Aviation Rulemaking
Advisory Committee

Fuel Properties -
Effect on Aircraft and Infrastructure

Task Group 6/7

FINAL REPORT—Revised 7/15/98a
Task Group 6/7 on Fuel Properties
Report to the Fuel Tank Harmonization Working Group of the FAA Aviation Rulemaking Advisory Committee

1.0 ABSTRACT

The Fuels Properties Task Group was charged with assessing the feasibility of using jet fuel with a higher flash point in the civil transport airplane fleet than required by current Jet A/Jet A-1 Specification, as a means of reducing the exposure of the fleet to flammable/explosive tank vapors. This report describes the efforts performed by Task Group 6/7 for the Aviation Rulemaking Advisory Committee (ARAC) Fuel Tank Harmonization Working Group.

Raising the minimum flash point of jet fuel will result in a combination of changes to other fuel properties, such as viscosity. The magnitude of change is dependent on the severity of flash point increase. The engine and APU manufacturers have no experience base for such modified fuels, and are concerned about the risk of adverse impact on altitude relight and low temperature operations (especially Extended Twin Operations, ETOPS). Mitigating actions, including hardware modifications, fuel specification revisions, use of additives and revised operational limits, have also been reviewed. Dependent on magnitude of change, laboratory, rig and/or full-scale engine testing on reference fuels may be required to quantify the impacts.

Raising the minimum flash point could also significantly raise the manufacturing cost and decrease the availability of the modified jet fuel. The predicted impact on jet fuel price could be significant. Again, the higher the flash point, the more severe the affect.
The fuel impacts are most severe outside of the U.S. because of the differences in overseas refinery configurations and product demand. Some countries indicated that changes in flash point are not viable options to which they would subscribe (Canada, United Kingdom, New Zealand, Australia, Japan, Russia and the Commonwealth of Independent States).

2.0 SUMMARY

The Fuels Properties Task Group (Task Group 6/7) was formed by the FAA-ARAC Fuel Tank Harmonization Working Group to assess the impacts of raising the minimum flash point, and possibly lowering the freeze point, of commercial Jet-A/A-1 aviation fuel. Task Group 6/7 was comprised of representatives from the engine powerplant and auxiliary power unit (APU) manufacturers, petroleum industry, airframe manufacturers, air carriers, and the Department of Defense. The impacts on Engines, APU's, hardware manufacturers, jet fuel availability and cost are based on evidence and information drawn from surveys conducted of refiners in the U.S. (by API/NPRA), Europe (by Europia), and Japan (by PAJ), as well as responses from other international refiners.

The findings of the Task Group are summarized below:

2.1 Impact on Engine Integrity, Operation and Maintenance

The predicted fuel changes identified will result in a combination of fuel properties that can fall outside the current experience base. The magnitude of property change and potential introduction of new molecules increases with increasing flash point. Evaluation of such changes identifies the following key issues:

- Increases in low temperature viscosity and decreases in volatility are fuel property changes that may adversely impact operation /safety including failure of engine/APU cold starts and high altitude relight (including cold soak relight).

- Reduced fuel pump life due to increased wear rate when operating on lower lubricity fuels which may result in component failure.

- The following increased maintenance cost effects were identified but not quantified:

    ⇒ Increased maintenance of combustion and turbine components due to poorer combustion quality.
    ⇒ Fuel system and injector nozzle cleaning at more frequent intervals due to fuel lacquering and coking.
    ⇒ Reduced fuel pump life due to increased wear rate.

- Depending on the magnitude of the flash point increase**,** laboratory rig or full engine testing on representative high flash point reference fuels may be required to fully evaluate/quantify these effects.

- Emissions testing to verify EPA / ICAO regulatory requirements becomes increasingly probable with magnitude of flash point change.

- Mitigating actions were examined. They may include: hardware modifications, fuel specification revisions, and revised aircraft operational limits. The use of new additives will require extensive evaluation and approval programs.

- Any change to the minimum flash point will also necessitate the installation of heated auxiliary power units at an estimated cost of $1 million per APU model.

- The magnitude of the flash point change will dictate the actions required and cost incurred to continue to meet civil airworthiness requirements.

2.2 Impact on Jet Fuel Properties

- An increase in the jet fuel flash point specification will result in shifts of fuel properties. At some increase in the flash point specification, a high flash Jet-A becomes a new fuel, never before produced or used, with properties unlike any other fuel. For example, the viscosity is expected to be significantly higher than JP-5.

- The uncertainty concerning jet fuel properties resulting from a large flash point specification increase is a significant concern. The engine manufacturers have no experience base for such modified fuels.

- As the minimum flash point is increased, the average flash point of the jet fuel pool is predicted to be 12-15°F (6-8°C) above the flash point specification in the U.S. due to pipeline specifications and test method precision

- The shifts in jet fuel properties are expected to occur by three mechanisms:

  1. By changes in the distillation cut points of conventional refining.
  2. By creating incentives for jet fuel to be produced by modified processing schemes.
  3. By causing localities relying on unique refinery configurations or crude sources to experience "magnified" shifts in jet fuel properties.

2.2.1 Changes in Distillation Cut Points of Conventional Refining

- The impact of mechanism 1 was quantified by the Jet Fuel Properties Survey. The results found potentially important adverse impacts on:

  ⇒ 10% Boiling Point
  ⇒ Viscosity
  ⇒ Aromatics Content
  ⇒ Smoke Point
  ⇒ Density
  ⇒ Jet Fuel Availability

    – Jet fuel distillation yield is reduced by more than 1% per °F flash point increase.
    – Many of the crude oils examined cannot produce Jet A-1 with a very high flash point.

- Extrapolations in the growth of jet fuel consumption indicate pressure already exists on jet fuel availability and properties. The yield loss associated with an increased flash point specification exacerbates this situation.

2.2.2 Creating Incentives to Produce Jet Fuel by Modified Processing

- The yield loss associated with an increased flash point specification can create incentives for jet fuel to be produced by modified processing schemes. The impact could not be quantified on the short time scale of this study but the use of unconventional refinery processing is a significant concern:

⇒ Larger flash point changes result in greater incentives for the use of modified processing schemes.

⇒ One example of an unconventional processing scheme results in the increased use of hydrotreated cracked stocks in jet fuel. This could push certain properties towards the specification limits resulting in adverse impacts on:

  - Aromatics Content
  - Smoke Point
  - Thermal Stability

⇒ The production of jet fuel by a different mix of conventional processing schemes should not impact fuel properties as much as the use of unconventional processing. However, the increased use of severe hydrotreating (a conventional process) is expected to negatively impact fuel lubricity.

