valid alternative to the above is to optimise hydrogen use such that the feed purity to the units is unchanged from current operation. In this way, the model is fully consistent with current operating conditions. For example, the improvements proposed in Projects 11 and 12 increase the feed purity to the FFHDS unit. In terms of hydrogen management, the optimum solution is to mix low-purity hydrogen with the higher purity feed to maintain the current feed conditions. In this way, the supply of high-purity hydrogen can be reduced, thus saving H_2 supply costs.

As described in Section 4.3, projects 2, 3, 4 and 6 are mutually exclusive, as they all compete for the same resources. This holds true when they are considered for combination with projects 10 to 12. The combinations are summarised in the table below with the corresponding incremental annual savings (relative to Project 10-12 base case savings).

	Incremental Savings of Project Combinations				
	Base Case	**Project 2**	**Project 3**	**Project 4**	**Project 6**
Base Case	0	$138,000	$224,000	$718,000	$299,000
Project 10	$3.36million	$224,000	$685,000	$1.0million	$1.2million
Project 11	$2.28million	$327,000	$910,000	$756,000	$1.5million
Project 12	$2.37million	$327,000	$855,000	$403,000	$1.5million

The table shows that, generally, the value of Projects 2, 3, 4 and 6 increases when combined with Projects 10-12. This is caused by the lower feed purity of the NHDS/Isom/Bensat unit, which allows the balance to be achieved by make-up coming principally from the No. 1 H_2 plant, thus saving in purchased H_2.

Note that, in the base-case comparison, the incremental saving from installing Project 10 instead of Project 12 is approximately $1million per year. Reviewing the combinations, it can be seen that the incremental benefit of Project 10 becomes less (except combinations with Project 4). Assuming that the most profitable combinations are implemented (i.e. combinations with Project 6), the incremental difference between Project 10 and Project 12 is approximately $700,000 per year. This would have to pay for the new compressor and piping required by Project 10.

Combinations with Project 2

Recycling No. 1 Light Hydro off-gas to the PRISM increases the amount of H_2 recovered and sent to the Mix Drum. The slight increase in purity and flow from the Mix Drum means that the amount of make-up can be reduced.

The feed purity to the NHDS/Isom/Bensat units is achieved by mixing letdown from the 1760# header with 99.9%-pure purchased H_2. If the purity and flow from the mix drum are increased, then more letdown can be used, saving a small amount of purchased H_2. Make-up to the system can also be reduced, saving in the Nos. 1 and 2 H_2 plants.

In the cases where the feed purity is reduced, the purity of gas in the 1760# header is already significantly higher due to make-up from the No. 1 H_2 plant. This means that a number of units are being fed with gas of higher purity than at present. By increasing the flow from the PRISM to the Mix Drum and simultaneously reducing the import of purchased H_2 by the same amount, the purity of the feed to the FFHDS unit reduces slightly. While this results in a net saving in the hydrogen system by reducing expensive import, it will also reduce credits for yield improvements in the FFHDS associated with higher feed purity.

Combinations with Project 3

The base case Project 3 is similarly limited by the NHDS/Isom/Bensat unit feed purity. Increasing the flow and purity in the Mix Drum allows hydrogen make-up from all three sources to be reduced.

Combining Project 3 with Projects 10-12 greatly increases the savings potential, since the flow to the Mix Drum is not limited by the NHDS/Isom/Bensat purity constraint. Instead, only the PRISM feed purity limit of 52% determines the extent to which the PRISM concentrate can be recycled to the inlet.

Again, similar to combinations with Project 2, a proportion of the savings is attributable to reducing the feed purity to the FFHDS unit. The resulting purity is still higher than in the base case, so that production benefits will still be apparent. However, the credits will be reduced compared with Projects 10-12 alone.

Combinations with Project 4

Combinations with Project 4 are the only ones where a general increase in the incremental benefit of the project is *not* observed.

Combination with Project 10 does increase the value of Project 4 in a similar manner to Projects 2 and 3. Increasing the flow of purified gas from the PRISM to the Mix Drum allows a greater flow in the letdown from 1760# to 735#. The result is a lower purity in the feed to the NHDS/Isom/Bensat units (93%), but reduces the make-up required from purchased hydrogen.

Projects 11 and 12 do not show the same increase in value by combination with Project 4. In both cases, additional H_2 make-up from the No. 1 plant increases the amount of gas in the 200# header, which must be compressed in the A and B compressors. In the base case, the compressors are still well within their capacity limits. However, when these projects are combined with Project 4, there is a further demand on the 1760# header to supply dilution gas for the idle PRISM. As a result, the compressor limits are reached, limiting the savings for these particular combinations.

Combinations with Project 6

Combining Projects 10-12 with Project 6 (operating the idle PRISM at lower pressure) results in the largest incremental improvement of all alternatives. This differs from the base case, where Project 4 was clearly the best stand-alone project.

In the base case, the limiting factor in operating the PRISM at lower pressure was the purity required in the 1760# header to supply the FFHDS and NHDS/Isom/Bensat units. Projects 11 and 12 increase the purity of the feed to the FFHDS and have significant flexibility in the feed purity to the NHDS/Isom/Bensat units. Consequently, the flow to the idle PRISM can be increased until the limit in the PRISM feed compressor is reached.

The increased flow from the Mix Drum has a small impact on the FFHDS feed purity (still well above the existing level) and can still achieve the minimum constraint of 85% purity in the feed to the NHDS/Isom/Bensat units.

The most profitable combination in terms of financial savings is Project 10 with Project 6. Comparing Projects 11 and 12, there is little difference in achievable savings. However, the best economic combination of projects is Project 12 with Project 6, particularly considering the lower investment required to realise Project 12. These two combinations have been defined as projects as follows:

- Project 14: Projects 10 and 6 Combined
  Initial Savings Estimate: $12,780 per day or $4.5million per year
- Project 15: Projects 12 and 6 Combined
  Initial Savings Estimate: $10,860 per day or $3.8million per year

4.5 Targeting Summary

The savings identified in Target 0 and Target 1 are small. This is a reflection of the high degree of integration at the Carson refinery, which results in only a small amount of H_2 being purged to fuel gas. The project ideas identified in these targeting stages can save approx. $220,000 per year.

The Target 2a projects address the use of the idle PRISM unit and the spare compressor.

Incorporating the idle PRISM into the network is likely to bring realistic benefits. The most attractive project idea has an estimated savings potential of approx. $1million per year

Target 2a shows that there is only a small benefit from using the spare compressor. While the compressor does not fit with the existing network of headers, or even with individual unit supply and outlet pressures, it has not been completely rejected. The benefits improve when some of the purity constraints are relaxed, in particular the NHDS/Isom/Bensat feed purity.

For Target 2b, some geographical constraints were relaxed, and the optimisation was allowed to consider a new header. While significantly higher savings can be achieved than for Target 2a, the complexity of the required process modifications is proportionally larger.

The most significant finding in Target 2b is the benefit of upgrading the existing 200psig Mix Drum to supply 91.6% purity. This can be achieved by re-routing some of the less pure streams to a separate "header". The savings do not take into account potential benefits to production and yield in the No.2 Light Hydro, Mid Barrel and Tail Gas units resulting from higher purity H_2 in the feeds.

Target 3 identified that the two key issues are the purity requirements of the NHDS/Isom/Bensat units and the links between the North and South areas. At present, a supply at 98% purity is delivered to the NHDS/isom/bensat units, while a feed of approximately 85% purity would be sufficient.

The most direct solution is to export H_2 directly from the No. 1 H_2 plant to the South area. There is sufficient capacity in the plant to replace most of the purchased hydrogen. Based on the relative value of the two hydrogen sources, this would represent a saving of approx. $3.4million per year. In this simplest case, extensive piping and a new compressor would be required.

Two alternatives were identified, the more attractive of which utilises the spare capacity in the A/B compressors to transport H_2 from the No.1 plant to the South area, using existing piping. Here, a saving of $2.4million per year can be achieved.

A feature of this alternative is that part of the supply from the No. 1 H_2 plant is fed to the 200 psig header. As a consequence, the purity of this header would be higher than at present. Since this gas is ultimately supplied to the FFHDS, HCK, and Tail Gas units, as well as the South area plants, the inlet purities to each of these units increases compared with current operation. Particularly for the HCK and FFHDS units, this is likely to provide additional production/yield benefits.

This feature raises a further issue. If the scope of the analysis is held rigidly to improvements in the H_2 system only, production credits are not considered. Increasing the H_2 purity to a unit merely provides an additional degree of freedom in the system that can be exploited.

For example, increasing the purity of the 200psig header means that the inlet to the FFHDS unit increases by 0.4% to 89.7%. Increasing the recycle around the unit reduces the feed purity such that the unit model is once again consistent. The effect is to reduce the make-up flow to the unit and, in turn, the amount of purchased H_2. There is thus an incentive to investigate the limits of the FFHDS recycle compressor.

Note: none of the benefits calculated in this study include any production/yield credits, which may significantly affect the optimum combination of conditions. Furthermore, the basis includes a simplified model of the PRISM. It is recommended that this model be reviewed comparing it with available design and operating data where possible. Again, this may have a significant effect on the chosen investment route.

5
INVESTMENT STRATEGY ROADMAP

The main deliverable of the work is an investment strategy RoadMap, (Figure 5-1) which can be used for decision support by refinery management. The RoadMap details benefits in terms of hydrogen savings, capacity debottlenecking, improved energy efficiency and environmental impact. The RoadMap puts BP in a position to select the most economical route that best meets its criteria for future hydrogen supply.

Of the various project options that are structured in the RoadMap, some will be mutually exclusive (shown in parallel) and some will be interdependent (shown in sequence). Every branch point in the RoadMap represents a management choice for a certain investment route.

The savings shown for the various RoadMap "routes" vary considerably, but are all based only on the costs of fresh H2 and of compression. No economic credits were taken for possible improvements in production and/or yield, caused by improved H2 purity to certain units, even though these may be substantial in some cases. Evaluating such credits was outside the scope of this project.

5.1 Global Issues

Many of the issues currently affecting businesses and legislature are environmentally driven. It is the push for reduced sulphur and aromatics in fuels that is increasing the demand for hydrogen in many refineries. At the same time, public opinion and hence legislation in many countries is demanding improvements in air quality by forcing down emissions of CO_2.

The HydrogenPinch approach contributes to the environmental balance by:

- aiding the continued profitable production of low sulphur fuels
- reducing utility consumption (fuel and power) and hence CO_2 emissions.

The contribution towards efficient fuel production is detailed in the previous sections of this report.

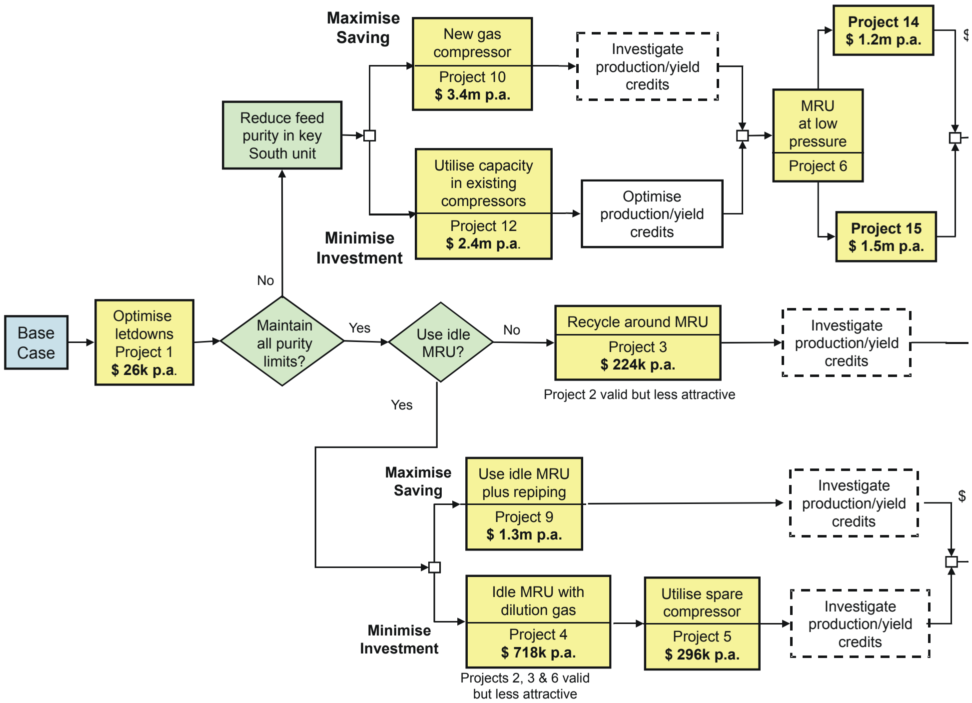

Figure 5-1
A RaodMap for Hydrogen-saving projects at BP Carlson

Improving hydrogen management impacts the global energy balance in 5 ways:

1. Reducing hydrogen production (as a result of increased recovery) will directly save fuel and power. Assuming that hydrogen generation is based on steam reforming of light hydrocarbons, reducing production will save fuel in the reformer reactor, and hence CO_2 emissions. Reducing throughput also saves compression power.
2. The reaction in a steam reformer converts hydrocarbons to hydrogen and CO_2. The hydrocarbons in question can be natural gas or refinery fuel gas. A reduction in throughput therefore positively affects fuel consumption and CO_2 emissions.
3. Recovering hydrogen from refinery fuel gas means that additional fuel will be required (assuming that the net demand for fuel stays constant). This fuel will generally be carbon-based and will result in increased CO_2 emissions.
4. A steam reformer is normally designed to generate steam from waste heat. Reducing hydrogen generation therefore reduces the availability of steam. Assuming that the energy requirements on site are otherwise fixed and constant, this steam must be replaced by steam boiler plant. This will thus have a negative impact on fuel consumption and CO_2 emissions.
5. Power for the site will be generated in steam turbines or gas turbines, either on-site or by a third party supplier. Globally, though, a saving in power will reduce fuel consumption and CO_2 emissions.

5.2 BP Carson Refinery Global Balance

The BP Carson refinery is supplied with hydrogen in part from a third party provider. For this balance, it was assumed that the external supply was based on steam reforming technology.

Generally, the projects developed for the BP Carson refinery result in a net reduction in fuel consumption and CO_2 emissions. However, most projects result in a net increase in power consumption.

The main projects recommended in the RoadMap are summarised as follows:

Project	Description	Annual Saving	Net Fuel Saving (MMBtu/h)	Net Power Saving (kW)	Net CO2 Reduction (MMlb/a)
14 (10+6)	New H2 Compressor + MRU at low pressure	$4.5m	33.1	-921	35.9
15 (12+6)	Utilise available compressor capacity + MRU at low pressure	$3.9m	11.3	-1790	12.3
1+4+5	Optimise letdowns + MRU with dilution gas + spare compressor	$1.0m	38.9	-864	42.2

6
SUMMARY AND CONCLUSIONS

Linnhoff March HydrogenPinch technology was used to identify a number of areas for potential improvement in the BP Carson refinery hydrogen system. A structured step-wise approach was adopted allowing identification and ordering of project ideas from "easy wins" through to more complex projects that impact processing unit operation.

Existing integration and recovery at the site is reasonably extensive. The amount of H_2 being burned as fuel is small, and the existing production and regeneration facilities are operating at, or close to, their limits. As a result, only small savings can be expected if these existing constraints are accepted as given.

Significant potential for improvement was identified in relation to three key areas:

- PRISM operation and the availability of a second PRISM unit.

  Project combinations utilising existing equipment with some additional piping were identified that could achieve up to $1.0m per year savings. More complex modifications could increase this saving to $1.3million per year.

- Capacity of No. 1 H2 plant.

  Increasing the capacity of the plant to its name-plate level opens up significant potential to replace purchased hydrogen.

- Feed purity to the NHDS/Isom/Bensat units in the South plant.

  The feed purity can potentially be reduced to 85% without adversely affecting the operation of the process. Projects were identified to exploit the full No. 1 H2 plant capacity and lower feed quality, giving savings of up to $3.4million per year.

The maximum saving achievable by combining projects is **$4.5million per year**. To realise this saving a new H_2 compressor would be required. However, it is expected that a slightly smaller saving of **$3.8million per year** would be achievable by making extensive use of existing pipework and available capacity in the A/B compressors.

The project incentives have been determined using a model of the hydrogen supply system. Capital cost estimates have not been carried out within this project. However, detailed engineering for the packages described in this report can be carried out by local contractor.

In addition to the identified improvements in hydrogen supply, the project combinations result in increased hydrogen purity to a number of units including the FFHDS. This offers scope for additional savings in production/yield. These benefits have not been evaluated in this work. It is recommended that the units are simulated to determine these additional savings.

An investment RoadMap has been developed, detailing alternative implementation routes of compatible project combinations and their benefits in terms of operating cost, capital avoidance, environmental impact, operability, and debottlenecking.

Hydrogen System Optimization Study for BP Carson Refinery (Los Angeles)

1006164

Final Report, July 2001

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This report describes research jointly sponsored by EPRI and the California Energy Commission.

The report is a corporate document that should be cited in the literature in the following manner:

Hydrogen System Optimization Study for BP Carson Refinery (Los Angeles), EPRI, Palo Alto, CA, California Energy Commission, Sacramento, CA: 2001. 1006164.

REPORT SUMMARY

New product specifications and the increased processing of heavier crudes mean that refiners are seeing a rise in hydrogen consumption per barrel of crude oil. Economic incentives for optimising the hydrogen system lie not only in reduced operating costs of hydrogen plant, but are particularly strong when optimised hydrogen usage can eliminate or postpone investment in new hydrogen plant. This project evaluated the scope for hydrogen savings at BP's Carson facility in Los Angeles, California.

Background
The effective management and efficient integration of hydrogen and off-gases are becoming increasingly important tasks for many of the world's oil refiners and petrochemicals producers. Legislation to reduce global emissions of greenhouse gases is enforcing the production of low-sulphur fuels with the result that hydrogen is in increasing demand in refineries. New product specifications and the increased processing of heavier crudes mean that BP, like other refiners, is seeing a rise in hydrogen consumption per barrel of crude oil. This trend is set to continue and, as a result, improving hydrogen management at refineries is becoming increasingly important.

Objectives
- To reduce refinery hydrogen system costs
- To improve hydrogen management in refinery processes
- To achieve capacity debottlenecking
- To improve energy efficiency and environmental impact.

Approach
The project team developed an investment strategy using HydrogenPinch™ Analysis techniques to identify and rank projects to improve refinery hydrogen system costs and increase efficiency at the BP Carson Refinery in Los Angeles, California. The method is based on Pinch Technology, which seeks to determine the minimum, or "target," hydrogen make-up to meet the demands of all process units in a network by matching hydrogen sources with appropriate sinks. Optimization software determines the hydrogen system routings that minimize the operating cost of the system. These techniques are complemented by a sensitivity analysis, which identifies both the process units where a decrease in hydrogen purity offers potential for operating cost savings and the units where an increase in hydrogen purity can be achieved at lowest cost. This is particularly important for achieving production and yield benefits.

Results

Only minimal scope for “easy win” projects was identified at the Carson Refinery, since existing integration and recovery measures at the site were already reasonably extensive. The amount of H_2 burned as fuel is small; and the existing production and regeneration facilities are operating at, or close to, their limits. Therefore, only small savings can be expected if these existing constraints are accepted as given. Significant potential for improvement was identified in relation to three key areas:

- Operation of an existing Membrane Recovery Unit (MRU) and the availability of a second, currently unused, MRU. Project combinations were identified that utilize existing equipment with some additional piping. These options could achieve savings of up to $1.0 million per year. More complex modifications could increase this saving to $1.3million per year.
- Increasing capacity of No. 1 H_2 plant. Iincreasing the capacity of the plant to its nameplate level opens up significant potential to replace purchased hydrogen.
- Reducing feed purity to a number of processes including hydrodesulfurization**,** isomerization and benzene saturation units in the South plant. Feed purity can reportedly be reduced to 85% without adversely affecting the operation of the process. Projects were identified to exploit the full capacity of the No. 1 H_2 plant and lower feed quality to the identified unit, resulting in savings of up to $3.4million per year.