2.2.3 Magnified Shifts in Localities with Unique Refinery Configurations or Crude Sources

- Localities relying on unique refinery configurations or crude sources may experience "magnified" shifts in jet fuel properties. Although this could not be quantified in the short time frame of this report, the following examples illustrate this concern:

⇒ Areas using predominately naphthenic crude oils (such as those found in California) might experience viscosity shifts much larger than average resulting in a significant number of batches being produced close to the specification limit.

- The increased use of severe hydroprocessing, to restore fuel availability, may cause some localities to receive mostly low lubricity fuel.

- Some fuel properties may be addressed by the use of additives.

2.3 Impact on Jet Fuel Availability and Manufacturing Cost

- The higher the flash point the more severe the impact.

- Higher flash points could result in significant shortfalls of jet fuel availability and could require at least five years for industry to endeavor to meet jet fuel demand.

- In the U.S., average refinery shortfalls of about 5% at 120 degrees and about 20% at 150 degrees could occur (weighted average, assuming 1 - 2 years lead time

- Outside the United States, requirements for higher flash point jet fuels could result in production shortfalls of 12% at 120 degrees and up to 49% at 150 degrees (weighted average, assuming 1 - 2 year lead time).

- The API survey results address jet fuel demand at 1998 levels. The survey does not address long-term changes in jet fuel demand, which is projected to grow by 6 - 15% more than other refined products by 2010. Environmentally driven reformulation of other fuels, (e.g., toward “light” diesel) will further increase demand for the jet fuel portion of the barrel. These pressures are likely to amplify the difficulties predicted for the 1998 level.

- Requirements for higher flash point jet fuels could result in United States refinery production cost increases of 1.5-2.2 cents per gallon at 120 degrees and 6-7.5 cents per gallon at 150 degrees (assuming 7% ROI). Based on current U.S. jet demand, this translates into annual costs of $350-520 million at 120 degrees and $1.4-1.7 billion at 150 degrees.

- Outside the United States, requirements for higher flash point jet fuel will result in refinery production cost increases of 3-15 cents per gallon at 120 degrees and more that 20 cents per gallon at 150 degrees. Based on current jet demand, this translates into annual costs of $320-900 million for the 120 to 150 range of flash points (assuming 15% ROI).

- The potential for increased production cost and decreased capacity could dramatically impact the market price of jet fuel. Price elasticity models have been used to calculate the increases in price that could occur for various combinations of capacity reductions and price elasticities. Based on a price elasticity of 0.2, the annual cost is $4 to $13 billion. No substitutions for jet fuel were assumed to be available.

2.3.1 Impact Outside the United States

- The difference between U. S. and non-U.S. availability and cost result from:

    - ⇒ The lower yields associated with the manufacture of lower freezing point Jet A-1, which is the predominant jet fuel outside the U.S.
    - ⇒ Markedly different regional petroleum product demand and refinery structure.

- Based on the surveys, more refiners worldwide than in the U.S. reported that it is not feasible to produce higher flash point jet fuels in the current refinery installations.

- The Task Group attempted to determine the potential for localized supply and demand imbalances due to increased flash point requirements. Results of informal surveys showed that individual refineries vary greatly in their flexibility to provide the same fuel volume at various flash points, but it was not generally possible to pinpoint specific airport supply imbalances in the U.S. Australia, New Zealand, and Japan were identified as subject to potential shortages of Jet A-1 fuel if flash point requirements are increased.

2.4 Other Issues

- As the minimum flash point increase, more refiners are likely to have difficulty producing gasoline and diesel that complies with current state and federal environmental regulations.

- Engine emissions may need to be remeasured for reporting purposes, and some number of engine models may been to be recertified.

- Commercial airlines will continue to uplift low flash fuels particularly in Russia and the Commonwealth of Independent States (C.I.S.) and Wide-Cut fuels in Northern Canada. In today's global market, there is no practical way to avoid mixing fuels from different parts of the world.

- Cold climate operation could become an issue at higher minimum flash points. Increasing the flash point would reduce the more volatile, low-boiling components of the fuel, which in turn leads to an increase in viscosity and exacerbates an already tenuous cold starting situation and APU in-flight starting problems.

- Russian aircraft and engines have not been designed to operate on high flash fuel. Impacts on their operability and airworthiness have not been determined.

The aviation fuel community has a high confidence level with currently produced fuel because of a long experience base. Task Group 6/7 cannot readily measure the existing margin to alter the fuel for all aircraft engine types. Effects from changes at a single source are difficult to determine because they are usually lost in the pool fuel volume, so that continuous operation at the extremes of the property limits is infrequent. Conversely, changes to the jet fuel pool as a whole, must of necessity, be viewed with concern. The concern for a change in minimum flash point to 110-120ºF is significant; for a change to 140ºF it is many times higher because refiners can be expected to change production methods and reduce specification margins on a broad scale. Possible mitigating actions to offset adverse effects on engine and APU operation might include hardware modifications, adjustments and re-calibrations. Other revisions of fuel specification requirements may be necessary in addition to the flash point increase the impact of such additional changes on availability has not been evaluated.

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4.0 INTRODUCTION

The purpose of this report is to evaluate the availability, cost, and risk associated with changing to a high flash point jet fuel for commercial aviation.

In November 1997, the FAA requested that the American Petroleum Institute (API) examine the ramifications (production, cost, schedule) of the United States commercial aviation industry utilizing a Jet A/A-1 type of fuel with a minimum flash point of 140°F(60°C) to 150°F(66°C) in place of the current Jet A/A-1 fuel. The FAA also requested that the API participate in a dialogue with FAA and industry technical specialists regarding this proposal. In a subsequent letter from the FAA dated February 26, 1998 to API, the petroleum industry was asked by the FAA-ARAC Fuel Tank Harmonization Working Group to develop and compile data on the availability of a Jet A type fuel (both domestic and international) with a higher flash and a possible lower freezing point. The FAA requested the assessment of possible impact on production volumes; short- and long-term cost increments and capital investments to make up any loss in production. For this assessment, flash points of 120°F(49°C) to 150°F(66°C) in ten degree increments were identified, as well as freezing points of -40°F(-40°C) and -53°F(-47°C).

The API, in conjunction with the National Petrochemical & Refiners Association (NPRA) conducted a survey of individual refineries to assess the availability and cost of producing high flash point fuel for commercial aviation in the U. S., Europe, and other parts of the world. This report presents the combined results of the API/NPRA survey (Appendix 1), European (EUROPIA) survey (Appendix 2), and the PAJ (Petroleum Association of Japan) survey (Appendix 3) and correspondence with some refineries in other parts of the world.

The aviation industry representatives assigned to Task Group 6/7 include jet fuel suppliers who are represented by the API, airlines, engine, auxiliary power unit (APU), and airframe manufacturers as well as government representatives, including the FAA. This Task Group has investigated the complex issues associated with raising the flash point and lowering the freezing point of commercial aviation jet fuel. The impacts on aircraft engines, APUs, aircraft systems, fuel transportation, fuel availability, and fuel cost as well as the possible implications on the production of other petroleum products have been studied. In addition, the Task Group has considered flight safety, certification issues, emissions, military experience, and the impact on fuel price.

5.0 REFERENCES

References are included in the individual sections.

6.0 BACKGROUND

6.1 The Development of Specifications

Just as military jet operation preceded commercial flights by more than 10 years, military fuel and commercial specifications showed the same time lag. The earliest U. S. Air Force specifications for grades JP-1 and JP-2 never achieved wide usage. Published in 1947, grade JP-3 maximized availability by a blend of kerosene and gasoline with the vapor pressure of aviation gasoline. After this wide-cut fuel caused high boiling losses in high altitude operations, subsequent changes were directed toward tightening quality, particularly volatility. First the wide-cut JP-4 reduced vapor pressure drastically in 1951; then the kerosene-type JP-8 removed lighter components altogether in 1979. By closely modeling JP-8 after the commercial Jet A-1 grade the Air Force hoped to maximize its availability. These volatility decreases were possible in part because of a continuing decrease in DOD fuel consumption, but JP-8 caused numerous performance problems, particularly with older equipment. In 1952 the U.S. Navy developed JP-5, a low volatility fuel, to protect aircraft carrier tankage. Because of the restrictive combination of high flash point and low freezing point and because its use has been primarily restricted to carrier operations, this fuel has always had limited use and availability.

ASTM specifications have included both kerosene and wide-cut grades since 1959, but the wide-cut grade, Jet B, has seen no use in the U. S. and only limited use outside the U.S.. Instead the Jet A grade has represented the best compromise between the properties of commercial kerosene and the requirements of aircraft operation within the U.S.. For international operations the Jet A-1 grade followed the British lead with a lower freezing point. Over the years the compromise between availability and performance has held up well except for two specification areas where shortages forced relaxations. Due to supply dislocations which required blending with less desirable crudes in 1973 an increase in aromatic content and a decrease in smoke point was permitted, provided the deviations were reported to the operators. At the same time the freezing point of Jet A-1 was raised from -50 to -47°C, a relaxation which was carried over into other specifications. Today the reporting requirements have been dropped and the decreases in combustion requirements have been made permanent in recognition of satisfactory aircraft performance. The changes were made only after reviews of equipment performance to assure the absence of unexpected secondary effects.

Selected requirements of U. S. military and commercial specifications are summarized in Table 1, attached. Only those properties thought to be influenced by an increase in flash point or freezing point have been included. For a later comparison Table 1 also contains the same requirements of the Russian specification, TS-1.

Overall, the current jet fuel specifications are experience based and tend to reflect solutions to past problems. Specifications, therefore, cannot be expected to anticipate new problems that might occur with fuels meeting current specifications. An example is the current focus on fuel lubricity difficulties that seem to have increased as refinery processing has been changing. Because this property has not caused difficulties in past commercial operations it is not currently limited. However, as this problem has become more prominent, efforts are underway to modify specifications to control this property. In the case of fuels produced from novel sources or new processes it is necessary to review the performance of such products before deciding on the applicability of existing specifications.

Specification→	ASTM D1655	Joint Check List	MIL-T-5624	MIL-T-5624	GOST 10227
Grade →	Jet A/A-1	Jet A-1	JP-5	JP-4	TS-1
Property ↓					
Aromatics, vol. % Max.	25	22 [a]	25.0	25.0	22
Sulfur, mass % Max.	0.3	0.30	0.40	0.40	0.25
Distillation, °C (°F)					
IBP		Report	Report	Report	150 Max.
10% rec. Max.	205 (400)	205 (400)	206 (403)	Report	
20% rec.		Report	Report	100 max.	
50% rec.	Report	Report	Report	125 max.	195 Max.
90% rec.	Report	Report	Report	Report	230 Max.
98% rec.					250 Max.
Final BP Max.	300 (575)	300 (575)	300 (575)	270	
Flash point, °C (°F) Min.	38* (100)	40* (104)	60** (140)		28 (82)
RVP, kPa (psi)				14 - 21 (2.0-3.0)	
Density, kg/m^3	775 – 840	775 – 840	788 - 845		775 Min.
Freezing point, °C (°F) Max.	-40 [b] (-40)	-47 (-53)	-46 (-51)	-58 (-72)	-50 (-58)
Viscosity @-20°C, cs Max.	8	8.0	8.5		8 @ -40
Specific energy, MJ/kg Min.	42.8	42.8	42.6	42.8	42.9
Smoke point, mm or Min.	25	25	19	20.0	25
Smoke point , mm + Min.	18	19			
Naphthalenes, vol. % Max.	3.0	3.0			
JFTOT @ 260°C	[c]				
Tube rating Max.	< 3	< 3	< 3	< 3	18 mg/100 mL Max.[d]
Pressure drop, mm Hg Max.	25	25	25	25	
Additives					
Anti-icing, vol. %	Agreement	Agreement	0.15 – 0.20	0.10 – 0.15	Agreement
Antioxidant	Permitted	Agreement[e]	Agreement[e]	Agreement[e]	Agreement
Corrosion inhibitor/	Agreement	Agreement	Required	Required	
Lubricity agent					Agreement
Metal deactivator	Permitted	Permitted	Permitted	Permitted	
Conductivity improver	Permitted	Required	Not permitted	Required	Agreement
Conductivity, pS/m	50 – 450 [f]	50 - 450		150 – 600	50 – 600[f]

<u>Section 6-1, Table 1--Critical Fuel Properties in Specifications</u>

[a] or 25% max + report % hydrogen
[b] Jet A-1 freezing point is -47°C (-53°F) maximum.
[c] ASTM D1655 permits retesting at 245°C.
[d] Different test method. Correlation with D 3241 (JFTOT) being established.
[e] Required if hydrotreated
[f] If conductivity improver is used
* Flash point by D 56 (Tag)
** Flash point by D 93 (PM)

6.2 The Manufacture of Jet Fuel

Generally in the US, the system to produce and consume petroleum products is well balanced. This actually is an operational constraint because there is relatively little storage capacity for refined products built into the distribution system. The U.S. refinery system is optimized to produce a large amount of motor gasoline and smaller amounts of "No. 2 fuels" (diesel fuel/heating oil) and "No. 1 fuels" (jet fuel, No. 1 diesel fuel and No. 1 fuel oil).