The maximum saving achievable by combining projects is $4.5million per year. To realise this saving, a new H_2 compressor would be required. However, it is expected that a slightly smaller saving of $3.8million per year would be achievable by making extensive use of existing pipework and available capacity in two existing compressors. This second option also offers significant production benefits by increasing hydrogen purity to key refinery processes. The project incentives have been determined using a model of the hydrogen supply system. Capital cost estimates were not carried out for this report. However, local contractors can carry out detailed engineering for the packages described in the report.

EPRI Perspective

Hydrogen Pinch evaluation is applicable across all refineries and other hydrogen users, resulting in energy savings and environmental mitigation. In this study, a global energy balance has shown that the proposed projects result in a net fuel saving and a corresponding reduction in CO_2 emissions. In general, however, a net increase in power consumption is predicted. The project combination corresponding to the maximum saving will reduce fuel consumption by 33 MMBtu/h and CO_2 emissions by 36 MMlb per year. Power consumption for this case would rise by 920 kW.

Keywords

Pinch technology
Energy efficiency
Oil refineries
Hydrogen
Global warming

ABSTRACT

The HydrogenPinch Analysis carried out by Linnhoff March for the BP Carson refinery in Los Angeles, California, resulted in the development of an investment strategy RoadMap detailing opportunities for:

- Reducing refinery hydrogen system operating costs
- Improving hydrogen management in refinery processes
- Capacity debottlenecking
- Improving energy efficiency and environmental impact.

The RoadMap highlights compatible project combinations with the potential to save up to $4.5 million per year. In terms of the global energy balance, investment routes can be selected that will reduce consumption of fuel by 11-39 MMBtu/h resulting in a reduction in CO2 emissions of 12-42 MMlb per year. In general, however, power consumption for these combinations will rise (860-1800 kW).

The HydrogenPinch approach demonstrated the ability to identify non-obvious project solutions in a systematic, step-wise way. Projects can thus be ranked from zero/low cost opportunities to sizeable investment alternatives.

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1
INTRODUCTION

BP operates a major full-conversion refinery at its Carson facility in Los Angeles, California. New product specifications and the increased processing of heavier crudes mean that BP, like other refiners, is seeing a rise in hydrogen consumption per barrel of crude oil. This trend is set to continue and, as a result, improving the refinery's hydrogen management is becoming increasingly important.

With the support of EPRI, BP commissioned Linnhoff March to carry out a HydrogenPinch project to evaluate the scope for hydrogen savings and to generate alternative flowsheets that would realise those savings.

Economic incentives for optimising the hydrogen system lie not only in reduced operating costs of hydrogen plant, but are particularly strong when optimised hydrogen usage can eliminate or postpone investment in new hydrogen plant. With rising refinery demands, this scenario is becoming increasingly relevant. Additionally, improvements in gas quality reaching the processing units can increase production and/or yield with the associated economic benefits that this brings.

The main focus of the work was the hydrogen system rather than the processing units. The results presented in this report are therefore in terms of hydrogen cost. However, where it was identified that proposed modifications would positively impact on the processing units this has been documented.

The Linnhoff March proprietary HydrogenPinch technology and software formed the basis of the study. The tools were used to:

- Aid in collecting data and developing the hydrogen balance
- Generate and simulate ideas for modifications to the complex hydrogen network taking into account the availability of spare equipment and spare capacity in existing equipment
- Structure the analysis into systematic targeting stages.

2
OBJECTIVES

The effective management and efficient integration of hydrogen and off-gases are becoming increasingly important tasks for many of the world's oil refiners and petrochemical producers. Legislation to reduce global emissions of greenhouse gases is enforcing the production of low-sulphur fuels and this means that hydrogen is in increasing demand in refineries. It is estimated that between 50% and 70% of existing refineries are either already short of hydrogen or will be in the next few years.

Linnhoff March was contracted by EPRI to carry out an analysis of the BP Carson Refinery using HydrogenPinch technology with the objective of developing decision support information in the form of an investment strategy RoadMap. This RoadMap details opportunities for:

- Reducing refinery hydrogen system costs
- Improving hydrogen management in refinery processes
- Highlighting potential for capacity debottlenecking
- Improving energy efficiency and environmental impact.

The RoadMap puts BP in a position to select the most economical route that best meets its criteria for future H2 supply.

The work was divided into two phases:

- Phase 1: for initial targeting, to quantify the potential for improving H2 utilization;
- Phase 2: for project development, to turn the identified potential into feasible projects that will achieve the targets in the most cost-effective manner.

2.1 Targeting Phase

The targeting phase is a systematic review of the refinery hydrogen system to establish its limitations and flexibilities and the potential improvements that can be achieved.

The basis for this review and subsequent project development is a consistent H2 balance for the site. This consists of a model that incorporates all hydrogen producers and consumers with their associated conditions of supply/production (flow, purity, pressure) and connectivity. The model includes existing levels of supply and demand as well as predicted future levels. In the particular case of the BP Carson refinery, the model was required to include the No.2 Light Hydro unit, which is being considered for the future.

The potential for improvement in the system, or "target", is determined in a series of steps corresponding to increasing degree of modification to the H2 system. Initially, only simple piping modifications are considered, while ultimately, the analysis considers installation of new compressors plus changes to the process conditions (e.g. H2 purity in process feeds). In this way, "easy wins" requiring little or no modification can be identified first, while more complex projects follow at later stages, when more and more constraints are relaxed. This procedure also identifies the key decisions that form the basis of the investment RoadMap.

Specific objectives of the targeting phase at the BP Carson refinery were to:

- Understand limitations and flexibilities of H2 usage
- Develop H2 balance models for future H2 demand levels
- Identify short-term "easy win" projects
- Quantify the potential to improve H2 utilization in a series of stepped targets, incorporating different degrees of system modification.

2.2 Project Development Phase

This phase involves a detailed review of the targets to develop the most cost-effective projects that will achieve, as closely as is technically and economically feasible, the theoretical level of savings that were identified in Phase 1. The procedure invariably identifies a number of alternatives that have an impact on, or are dependent on, strategic site development issues. These alternatives thus determine the final form of the RoadMap.

Specific objectives of the project development phase at the BP Carson refinery are:

- Systematic identification of key inefficiencies and bottlenecks in the system
- Evaluation of all integration opportunities and alternatives for H2 re-use and regeneration that lead to improved plant operability and higher system efficiency
- Conceptual design and economic evaluation of projects to meet the targets and overcome bottlenecks
- Development of an investment RoadMap highlighting benefits of alternative strategies in terms of operating cost, capital avoidance, environmental impact, operability, and debottlenecking.

3
DATA BASIS

BP supplied the base-case data used for the analysis of the hydrogen system. The balance corresponds to a case where all refinery units (including the planned No.2 Light Hydro unit) are fully operational and running in steady state.

The supplied data formed a very good basis for the preparation of the overall site H_2 balance. Additional information was only required to establish the internal flows within certain process units. Linnhoff March's proprietary software was used to finalise the balance.

3.1 Hydrogen Producers and Consumers

The BP Carson refinery site is divided geographically into North and South plants with process units in both areas. The non-utility refinery process units can be divided into hydrogen producers and consumers as follows:

Producers

- No. 1 reformer (North)
- No. 2 reformer (North)
- No. 3 reformer (North)

Consumers

- FFHDS (North)
- HCK (North)
- Jet (North)
- Mid Barrel (North)
- No. 1 Light Hydro (North)
- No. 2 Light Hydro (South -planned)
- NHDS/Isom/Bensat (South)

For the purposes of the analysis, the hydrogen consumers were defined as closely as possible according to the scheme shown in Figure 3-1.

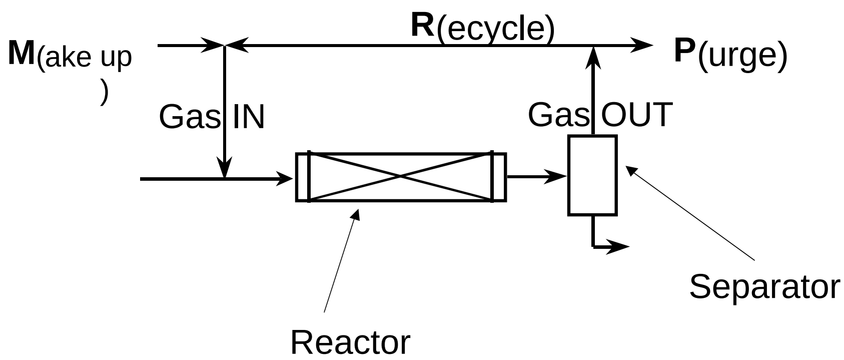

Figure 3-1
General Definition of Process Unit Hydrogen Balance

The main part of the process, where H_2 is only present in a mixture with feeds and products (i.e. in reactors and separators), is modelled as a black box. Once hydrogen is removed from the process streams for recycle, purge or re-use, it is effectively available for integration with other processes. Only then is it represented as a hydrogen stream in the balance.

The data required to describe base-case (normal) operation of the plant is:

- Flow (**M**ake up, **R**ecycle and **P**urge)
- Pressure
- Composition at the inlet (IN) and outlet (OUT) (molar/volume basis)

  - H_2

  - C_1 - C_3 etc.

In most cases, model development is iterative, with the software indicating where additional measurements are needed. However, in this case, the initial data was good, requiring no additional data gathering. This saved a large amount of time during the study.

Note that the NHDS, Bensat, and Isom units have been combined in a simplified black box representation. Because the interconnecting streams within this unit must remain unchanged, the analysis considers only the main inlet and outlet streams.

3.2 Hydrogen System Utilities

The HydrogenPinch approach minimises operating cost within the constraints of the system. The cost of hydrogen supply, treatment of off-gas and H_2 regeneration are a key part of this.