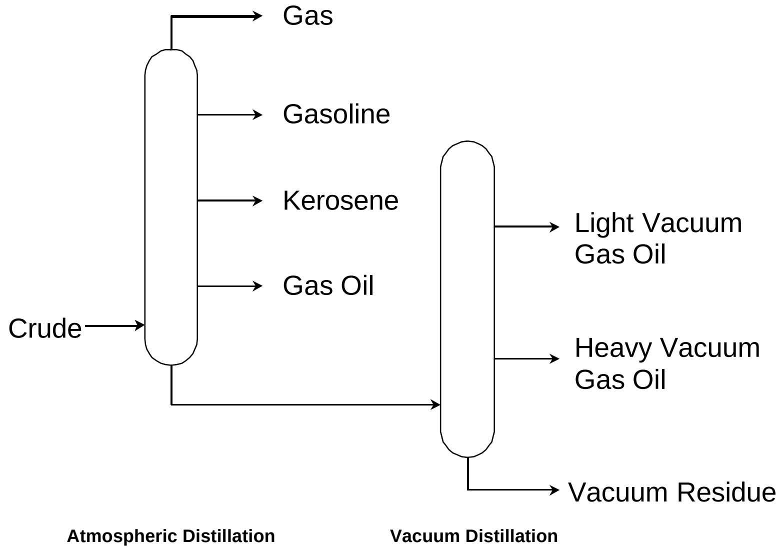
The production of petroleum products is a complex process. Some of the complexity of the system is retained in this overview, despite the temptation to simplify, because the impact of jet fuel specification changes can only be appreciated with some knowledge of the complexity of the production system.

6.2.1 Conventional Processes

6.2.1.1 The Crude Unit

Petroleum products originate from crude oil. There is no such thing as a "typical" crude oil. All crude oils are unique mixes of many different chemical compounds. An important variable of crude oils is the yield of light products (gasoline, No. 1 fuels, and No. 2 fuels) that they can produce when distilled. The demand for a crude oil generally correlates with the yield of light products that can be produced from it. Crude oil is processed into petroleum products at refineries. Refineries vary greatly in complexity. The simplest refinery consists of only an atmospheric crude distillation unit. Most refineries, however, also have a vacuum distillation unit in which case the units, together, are known as the crude unit (Section 6.2, Figure 1.)

Section 6.2 Figure 1. Schematic Diagram of a Crude Unit.



The crude unit separates crude oil into various fractions (or streams) by distillation. The typical streams produced from a crude unit are:

Stream	Typical Boiling Range °F	°C	Finished Products or Disposition
Gas	<100	<38	Liquefied Petroleum Gas
Gasoline	100 – 400	38 – 205	Gasoline/Naphtha
Kerosene	300 – 500	150 – 260	Jet Fuel, No. 1 Diesel, No. 1 Fuel Oil
Gas Oil	400 – 650	205 – 345	Diesel Fuel, No. 2 Fuel Oil, Heating Oil, Cracker Feed
Vacuum Gas Oil	600 – 1000	315 – 540	Lube, Cracker Feed
Residue	>1000	>540	Asphalt, Coker Feed

According to the API/NPRA Aviation Fuel Properties Survey (Appendix 1), 78% of the capacity to make jet fuel in the U.S. is production from crude units.

In operating a crude unit there are basically only three parameters that can be adjusted to influence the yield of jet fuel:

1. The selection of crude oil(s) processed.
2. The front end cut point (lower end of boiling range) of the jet fuel stream (to trade off with naphtha yield).
3. The back end cut point (upper end of boiling range) of the jet fuel stream (to trade off with diesel fuel yield).

Jet fuel is generally the most highly specified fuel (ASTM D1655 in the U.S) that a refiner makes. The flash point specification limits the amount of naphtha that can be incorporated into jet fuel. The aromatics, smoke point, naphthalenes, freeze point, and viscosity specifications often constrain the back end cut point of jet fuel.

The challenge facing the operator of a simple refinery in reacting to flash point specification changes is illustrated by considering jet fuel yield changes from a common crude oil. With this light crude about half the jet fuel yield is lost at 140°F (60°C) flash point versus the current specification. The following table was prepared assuming perfect distillation, and a release limit 8°F (4.4°C) above the specification minimum. It shows that the light crude yield loss would be:

Flash Point Specification, °F (°C)	**100 (38)**	**120 (49)**	**140 (60)**
Initial Boiling Point, °F (°C)	260 (127)	302 (150)	353 (178)
End Point, °F (°C)	555 (291)	538 (281)	501 (261)
Yield Loss, %	0	19	48
Freeze Point, °F (°C)	-40 (-40)	-40 (-40)	-40 (-40)
Flash Point, °F(°C)	108 (42)	128 (53)	148 (64)

Note that for crudes, such as this, where jet fuel yield is constrained by freeze point, jet fuel yield is lost both at the front end (increased initial boiling point to meet flash point) and the back end (reduced end point). To understand this, it is necessary to appreciate that jet fuel distilled from crude oil usually contains a small but significant amount of higher boiling straight-chain paraffin molecules. When the fuel is cooled to low temperatures, these paraffin molecules can associate to form wax crystals. To avoid the possibility of fuel flow problems, a freeze point specification is included in ASTM D1655 to ensure that wax crystals do not form at fuel temperatures normally encountered during aviation operations. The lower boiling portions of jet fuel are effective solvents for dissolving wax crystals. As the initial boiling point of a jet fuel is increased (to reduce flash point), solvency for wax crystals is lost. This requires that the end point of the fuel be reduced to remove the straight-chain paraffin molecules that can form wax so that the fuel can meet the freeze point specification.

In reality, crude units do not provide perfect distillation. Capital for upgrading the refineries is required to improve stripping to sharpen the cut point between the naphtha and jet fuel streams.