Hydrogen is supplied to the processes from two hydrogen plants plus imported purchased hydrogen.

- No.1 H_2 plant is located in and supplies to the North area. The plant is fed with natural gas as well as concentrated waste gas from the PRISM regeneration unit. The plant is currently operating ten percent below its name-plate capacity, producing hydrogen at 95% purity.
- No. 2 plant is located in the South area but supplies mainly the North area. The plant is currently operating at its maximum capacity and produces H_2 with a purity of 99.9%
- At present, purchased H_2 is imported to the South area, where its high pressure means that it can be used to supply the units there without additional compression. Gas is supplied at 800psig and 99.9% purity.

Outlet streams from the processes that cannot be used as feedstock to other processes have three possible uses:

- Feedstock for the hydrogen plants
- Fuel gas
- Feed for the PRISM unit, which produces a hydrogen-rich permeate stream and a concentrated waste stream. The waste stream can itself be supplied to the hydrogen plants as feedstock.

In the existing H2 system a single PRISM membrane regeneration unit is currently in operation. A second PRISM unit is available but unused. This second unit is known as the “Idle PRISM”.

PRISM performance has been modelled to reflect existing operation. This relates hydrogen recovery and removal ratio to the feed. It is recognised, however, that higher impurity levels in the feed will result in condensation of C3+ components in the gas stream. This limits both the existing PRISM unit and utilisation of the idle unit.

3.3 Base-Case Operating Costs

In addition to costs of utilities, such as hydrogen make-up, costs are associated with the fuel gas sink, gas regeneration and compression. It has been assumed here that regeneration costs can be represented entirely by the cost of compressing the feed.

In the evaluation, a value was assigned to fuel gas corresponding to the heat of combustion of H_2 ($825/MMSCF). Thus, if less H_2 is fed to the fuel gas system, more natural gas must be used to provide the equivalent heating duty. For example, a fuel gas stream of 1.5 MMSCFD and 17% H_2 has a value of:

$$1.5 * 0.17 * 823 = 210 \text{ \$/day}$$

The hydrogen that is fed to the H_2 plants could be expected to have some value as a feedstock. However, within the refinery it is regarded as economically beneficial to reduce the hydrogen in this stream (i.e. the hydrogen has a negative value in this context). Any H_2 in the feed flows straight through the units and only uses up valuable capacity and requires unnecessary heating/cooling. Because of the difficulty of assigning a value to this gas, a conservative approach was adopted assuming a nominal small negative value. The targets thus produced still aim to reduce this H_2 flow, but no economic significance is attached to it.

To fully account for compression costs, a variable cost is assigned to the link between each source and sink of hydrogen. This not only accounts for existing compressors but also allows the HydrogenPinch optimisation procedure to determine where an additional compressor could be installed cost effectively. These costs are calculated based on the following equation:

$$\text{Power} = P_1 * V_1 * \ln(P_2/P_1) * C$$

Where: V_1 = actual volume of 1SCF in CF
P_1 = inlet pressure (psia)
P_2 = outlet pressure (psia)
C = site-specific derived constant = 3.51
Power = compressor power (kW/MMSCFD throughput)

The constant C was derived from a best-fit calculation based on reference data provided for five key compressors on the site. The calculated powers do not exactly match real-life powers because the use of a single constant does not allow for properties such as changing efficiency. However, the approach works well as it allows for the possibilities of connecting new streams to existing compressors and exploiting available pressure to avoid the need for compression.

Utility	Cost $/MMSCF
No. 1 H2 Plant	Base
No. 2 H2 Plant	1.1 x Base
Purchased H2	2 x Base
Fuel gas (H2 content)	823
Compression power	0.04 $/kWhr

3.4 Base-Case Hydrogen Balance

Figure 3-2 shows the balance that was developed from the base-case data. The figure shows the connectivity of the process units and the use of H_2 headers. The main headers are:

- High pressure – 1760psig-1570psig feeding the FFHDS and HCK units

- Medium pressure – 735psig feeding the South plant units
- Low pressure – 200psig fed by the Jet, Nos.1-3 reformers, PRISM and No. 2 Light Hydro, and feeding the Tail Gas, Mid Barrel and A/B compressors
- Very Low pressure – 100psig feeding the PRISM and fuel gas.

This balance is a snapshot of operation, assuming that all units are running at steady state. It serves as the basis for calculating the savings. The operating costs (incl. compression cost) for this case is **$54.7 million per year**.

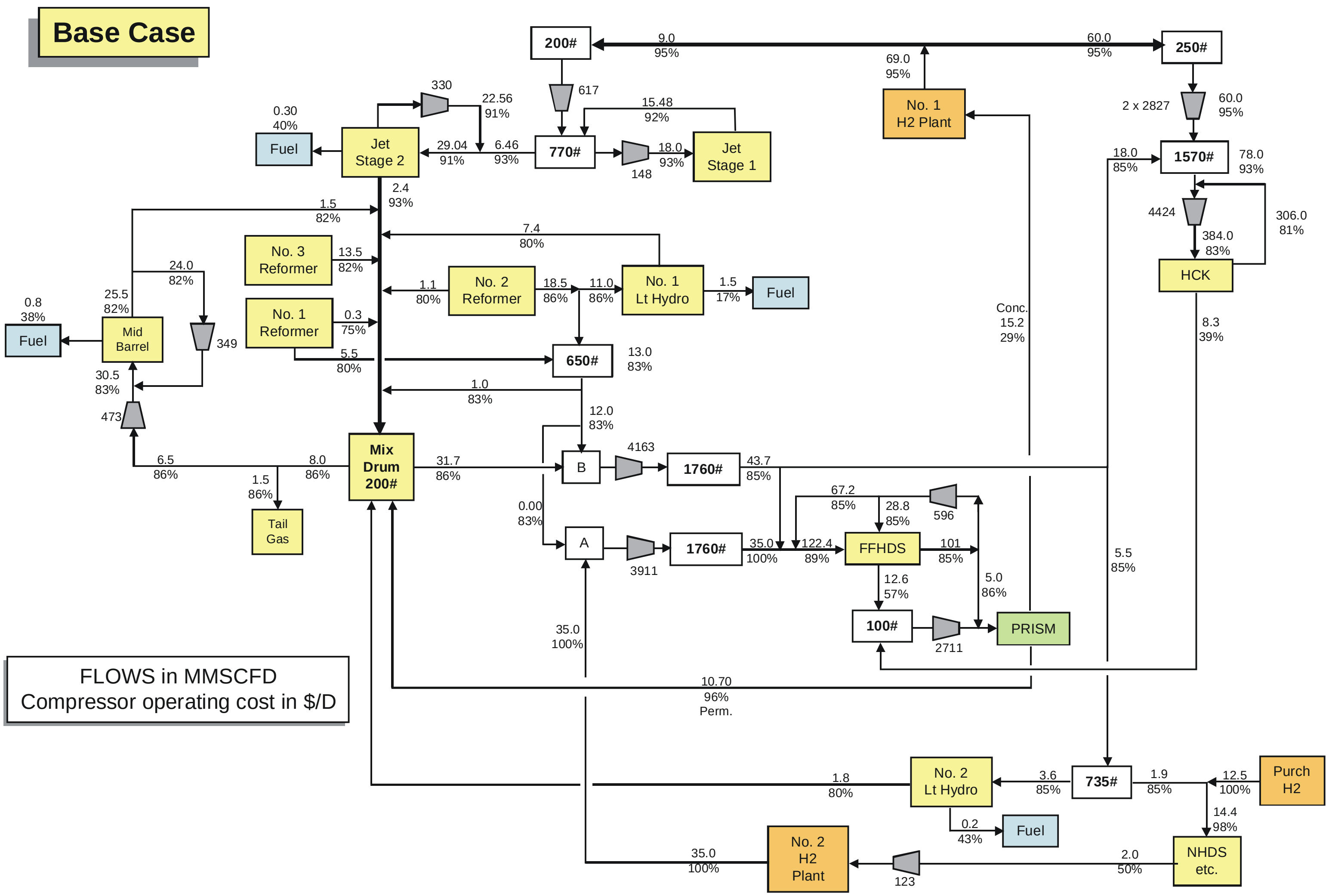

Figure 3.2: Base Case Hydrogen Balance

Figure 3-2
Base Case Hydrogen Balance

3.5 Limitations and Opportunities

Figure 3-3 shows a schematic drawing of the refinery, which illustrates a number of the constraints that were identified during this project.

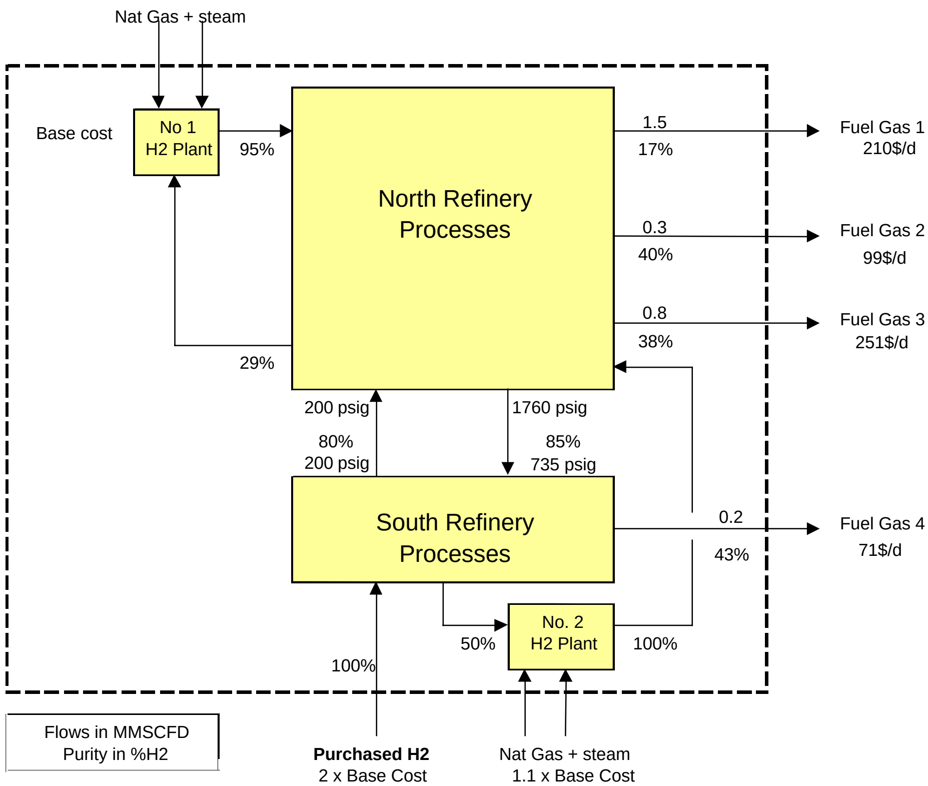

Figure 3-3
Schematic Hydrogen Balance

The diagram shows that the value of H_2 going to fuel gas is very small. Therefore, any absolute H_2 savings will, by balance, be equally small. In fact, if all of it can be recovered, there would only be a saving of $630 per day or $223,000 p.a.