6.2.1.2 Jet Fuel Hydrotreating/Hydrodesulfurization

Most refineries have one or more units to "finish" jet fuel. Kerosene from the crude unit may, depending upon crude sources, contain too much sulfur and/or mercaptan sulfur (R-SH) to meet specifications. A common unit that removes both forms of sulfur from jet fuel is the catalytic hydrotreater. In this unit, jet fuel is treated with hydrogen at moderately high pressure (200-800 psi) and temperature (500-700°F, 260-370°C) in the presence of a metal catalyst to reduce sulfur and remove it from the fuel.

6.2.1.3 Merox Process

An alternative process often used for finishing jet fuel that has acceptable sulfur content but high mercaptan sulfur is the Merox process. The Merox process converts mercaptans to disulfides by the following oxidation reaction:

$$2\ RSH + \tfrac{1}{2}\ O_2 \rightarrow RSSR + H_2O$$

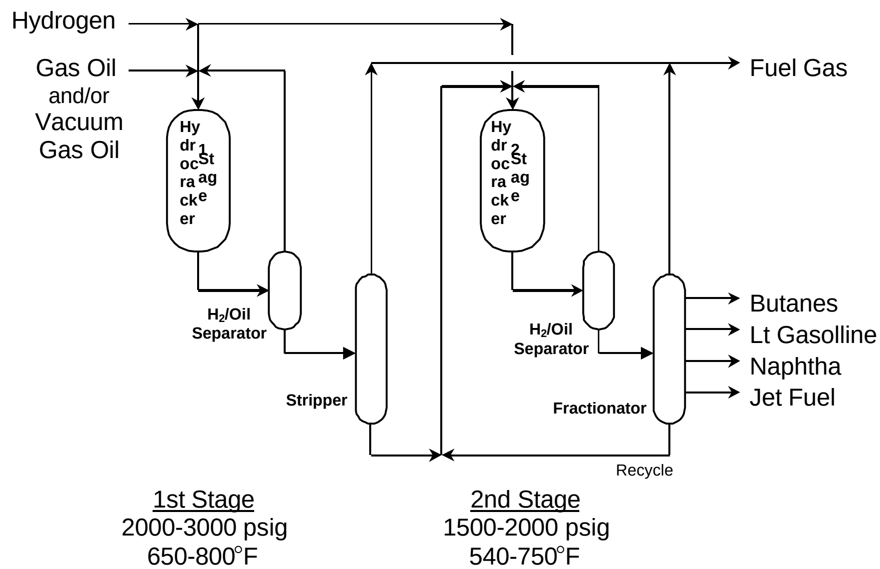
6.2.1.4 High Pressure Hydrotreating/Hydrocracking

According to the API/NPRA Aviation Fuel Properties Survey (Appendix 1), 22% of the capacity to make jet fuel in the U.S. is found in hydrocracking units. Hydrocracker units (Section 6.2, Figure 2) are used in complex refineries to convert low-value petroleum fractions into valuable light components by breaking large, high boiling molecules, into smaller molecules. The large molecules are cracked by the action of a catalyst at very high temperature (600-800°F, 315-425°C) in the presence of very high pressure (up to 3000 psi) hydrogen. The operating conditions are such that hydrogen adds to unsaturated (cracked) molecules to prevent the formation of coke that would deactivate the catalyst. Hydrocrackers produce good quality jet fuel in terms of aromatics content, smoke point, and oxidative thermal stability.

Hydrocrackers units are expensive to install and operate because they use hydrogen gas at very high pressure and temperature. The expense arises both from the unit construction/installation (driven by the cost of the large, high-pressure vessel and the hydrogen compressors) and operation (cost of hydrogen and energy to compress it). Because of their high cost, many U.S. refineries and a large proportion of the refineries outside of the U.S. do not have hydrocracking units.

Hydrocracking is not a means to tailor molecules to any required form: increased jet fuel flash point specifications are expected to reduce jet fuel yields from existing hydrocrackers by the same mechanisms as crude unit yield losses described above. Note that this is seen in the API survey where refineries both with and without hydrocrackers predict similar jet fuel yield losses. Hydrocracker operators have some (limited) ability to tune the mix of products produced by the unit. Typical parameters are hydrocracking severity (function of temperature and hydrogen pressure) and recycle (proportion of product streams fed back into the hydrocracker). For example, some hydrocracker units are operated to recycle diesel fuel to extinction so that gasoline and jet fuel yields are enhanced and diesel fuel production is eliminated. A disadvantage of increased severity and recycle-to-extinction is that both strategies tend to increase the yield of gaseous products that have relatively little value versus light products.

Section 6.2 Figure 2. Schematic Diagram of a Two-Stage Hydrocracker



6.2.1.5 Catalytic Cracking/Thermal Cracking

Catalytic and thermal cracking units are often found in complex refineries. There are many variations in the way that these processes are implemented in various refineries including:

- FCC (Fluidized Catalytic Cracker)
- Delayed Coker
- Visbreaker

These units use high temperature, with catalyst in the case of FCC, to crack large molecules to light products. The units do not use high hydrogen pressure so cracked products are relatively high in unsaturated compounds.

This provides high octane quality in the gasoline produced but most of the product produced in the boiling range compatible with No. 1 and No. 2 fuels is used for diesel fuel or is used as feed to hydrocracker units. In principle thermally or catalytically cracked streams boiling in the No. 1 fuel range could be hydrotreated to stabilize them and then blended into jet fuel. This is not usually done for several reasons. Some of the streams (FCC distillates, for example) contain so much aromatics that only a very small amount can be blended into jet fuel before exceeding D1655 aromatics and/or smoke point specifications. The streams from these processes are more difficult to hydrotreat and cause operational problems in the jet fuel hydrotreater operation. Further, if hydrotreating is not done properly, the fuel can have poor stability performance despite meeting specifications. With sufficient incentive, refiners having these streams might use them to increase jet fuel yield. Note that if this type of blending were done, many more batches of jet fuel pushing the aromatics and/or smoke point specifications would be produced than currently occur.

6.2.2 Refinery Configuration Issues

Existing refineries have specific processing units that may constrain their upgrade path. For example, if a refinery has an FCC unit to upgrade gas oil and/or vacuum gas oil, the refinery is unlikely to add a new hydrocracker unit and mothball the FCC unit.

6.2.3 Advanced Processes for Jet Fuel Production

6.2.3.1 Aromatics Saturation of Cracked or Aromatic Streams

With sufficient incentive, a refiner might choose to install a new high-pressure hydrogenation unit to saturate the aromatics and olefins in thermally or catalytically cracked streams boiling in the No. 1 fuel range. This would tend to increase the content of naphthenes in jet fuel. Increased naphthenes in jet fuel are not expected to cause problems but equipment/engine builders need to confirm this before widespread implementation. The aromatic saturation process can also be employed to increase jet fuel yields from aromatic crude oils.

6.2.3.2 Jet Fuel Synthesis by Fischer-Tropsch Chemistry

Kerosene from Fischer-Tropsch synthesis will be used to enhance jet fuel production in South Africa. Fischer-Tropsch chemistry produces pure paraffins (after hydrotreating to remove oxygenates) from synthesis gas (made from natural gas or coal). This kerosene is so low in aromatics that specifications require that it be blended with conventionally produced streams to avoid problems with seal shrinkage. Furthermore, specification changes have been proposed to define a lubricity and minimum aromatics requirement. Blending also helps to improve the poor lubricity performance of this kerosene. The production of blending streams for jet fuel by Fischer-Tropsch synthesis contributes little to jet fuel production on a world-wide basis because Fischer-Tropsch processing is generally more expensive than conventional processing.

6.2.4 Experimental Processes for Jet Fuel Production

The following processes have not been used commercially for jet fuel production and are not expected to contribute to jet fuel production in the near term. They are included here for the sake of completeness.

6.2.4.1 Catalytic Dewaxing

Catalytic dewaxing is not used commercially for jet fuel production. Catalytic dewaxing was developed and commercially implemented to improve the low temperature performance of diesel fuel. It could be adapted and installed in refineries to increase jet fuel yield. The use of this processing would permit many crudes to be distilled to higher end points resulting in raw kerosene streams failing jet fuel freeze point specifications.

Catalytic dewaxing could then be applied to the kerosenes to bring the freeze point of the finished fuel into compliance with the specification.

Catalytic dewaxing works by selectively removing the straight-chain paraffin molecules that form wax. Catalytic dewaxing probably will not provide a significant increase in jet fuel yield from crude oils where yield is constrained by smoke point instead of freeze point.

6.2.4.2 Jet Fuel Synthesis by Alkylation

Alkylation is not used commercially to produce jet fuel. Alkylation units are used by refiners to make high octane, non-aromatic gasoline and aviation gasoline from *I*-butane and olefins (butenes, or mixtures of butenes with propylene or amylenes) via acid catalysis. Refiners use the process because it converts gaseous by-products to valuable gasoline. In principle, it is possible to employ alkylation to produce jet fuel-range molecules. This type of processing might play a role in jet fuel production if incentives become large enough, but significant process development and refinery capital investment would be required before commercialization. An even greater amount of work should be done to ensure that the resulting jet fuel is suitable for aviation operations. In particular, any impact of impurities arising from the acid catalyst would need to be known and judged acceptable by equipment/engine manufacturers.

6.3 Transportation from Refinery Gate to Airport

Jet fuel leaving the shipping tank in a refinery is generally destined for a terminal which is a distribution center for more local deliveries. The fuel can travel by water, pipeline, rail or road, but almost always in large volumes. In the U. S. most jet fuel goes to terminals by large common carrier pipelines which are both multi-product and fungible in nature. These lines carry all distillate products, from gasoline to diesel fuel and heating oil and each product grade contains products from numerous shippers, all meeting the same specification (“fungible product”). Product grades follow each other with no physical separation and individual product quality is maintained by using very large tenders and minimizing inter-product mixing by turbulent flow in the pipeline. In addition, pipelines often add a shipping margin on critical properties. Additives in all products are carefully controlled to avoid cross-contamination. Mixed product or interface is minimized by cutting the higher quality product into the lower quality wherever possible. Because jet fuel is in contact with gasoline and/or diesel fuel, care must be taken to prevent jet fuel flash point decreases through gasoline mixing and thermal stability and freezing points deterioration by diesel or heating oil addition. An additional U. S. problem is the presence of dyed high sulfur diesel and heating oil which cannot be allowed to mix with jet fuel.

In much of the rest of the world jet fuel is most likely to be delivered by pipelines or ocean tankers. These ships may carry jet fuel in dedicated compartments or may depend on cleaning and careful product sequence to operate as multi-product vessels. Because batches are smaller, supplier identity is usually maintained. While commercial U. S. jet fuel moves by rail cars only in Alaska, such transport is common elsewhere. Road transport to terminals is used only where distances are short. Product is usually unfiltered until it reaches the terminal.

During terminal to airport transport most jet fuel is moved by single product means. Some pipelines are fungible and carry only jet fuel. Road transports are segregated by supplier and tend to be restricted to jet fuel. Wherever possible, barges carry only jet fuel because of cleaning difficulties. In this portion of the system much of the equipment is internally coated to minimize contamination. Product is always filtered when leaving the terminal.

On airports the fuel may travel from storage to the aircraft by special trucks equipped with their own pumps (“fuelers”) or it may move underground to loading gates through pressurized piping (“hydrant system”). The fuel is always filtered into and out of storage and again into aircraft. Water and solid contaminants are constantly removed to furnish clean and dry product to the aircraft. Product at airports is normally commingled among suppliers, but some airports may have single suppliers, thereby amplifying the effects of any property changes.

A major difference between the U. S and the rest of the world is the fuel custody on the airport. In the U. S., custody is transferred at the airport boundary and the fuel on the airport belongs to the airline. Generally, outside the U. S. the fuel supplier maintains ownership and handles fuel up to the aircraft skin. Because the responsibility for quality control is with the owner, U. S. airport quality controls rests with the airlines, while elsewhere the fuel suppliers are responsible.

6.4 Aircraft Fuel System Design

The major components of a typical commercial air transport fuel system are (1) vented tanks using primarily the wing box, (2) an engine fuel feed and transfer system, and (3) a fuel quantity measurement and indication system. Fuel tanks are usually located within the wing box of the airplane. A minimum of one tank is required for each engine. For example, on a twin engine aircraft, there is at least one tank located in each wing of the aircraft. If the aircraft size and range require additional fuel capacity, then the center wing box is designed to hold fuel. On a four engine aircraft there are two main tanks in each wing with additional capacity provided by the center tank. For long-range aircraft, fuel can be stored in reserve tanks also located in the wings, in the horizontal stabilizer, and occasionally in body tanks. All tanks (except body tanks) are integral with aircraft structure and are sealed on the inside to eliminate leaks.