The diagram also shows the three sources of make-up hydrogen - two H_2 plants and purchased hydrogen. The internal make-up sources are considerably cheaper than purchased H_2. However, as the two H_2 plants are operating at or near maximum capacity, there is also little or no scope to switch between utility levels (between the different sources).

There is one stream that might be exploited to give savings. The PRISM concentrate that is returned to the No. 1 H_2 plant has no value, so recovery of this stream does not represent a saving in itself. However, if hydrogen can be recovered from this stream at a purity that can be used within the refinery, this will reduce the amount of make-up that is required.

This stream carries only 29% H_2 and can therefore not be used directly in any other unit. To realise a saving by recovering its hydrogen, the capacity of the PRISM must be improved. At present, performance is limited by the level of impurity in the unit feed. Higher hydrocarbon concentrations than in current operation would lead to condensation on the membrane, reducing its effectiveness. Since recovering more hydrogen from the concentrate means that, by default, the concentration of impurity increases, it can be seen that the problem of condensation must be addressed if the existing or idle PRISM units are to be used for this purpose. This can be achieved in a number of ways:

- Operate the idle PRISM unit at low pressure downstream of the existing unit, thereby avoiding the hydrocarbon dew point
- Use chilling to cool the PRISM feed and condense the heavier impurities. When the gas is heated to its normal feed temperature, it will be further from the hydrocarbon dew point.

The total H_2 content of the concentrate stream is 4.4 MMSCFD. The maximum saving corresponds to complete recovery and reducing generation in the No. 1 H_2 plant ($1.6million p.a.) or H_2 import ($3.2million p.a.). However, it will not be possible to recover the entire hydrogen content of the concentrate stream by the means outlined above and any additional recovery will be accompanied by other costs such as refrigeration or compression. The savings will therefore be significantly less than the maximum.

To summarise the above points, if the H_2 system constraints are accepted as given, potential for improvement will be limited.

- Absolute hydrogen savings by recovery from fuel gas will be very small
- Savings are limited from switching between utility levels, since the H_2 plants are currently operated at or near maximum capacity
- Improving the regeneration capability of the PRISM units opens up potential for recovering H_2 from the PRISM concentrate.
- In order to make significant savings, therefore, it will be necessary to identify and exploit any flexibility in the system that can be achieved by changing process conditions. Two key parameters identified during the course of this work are:
- The nameplate capacity of the No. 1 H_2 plant is ten percent higher than the current maximum achievable throughput, but could be increased to the nameplate capacity with some relatively small investment. This additional generation capacity is at the lowest cost level. If it can somehow be exploited to replace imported hydrogen, a maximum saving of $3.9million p.a. is possible
- The feed purity to the NHDS/Isom/Bensat units in the South plant is much higher than required. At present, the feed is 98% H_2, principally from purchased imported H_2. This can potentially be reduced to 85% without adversely affecting the operation of the processes.

A further flexibility identified by BP was the availability of a spare compressor. Without this spare unit, any attempt to increase hydrogen recovery that would require additional compression would incur a significant investment cost. Considering the compressor in the analysis therefore opens up further potential for cost-effective recovery.

The most significant constraint to be incorporated in the analysis is the geographical separation of the North and South plants. The large distance makes the cost of new connections between the areas almost prohibitive. It was therefore important to identify potential for improvement that would require no additional piping links between the North and South plants.

4
TARGETING RESULTS

Initially, three targets were defined. However, interactions between projects made the boundaries between phases increasingly unclear, so additional steps were included. The original targets 1, 2 & 3 were re-defined as follows:

- Target 0 – identifying potential for improvement without any additional equipment, e.g. reducing compression costs by adjusting letdown flows
- Target 1 – determining savings potential from simple repiping projects
- Target 2a – determining the benefit of exploiting existing spare equipment (PRISM and compressor)
- Target 2b – identifying scope for improvement by addition of new equipment, e.g. compressors, headers, N/S refinery links
- Target 3 – Assessing the potential benefits of changing process conditions (including specific changes proposed by BP).

In the following sections, the target savings for each step are described and the projects to achieve these savings are listed.

4.1 Target 0

The benefits defined for all projects in this report include not only the benefits from the infrastructure changes described but also the benefits from optimising the letdown flows around the system to fit best with the new set-up.

As a starting point, it is necessary to calculate how much can be saved in the system without any investment in new equipment, so that the incremental benefit resulting from investment can be fully appreciated. It is, of course, necessary to address the impact on the operability of the plant resulting from these changes.

There are three letdowns on the plant:

- 1760 psig to 1570 psig
- 1760 psig to 735 psig
- 650 psig to 200 psig

Using the optimiser to assess these flows shows that the 650 to 200 psig letdown can be eliminated and that this is the major source of the saving. Minor adjustments can be made to the other letdowns.

The saving that results is almost entirely associated with a reduction in compressor power. This has been named Project 1.

> Initial Savings Estimate:
> $72 per day or $26,000 per year

This can be regarded as a base case for all other savings, since this is the optimal configuration of the letdowns. All other targets should be compared with these small savings to obtain a true picture of the savings resulting from more complex modifications.

4.2 Target 1

The targeting phase of the work determines the theoretical minimum hydrogen system cost, which allows a review of potential at each stage. The project development phase can then be tailored once the size of this potential is known.

Figure 4-1 shows the hydrogen composite curves for the BP Carson refinery. The curves relate hydrogen sources (red) with hydrogen sinks (blue) in the target configuration. The target represents the theoretical best fit of process sources to sinks.

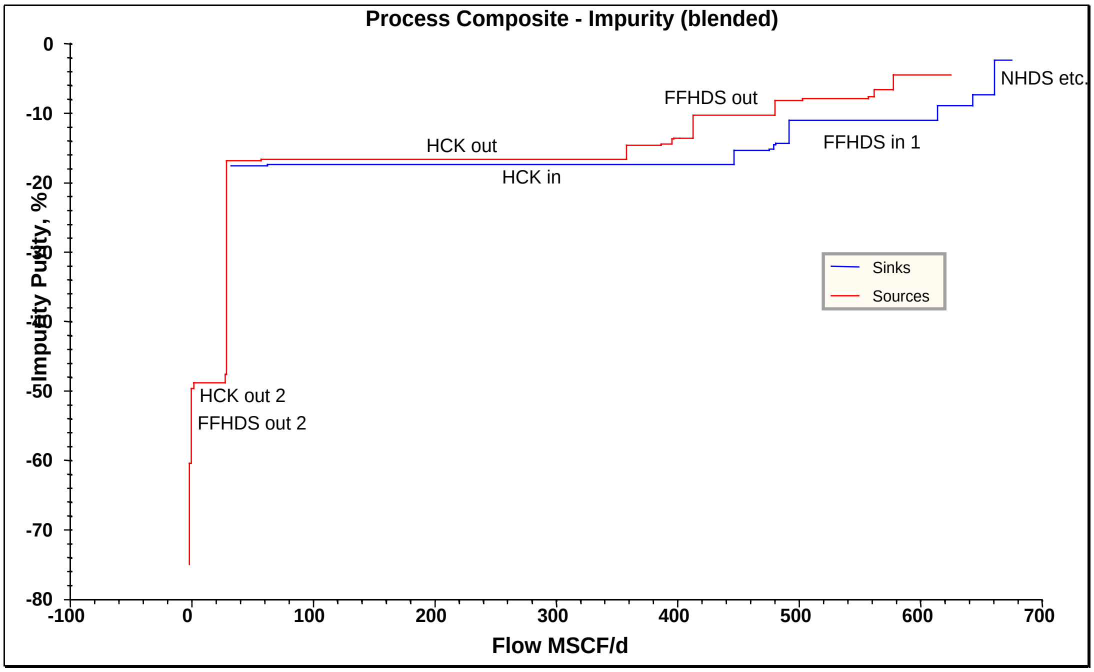

Figure 4-1
Hydrogen Composite Curves

In practice, achieving this target would generally require a high degree of complexity in the piping system and a large number of connections with small flows. In most cases, therefore, achieving the target savings is unlikely, but closely approaching them is possible.

The composite curves show that the HCK unit dictates minimum hydrogen consumption. This minimum, or target, is greater than 99% of existing utility consumption, indicating that the potential for improvement achievable by simple repiping is less than 1% of the current operating cost.

Note that Target 1 was constrained to allow new piping within, but not between, the North and South plants.

Two projects were identified from Target 1:

- Project 2: Feed fuel gas from No. 1 Light Hydro to the PRISM
  Initial Savings Estimate: $390 per day or $138,000 per year
- Project 3: Improve H2 Recovery at the Prism Unit
  Initial Savings Estimate: $633 per day or $224,000 per year

These projects are essentially competing for the same savings opportunity and the incremental benefit from combining the two ideas is negligible. Therefore, the two projects can be considered to be mutually exclusive.