The tanks are vented to the atmosphere such that there is at least one open vent port for each tank under all conditions. The vent system maintains inside tank pressure at near ambient pressure by allowing airflow into and out of the tanks during refueling, fuel use, and during climb and descent. The vent system is designed not to exceed the pressure limits for tanks.

Tanks are designed to minimize trapped fuel and a sump (drain) is provided in each tank to collect water and particles of debris. Most large aircraft have continuously operating water scavenging (removal) system or the sumps are manually drained regularly. An independent fuel feed system is required for each engine with a capability to cross-feed to the other engine(s) when necessary. A typical engine fuel feed system consists of electrically driven boost pumps in the tanks, fuel lines, valves and fittings. In addition, the engine has the capability to draw fuel from the tank if for some reason the boost pumps become inoperative. An independent fuel feed system is also provided for the auxiliary power unit (APU). The system is designed for rapid pressure fueling and for defueling. Some aircraft are designed to jettison fuel overboard if it becomes necessary to land before enough fuel is used to reduce aircraft weight in order to satisfy landing requirements.

The system design philosophy, along with experience gained in fleet operation, has evolved into current design standards. Each aircraft is certified to fly on specified fuel types. These generic fuel types include the kerosene fuels — Jet A/A-1, JP-8, JP-5, & TS-1, and wide-cut fuels — JP-4 & Jet B. However, some of the newer airplane models are not certified to use any wide-cut fuel. Flight tests are conducted under extreme operating conditions to ensure that the fuel system as designed will provide the specified fuel to the engine without interruption.

6.5 Current Jet Fuel Demand

Jet fuels delivered to the airlines conform to the property requirements identified in one or more of the many different jet fuel specifications used throughout the world. The majority of these fuels can be grouped into three main types of kerosene fuels. They are Jet A, Jet A-1, and TS-1. There is a very small amount of wide-cut fuel (JP-4 and Jet B) used by commercial airlines in Northern Canada and at some remote locations worldwide that also serve as military airfields.

About 38% of the jet fuel is up-lifted in the United States. (See Table 1) U. S. consumption together with Western Europe accounts for 57% of the world jet fuel demand. It is estimated that a change in jet fuel flash point, which may be implemented in the U.S. and Europe, would prompt similar changes in other jet fuel specifications effectively covering over 70% of the delivered jet fuel. Today, only about 7% of all jet fuel manufactured for the worldwide fleet has a flash point less than 100^{o}F(38^{o}C). These data[1] are estimates only, since details are not available on consumption of jet fuel by type.

[1] Section 6.5 Ref. 1. Derived from the International Energy Annual, DOE/EIA-0219(96), February 1998.

	Jet A	Jet A-1	TS-1
U. S.	1,514		
Other North America	65	66	
Central & South America		146	
Western Europe		771	
Africa		125	
Middle East		154	
Former Soviet Union			267
Eastern Europe		25	
China		86	20
Other Far East		753	
Total	1,579	2,126	287

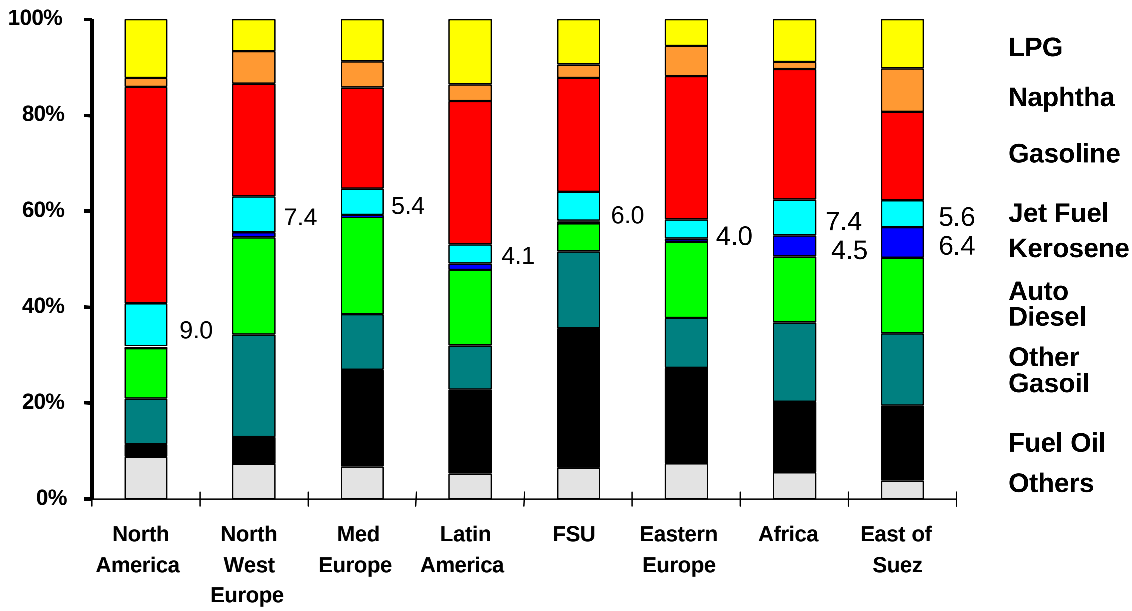
Section 6.5, Table 1—Approximate Consumption of Jet Fuel in 1995 (thousands of barrels per day; barrel = 42 U.S. gallons)

6.6 Demand for Other Distillates

Oil refineries produce a wide spectrum of products from crude oil, ranging from Liquefied Petroleum Gas (LPG) to Bitumen. The demand for each of these products varies from region to region depending on local circumstances. For example, in some regions fuel oil is used for power generation and kerosene is a domestic cooking fuel, in others power generation and domestic cooking are both fueled by natural gas.

One of the most striking differences is gasoline/gas oil balance between North America and Europe, illustrated in Figure 1. North America is primarily a gasoline economy and refineries are configured to maximize gasoline production. Diesel/gas oil demand and production is relatively low. In Europe, the demand for gasoline and gas oil is much more balanced. This European balance is typical of most regions of the world. In this context, North America has the unusual demand pattern.

One of the consequences of this difference is that, in Europe and the rest of the world, there is real competition between jet fuel and gas oil/diesel for the distillate fraction of the barrel in addition to the more constrained freeze point of Jet A-1.