4.3 Target 2

The curves in Figure 4-1 indicate that, to improve savings, streams of low purity must be "upgraded" to at least the concentration of the HCK feed. This can be achieved by increasing regeneration capability, for example by condensing heavies from the PRISM feed, or by utilising the idle PRISM unit (considered mainly as part of Target 2).

Target 2 was subdivided to consider use of existing spare equipment (2a) and installation of new equipment (2b).

Three projects were identified from **Target 2a**:

- Project 4: Idle PRISM fed with PRISM conc.
  Initial Savings Estimate: $2026 per day or $717,000 per year
- Project 5: Use Spare Compressor
  Initial Savings Estimate: $88 per day or $31,000 per year
- Project 6: Idle PRISM operating at lower pressure
  Initial Savings Estimate: $844 per day or $299,000 per year

The best project in terms of financial savings is clearly Project 4, which brings the Idle PRISM on-line. Thus, when considering combinations of projects, this project should be included, although it is also worth further investigating the alternative low-pressure operation of the Idle PRISM (Project 6). The operational changes described in Project 1 are also included as a matter of course.

Projects 2 and 3 both involve addition of a low-purity stream into the PRISM unit, which means that the purity of the PRISM concentrate stream drops by about 4%. This dramatically affects Project 4, as it increases the amount of dilution gas required to increase the inlet purity to the Idle PRISM to its limit of 52%. Following this through the system, the difference between the Idle PRISM permeate and the dilution gas flowrates reduces and the overall combined project saving drops to a value below that achievable by Project 4 alone. Project 4 can therefore be considered mutually exclusive to Projects 2 and 3.

Projects 2 and 3 also have a negative impact on Project 6 for similar reasons in that they drive down the purities in the PRISM/Idle PRISM units and ultimately eliminate any benefit.

Project 5, on the other hand, appeared unattractive due to the low savings that could be achieved as a result of the purity constraints in the system. However, implementing Project 4 or Project 6 changes this situation because these projects increases the amount of purer H_2 available by the introduction of additional permeate flow.

The most attractive combinations have been defined as two separate projects:

- Project 7: Projects 5 and 6 Combined
  Initial Savings Estimate: $2121 per day or $751,000 per year
- Project 8: Projects 4 and 5 Combined
  Initial Savings Estimate: $3170 per day or $1.1million per year

In Project 4, the No.2 H_2 plant production is reduced by 1.4 MMSCFD. An additional consideration at this point would be to fully utilise of this plant to reduce the amount of purchased H_2. This would require installation of a new compressor to feed the additional gas into the 735# header. In conjunction with Project 4 this would be worth $1230 per day in purchased hydrogen, or $500,000 per year.

For **Target 2b**, a single project was identified:

- Project 9: Upgrade Mix Drum and use Idle PRISM
  Initial Savings Estimate: $3670 per day or $1.3million per year

While this project would result in comparatively large savings, it is a relatively complex design. It would therefore be expected to have a correspondingly high investment cost.

The most significant result is the benefit of increasing hydrogen purity in the existing 200psig mix drum to 91.6% purity. Apart from allowing increased use of this gas in the South plant, this results in higher purity hydrogen being fed to the No.2 Light Hydro, Mid Barrel and Tail Gas units. Potentially, this could result in benefits to production and yield in these units. This has not been included in the estimated savings.

Considerations that could add to the attractiveness of Project 9 are:

- It would use the Idle PRISM in a location near the HCK unit. This is where it was located in the past and where a footprint for the equipment still exists.
- Sending the stream from Reformer 1 to the HCK feed compressor inlet, instead of to the 650psig header, implies less need for compression inside the Reformer 1 black box.

Project 9 includes some of the elements of projects 2-6 so can be considered mutually exclusive to all of them.

4.4 Target 3

Target 3 investigates the potential for improving the hydrogen system by modifying key process parameters, e.g. unit feed purities. A sensitivity analysis was used to identify the key units. Figure 4-2 shows the results of this analysis.

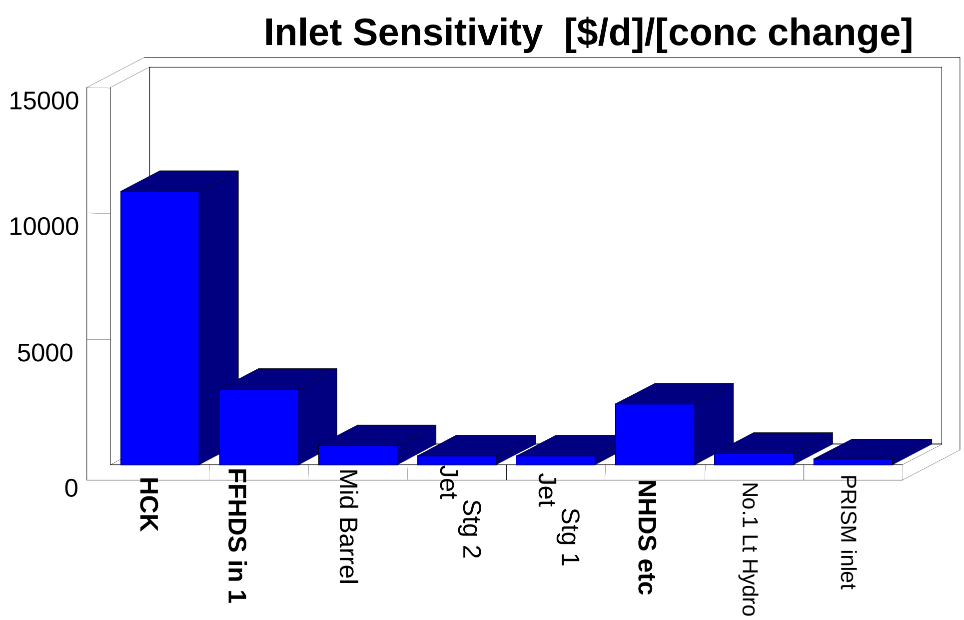

Figure 4-2
Results of Sensitivity Analysis

The bar graph shows the effect on hydrogen system operating cost of a marginal impurity increase in the feed to each unit. Note that this does not take into account any production/yield effects of the increase in impurity.

In this case, the two units where a decrease in hydrogen purity would result in the largest potential savings are the HCK and the FFHDS units. However, BP are more interested in *increasing* hydrogen purity in these units to improve production. In this regard, the plot shows that increasing hydrogen purity to these units is likely to cause the highest operating cost increase of all units on site.

The next most promising unit is the NHDS/Isom/Bensat area in the South plant. As long as reducing feed purity to these units does not adversely affect their operation, it is likely to offer substantial benefits in the operating cost of the hydrogen system.

At present, this (combined) unit is operated with a feed purity of 98% H_2. Discussions with BP indicated that a purity as low as 85% would still be acceptable and not compromise yield/production. Currently, the unit uses a substantial amount of make-up from purchased H_2, which is at the correct pressure to feed the units. The No. 2 H_2 plant product is at a much lower pressure, so is more suited to feed the A/B compressors in the North plant. The results of the sensitivity analysis indicate that this configuration should be reviewed.

Figure 4.3 shows the result of repeating the sensitivity analysis after lowering the inlet purity to the NHDS/Isom/Bensat units. The key effect is that the saving that would be achieved in the HCK and FFHDS units by changing the feed purity is now much reduced. Where Figure 4.2 showed a saving in the order of 10,000 $/day from lowering the HCK feed concentration, lowering the feed purity to the NHDS/Isom/Bensat units reduces the potential savings in the HCK to less than 600 $/day for the same modification.

While this shows the potential saving from reducing feed purity to a unit, it can also be interpreted the other way round – to indicate how much it would cost to *increase* the feed purity, as BP would like to do. The result thus shows that modifying the feed purity to the NHDS/Isom/Bensat units should have the beneficial side effect of reducing the cost associated with increased feed purity to the HCK and FFHDS units. There is therefore a double incentive for reducing the NHDS/Isom/Bensat units feed purity:

- Reducing hydrogen system operating cost

- Reducing the cost of feeding purer H_2 to the HCK and FFHDS units.

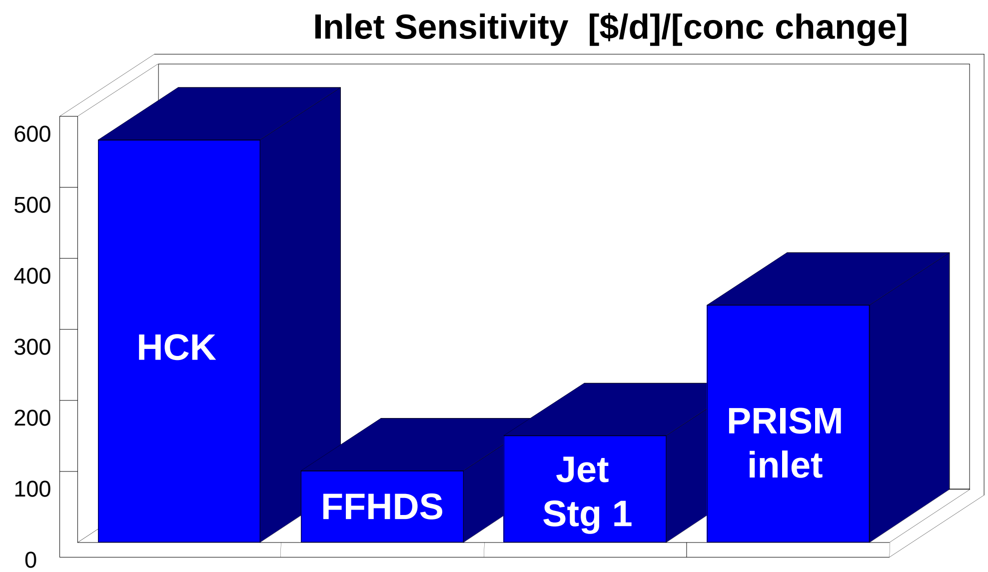

Figure 4-3
Results of Sensitivity Analysis

Three main projects were identified from Target 3:

- Project 10: Feed No. 1 H_2 Plant to 735psig Header
  Initial Savings Estimate: $9493 per day or $3.4million per year
- Project 11: Change "NHDS etc." inlet purity utilising spare compressor
  Initial Savings Estimate: $6426 per day or $2.3million per year
- Project 12: Change "NHDS etc." inlet purity, utilising A/B compressors
  Initial Savings Estimate: $6692 per day or $2.4million per year

All three projects achieve the same end-savings in H_2 make-up by exploiting the additional capacity in No. 1 H_2 plant and a lower feed purity in the NHDS/Isom/Bensat units. They are therefore mutually exclusive.

Project 10 is the most capital intensive, requiring a new compressor and significant new piping from No. 1 H_2 plant to the 735psig header. However, the estimated savings are such that this could be attractive. Also, there appears to be an unused connection from the HCK unit to the 735psig header, which passes by the No.1 H_2 plant and could perhaps be used to transport gas to the South area.

Project 12 has the least capital investment, utilising existing pipework and available capacity in the A/B compressors. The possible disadvantage of this project is that it uses up available capacity, which may impact on required levels of operability and flexibility.

Project 12 in particular has a significant impact on the feed purity to some of the process units. The models used to evaluate savings are conservative and do not evaluate monetary (or other) credits for yield/production improvements. Although, in this case, the feed purity has increased, it has been assumed that the outlet H_2 purity remains unchanged.

An equally valid alternative to the above is to optimise hydrogen use such that the feed purity to the units is unchanged from current operation. In this way, the model is fully consistent with current operating conditions. For example, the improvements proposed in Projects 11 and 12 increase the feed purity to the FFHDS unit. In terms of hydrogen management, the optimum solution is to mix low-purity hydrogen with the higher purity feed to maintain the current feed conditions. In this way, the supply of high-purity hydrogen can be reduced, thus saving H_2 supply costs.

As described in Section 4.3, projects 2, 3, 4 and 6 are mutually exclusive, as they all compete for the same resources. This holds true when they are considered for combination with projects 10 to 12. The combinations are summarised in the table below with the corresponding incremental annual savings (relative to Project 10-12 base case savings).

	Incremental Savings of Project Combinations				
	Base Case	**Project 2**	**Project 3**	**Project 4**	**Project 6**
Base Case	0	$138,000	$224,000	$718,000	$299,000
Project 10	$3.36million	$224,000	$685,000	$1.0million	$1.2million
Project 11	$2.28million	$327,000	$910,000	$756,000	$1.5million
Project 12	$2.37million	$327,000	$855,000	$403,000	$1.5million

The table shows that, generally, the value of Projects 2, 3, 4 and 6 increases when combined with Projects 10-12. This is caused by the lower feed purity of the NHDS/Isom/Bensat unit, which allows the balance to be achieved by make-up coming principally from the No. 1 H_2 plant, thus saving in purchased H_2.

Note that, in the base-case comparison, the incremental saving from installing Project 10 instead of Project 12 is approximately $1million per year. Reviewing the combinations, it can be seen that the incremental benefit of Project 10 becomes less (except combinations with Project 4). Assuming that the most profitable combinations are implemented (i.e. combinations with Project 6), the incremental difference between Project 10 and Project 12 is approximately $700,000 per year. This would have to pay for the new compressor and piping required by Project 10.

Combinations with Project 2

Recycling No. 1 Light Hydro off-gas to the PRISM increases the amount of H_2 recovered and sent to the Mix Drum. The slight increase in purity and flow from the Mix Drum means that the amount of make-up can be reduced.

The feed purity to the NHDS/Isom/Bensat units is achieved by mixing letdown from the 1760# header with 99.9%-pure purchased H_2. If the purity and flow from the mix drum are increased, then more letdown can be used, saving a small amount of purchased H_2. Make-up to the system can also be reduced, saving in the Nos. 1 and 2 H_2 plants.

In the cases where the feed purity is reduced, the purity of gas in the 1760# header is already significantly higher due to make-up from the No. 1 H_2 plant. This means that a number of units are being fed with gas of higher purity than at present. By increasing the flow from the PRISM to the Mix Drum and simultaneously reducing the import of purchased H_2 by the same amount, the purity of the feed to the FFHDS unit reduces slightly. While this results in a net saving in the hydrogen system by reducing expensive import, it will also reduce credits for yield improvements in the FFHDS associated with higher feed purity.

Combinations with Project 3

The base case Project 3 is similarly limited by the NHDS/Isom/Bensat unit feed purity. Increasing the flow and purity in the Mix Drum allows hydrogen make-up from all three sources to be reduced.

Combining Project 3 with Projects 10-12 greatly increases the savings potential, since the flow to the Mix Drum is not limited by the NHDS/Isom/Bensat purity constraint. Instead, only the PRISM feed purity limit of 52% determines the extent to which the PRISM concentrate can be recycled to the inlet.

Again, similar to combinations with Project 2, a proportion of the savings is attributable to reducing the feed purity to the FFHDS unit. The resulting purity is still higher than in the base case, so that production benefits will still be apparent. However, the credits will be reduced compared with Projects 10-12 alone.

Combinations with Project 4

Combinations with Project 4 are the only ones where a general increase in the incremental benefit of the project is *not* observed.

Combination with Project 10 does increase the value of Project 4 in a similar manner to Projects 2 and 3. Increasing the flow of purified gas from the PRISM to the Mix Drum allows a greater flow in the letdown from 1760# to 735#. The result is a lower purity in the feed to the NHDS/Isom/Bensat units (93%), but reduces the make-up required from purchased hydrogen.

Projects 11 and 12 do not show the same increase in value by combination with Project 4. In both cases, additional H_2 make-up from the No. 1 plant increases the amount of gas in the 200# header, which must be compressed in the A and B compressors. In the base case, the compressors are still well within their capacity limits. However, when these projects are combined with Project 4, there is a further demand on the 1760# header to supply dilution gas for the idle PRISM. As a result, the compressor limits are reached, limiting the savings for these particular combinations.

Combinations with Project 6

Combining Projects 10-12 with Project 6 (operating the idle PRISM at lower pressure) results in the largest incremental improvement of all alternatives. This differs from the base case, where Project 4 was clearly the best stand-alone project.

In the base case, the limiting factor in operating the PRISM at lower pressure was the purity required in the 1760# header to supply the FFHDS and NHDS/Isom/Bensat units. Projects 11 and 12 increase the purity of the feed to the FFHDS and have significant flexibility in the feed purity to the NHDS/Isom/Bensat units. Consequently, the flow to the idle PRISM can be increased until the limit in the PRISM feed compressor is reached.

The increased flow from the Mix Drum has a small impact on the FFHDS feed purity (still well above the existing level) and can still achieve the minimum constraint of 85% purity in the feed to the NHDS/Isom/Bensat units.

The most profitable combination in terms of financial savings is Project 10 with Project 6. Comparing Projects 11 and 12, there is little difference in achievable savings. However, the best economic combination of projects is Project 12 with Project 6, particularly considering the lower investment required to realise Project 12. These two combinations have been defined as projects as follows:

- Project 14: Projects 10 and 6 Combined
  Initial Savings Estimate: $12,780 per day or $4.5million per year
- Project 15: Projects 12 and 6 Combined
  Initial Savings Estimate: $10,860 per day or $3.8million per year

4.5 Targeting Summary

The savings identified in Target 0 and Target 1 are small. This is a reflection of the high degree of integration at the Carson refinery, which results in only a small amount of H_2 being purged to fuel gas. The project ideas identified in these targeting stages can save approx. $220,000 per year.

The Target 2a projects address the use of the idle PRISM unit and the spare compressor.

Incorporating the idle PRISM into the network is likely to bring realistic benefits. The most attractive project idea has an estimated savings potential of approx. $1million per year

Target 2a shows that there is only a small benefit from using the spare compressor. While the compressor does not fit with the existing network of headers, or even with individual unit supply and outlet pressures, it has not been completely rejected. The benefits improve when some of the purity constraints are relaxed, in particular the NHDS/Isom/Bensat feed purity.

For Target 2b, some geographical constraints were relaxed, and the optimisation was allowed to consider a new header. While significantly higher savings can be achieved than for Target 2a, the complexity of the required process modifications is proportionally larger.

The most significant finding in Target 2b is the benefit of upgrading the existing 200psig Mix Drum to supply 91.6% purity. This can be achieved by re-routing some of the less pure streams to a separate "header". The savings do not take into account potential benefits to production and yield in the No.2 Light Hydro, Mid Barrel and Tail Gas units resulting from higher purity H_2 in the feeds.

Target 3 identified that the two key issues are the purity requirements of the NHDS/Isom/Bensat units and the links between the North and South areas. At present, a supply at 98% purity is delivered to the NHDS/isom/bensat units, while a feed of approximately 85% purity would be sufficient.

The most direct solution is to export H_2 directly from the No. 1 H_2 plant to the South area. There is sufficient capacity in the plant to replace most of the purchased hydrogen. Based on the relative value of the two hydrogen sources, this would represent a saving of approx. $3.4million per year. In this simplest case, extensive piping and a new compressor would be required.

Two alternatives were identified, the more attractive of which utilises the spare capacity in the A/B compressors to transport H_2 from the No.1 plant to the South area, using existing piping. Here, a saving of $2.4million per year can be achieved.

A feature of this alternative is that part of the supply from the No. 1 H_2 plant is fed to the 200 psig header. As a consequence, the purity of this header would be higher than at present. Since this gas is ultimately supplied to the FFHDS, HCK, and Tail Gas units, as well as the South area plants, the inlet purities to each of these units increases compared with current operation. Particularly for the HCK and FFHDS units, this is likely to provide additional production/yield benefits.

This feature raises a further issue. If the scope of the analysis is held rigidly to improvements in the H_2 system only, production credits are not considered. Increasing the H_2 purity to a unit merely provides an additional degree of freedom in the system that can be exploited.

For example, increasing the purity of the 200psig header means that the inlet to the FFHDS unit increases by 0.4% to 89.7%. Increasing the recycle around the unit reduces the feed purity such that the unit model is once again consistent. The effect is to reduce the make-up flow to the unit and, in turn, the amount of purchased H_2. There is thus an incentive to investigate the limits of the FFHDS recycle compressor.

Note: none of the benefits calculated in this study include any production/yield credits, which may significantly affect the optimum combination of conditions. Furthermore, the basis includes a simplified model of the PRISM. It is recommended that this model be reviewed comparing it with available design and operating data where possible. Again, this may have a significant effect on the chosen investment route.

5
INVESTMENT STRATEGY ROADMAP

The main deliverable of the work is an investment strategy RoadMap, (Figure 5-1) which can be used for decision support by refinery management. The RoadMap details benefits in terms of hydrogen savings, capacity debottlenecking, improved energy efficiency and environmental impact. The RoadMap puts BP in a position to select the most economical route that best meets its criteria for future hydrogen supply.

Of the various project options that are structured in the RoadMap, some will be mutually exclusive (shown in parallel) and some will be interdependent (shown in sequence). Every branch point in the RoadMap represents a management choice for a certain investment route.

The savings shown for the various RoadMap “routes” vary considerably, but are all based only on the costs of fresh H2 and of compression. No economic credits were taken for possible improvements in production and/or yield, caused by improved H2 purity to certain units, even though these may be substantial in some cases. Evaluating such credits was outside the scope of this project.

5.1 Global Issues

Many of the issues currently affecting businesses and legislature are environmentally driven. It is the push for reduced sulphur and aromatics in fuels that is increasing the demand for hydrogen in many refineries. At the same time, public opinion and hence legislation in many countries is demanding improvements in air quality by forcing down emissions of CO_2.

The HydrogenPinch approach contributes to the environmental balance by:

- aiding the continued profitable production of low sulphur fuels
- reducing utility consumption (fuel and power) and hence CO_2 emissions.

The contribution towards efficient fuel production is detailed in the previous sections of this report.

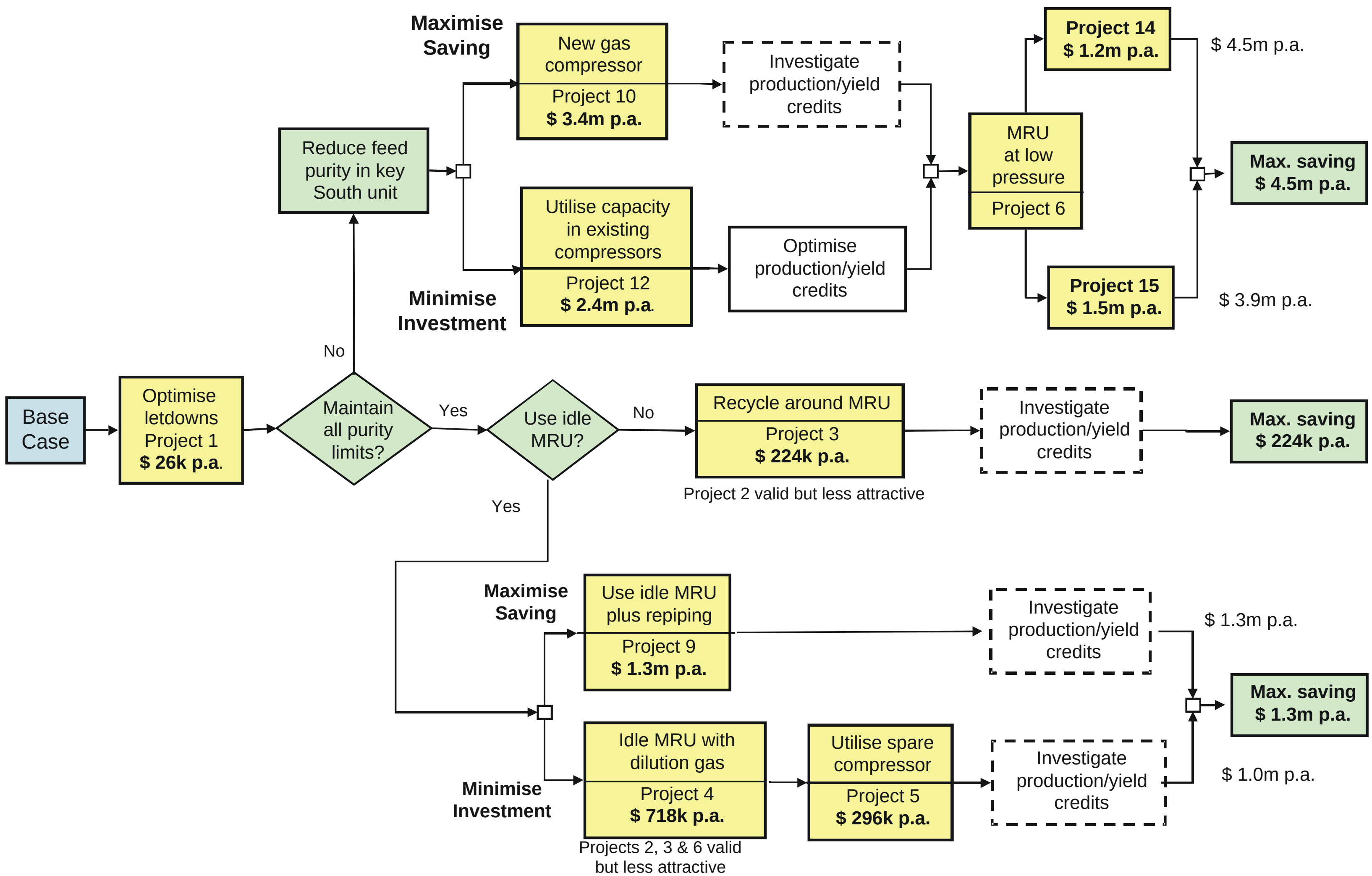

Figure 5-1
A RaodMap for Hydrogen-saving projects at BP Carlson

Improving hydrogen management impacts the global energy balance in 5 ways:

1. Reducing hydrogen production (as a result of increased recovery) will directly save fuel and power. Assuming that hydrogen generation is based on steam reforming of light hydrocarbons, reducing production will save fuel in the reformer reactor, and hence CO_2 emissions. Reducing throughput also saves compression power.
2. The reaction in a steam reformer converts hydrocarbons to hydrogen and CO_2. The hydrocarbons in question can be natural gas or refinery fuel gas. A reduction in throughput therefore positively affects fuel consumption and CO_2 emissions.
3. Recovering hydrogen from refinery fuel gas means that additional fuel will be required (assuming that the net demand for fuel stays constant). This fuel will generally be carbon-based and will result in increased CO_2 emissions.
4. A steam reformer is normally designed to generate steam from waste heat. Reducing hydrogen generation therefore reduces the availability of steam. Assuming that the energy requirements on site are otherwise fixed and constant, this steam must be replaced by steam boiler plant. This will thus have a negative impact on fuel consumption and CO_2 emissions.
5. Power for the site will be generated in steam turbines or gas turbines, either on-site or by a third party supplier. Globally, though, a saving in power will reduce fuel consumption and CO_2 emissions.

5.2 BP Carson Refinery Global Balance

The BP Carson refinery is supplied with hydrogen in part from a third party provider. For this balance, it was assumed that the external supply was based on steam reforming technology.

Generally, the projects developed for the BP Carson refinery result in a net reduction in fuel consumption and CO_2 emissions. However, most projects result in a net increase in power consumption.

The main projects recommended in the RoadMap are summarised as follows:

Project	Description	Annual Saving	Net Fuel Saving (MMBtu/h)	Net Power Saving (kW)	Net CO2 Reduction (MMlb/a)
14 (10+6)	New H2 Compressor + MRU at low pressure	$4.5m	33.1	-921	35.9
15 (12+6)	Utilise available compressor capacity + MRU at low pressure	$3.9m	11.3	-1790	12.3

1+4+5	Optimise letdowns + MRU with dilution gas + spare compressor	$1.0m	38.9	-864	42.2

6
SUMMARY AND CONCLUSIONS

Linnhoff March HydrogenPinch technology was used to identify a number of areas for potential improvement in the BP Carson refinery hydrogen system. A structured step-wise approach was adopted allowing identification and ordering of project ideas from “easy wins” through to more complex projects that impact processing unit operation.

Existing integration and recovery at the site is reasonably extensive. The amount of H_2 being burned as fuel is small, and the existing production and regeneration facilities are operating at, or close to, their limits. As a result, only small savings can be expected if these existing constraints are accepted as given.

Significant potential for improvement was identified in relation to three key areas:

- PRISM operation and the availability of a second PRISM unit.

  Project combinations utilising existing equipment with some additional piping were identified that could achieve up to $1.0m per year savings. More complex modifications could increase this saving to $1.3million per year.

- Capacity of No. 1 H2 plant.

  Increasing the capacity of the plant to its name-plate level opens up significant potential to replace purchased hydrogen.

- Feed purity to the NHDS/Isom/Bensat units in the South plant.

  The feed purity can potentially be reduced to 85% without adversely affecting the operation of the process. Projects were identified to exploit the full No. 1 H2 plant capacity and lower feed quality, giving savings of up to $3.4million per year.

The maximum saving achievable by combining projects is **$4.5million per year**. To realise this saving a new H_2 compressor would be required. However, it is expected that a slightly smaller saving of **$3.8million per year** would be achievable by making extensive use of existing pipework and available capacity in the A/B compressors.

The project incentives have been determined using a model of the hydrogen supply system. Capital cost estimates have not been carried out within this project. However, detailed engineering for the packages described in this report can be carried out by local contractor.

In addition to the identified improvements in hydrogen supply, the project combinations result in increased hydrogen purity to a number of units including the FFHDS. This offers scope for additional savings in production/yield. These benefits have not been evaluated in this work. It is recommended that the units are simulated to determine these additional savings.

An investment RoadMap has been developed, detailing alternative implementation routes of compatible project combinations and their benefits in terms of operating cost, capital avoidance, environmental impact, operability, and debottlenecking.