Section 6.6, Figure 1--Variation in the Demand for Products Across Different Regions of the World

This dramatic difference in cut of the barrel demands between North America and Europe is one of the main reasons for the different impacts on jet fuel availability predicted for changes in flash point.

It should also be noted that forthcoming legislative changes for diesel fuel in Europe are likely to raise the competition for kerosene molecules as diesel fuels are required by legislation to decrease and more kerosene will be required to meet the diesel fuel demand.

6.7 Military Experiences

During the most recent fiscal year (FY 1997, ending 30 September 1997), the Defense Energy Support Center (DESC, formerly the Defense Fuel Supply Center, or DFSC) purchased worldwide, on behalf of the U.S. government (mostly the military), 82.8 million barrels (MMB) of jet fuels, or about 227 thousand barrels per day (MBD). These purchase volumes are on the same order of magnitude as the largest airlines. Of these volumes, about 216MBD (95.5 percent) were purchased “in bulk” – mostly large pipeline, tanker, or barge lots lifted directly from a refinery or large terminal. Worldwide “intoplane” volumes, those delivered directly by vendors to the wings of aircraft being refueled at commercial airports, totaled about 10MBD. While military fuel use has declined markedly with the current defense downsizing (down 42.1 percent since FY 1988), it is expected to be level near current levels for the next several years.

U.S. military jet fuels are almost entirely kerosene-based fuels. Of the FY 1997 volumes, only 2.8MBD, or 1.2 percent of the total, was wide cut JP-4 fuel (similar to commercial Jet B fuel). Bulk JP-8 accounted for 165MBD (72.6 percent) of total volumes. JP-8 is very similar to the commercial Jet A-1 fuel, which is the predominant kerojet fuel outside of North America. It is used by land-based U.S. military aircraft – Air Force and Army aircraft, plus some Navy and Marine Corps aircraft that do not routinely visit aircraft carriers during their missions. Intoplane volumes (4.5 percent of the total) are almost entirely Jet A-1 or Jet A, the commercial fuel most commonly sold in the United States. The remaining 49.1MBD (21.7 percent) of U.S. military jet fuel volumes are bulk JP-5, a high flash point kerojet fuel for the Navy and Marine Corps

Of U.S. military bulk fuel volumes, 72.3 percent are purchased in the United States. Given that the military jet fuels do not meet U.S. domestic commercial specifications, they cannot be handled fungibly with commercial product. Thus, they must often be custom manufactured, and segregated from commercial fuels – whether at the refinery or throughout the downstream distribution system. Overseas, the situation is less complicated, because JP-8 is essentially Jet A-1 plus an additive package (which can often be injected downstream of the refinery). Some U.S. domestic refiners who are U.S. military suppliers are understood to make their commercial fuel to the more restrictive military specifications in order to rationalize their on-site operations. Despite the specification differences, The DESC has been able to procure JP-8 in the United States at prices which are approximately equal to domestic Jet A prices. The more restrictive JP-5 specification results in fewer suppliers and prices that run some 1 to 3 cents per gallon above commercial jet fuel on the U.S. Gulf Coast. It should be noted that JP-5 is a very low volume specialty project that accounts for about 3 percent of U.S. jet fuel production.

Throughout most of the post-World War Two period, most land-based U.S. turbine powered military aircraft have used the wide cut JP-4 fuel, which was developed in 1951. The U.S. Air Force developed the JP-8 specification in 1972 in response to their combat experience in Vietnam. The new fuel specification promised better survivability in combat and greater safety in operations and handling. Land-based U.S. military aircraft have been interoperable among JP-4, JP-5, and JP-8 since 1976.

The worldwide conversion of land-based U.S. military aircraft took place in several phases from 1979 through 1995. The impending conversion of domestic military requirements was announced in November 1991, and carried out in a regional phase-in from October 1993 through October 1995. Because the domestic conversion involved some 200 MBD of JP-4 requirements (about 15 percent of U.S. jet fuel consumption at the time), the military anticipated problems with product availability, and cost increases of some 5 to 10 cents per gallon over JP-4.

The U.S. domestic conversion was completed successfully in 1995, with actual product costs only 2 to 3 cents above JP-4 prices. The successful conversion was due to several factors: 1) projected JP-8 requirements declined due to force downsizing, 2) a U.S. recession reduced overall U.S. jet fuel consumption, 3) aircraft operating efficiency continued to improve, and 4) the U.S. refining industry had leadtime of 2 to 4 years to prepare for the change.

The Air Force experienced some operational impacts as a result of conversion from JP-4 to JP-8. The two most significant issues were (1) efficient operation of older aircraft/engines, and (2) seal/sealant material leaks. As a result of the changes in viscosity and volatility between JP-4 and JP-8 the Air Force did experience some operational difficulties with specific older model aircraft and engines. This was particularly true in cold weather locations. Some aircraft and engines experienced cold weather start difficulties and lost some altitude relight capability. Most of these issues were addressed by changes to fuel scheduling systems, fuel controls, nozzles and burners. The small volumes of JP-4 that continue to be procured are in response to these lingering, minor issues.

The Air Force also experienced a widespread problem with seals and sealant materials that were related to differences in aromatic content between JP-4 and JP-8. This was predominately resolved by changing “O” rings. Although it did require maintenance action to change the seals this was a one-time issue and not a major impediment to the conversion. In addition to these issues related to the JP-4/JP-8 conversion, DESC and the services have experienced quality problems with kerosene-based jet fuels, which are related to changes in refinery processes and feedstocks. In general, these issues have been resolved on an individual basis.

7.0 DESIGN ALTERNATIVES

Task Group 6/7 examined the impact of a range of minimum flash points as design alternatives.

Other design alternatives would be the consideration of other technologies, or flash point changes in combination with other technologies. It is beyond the scope the Task Group 6/7 to make such comparisons.

8.0 INSTALLATION/RETROFIT REQUIREMENTS

8.1 Fuel Phase-in Requirements

Major fuel specification changes (such as flash point) require large lead times for refineries to implement the necessary investments if they should decide to do so and continue to produce the fuel and greater lead time for refiners to make potential investments to produce the fuel. Typically, refineries need four to five years to complete major capital projects, which includes design and planning, obtaining the necessary permits, construction, and start up. For example, Federal reformulated gasoline was implemented in 1995 (five years after the Clean Air Act mandating RFG was passed). In addition, a transition period of three months should be considered to allow the new fuels to replace the current fuels in the supply and distribution system.

8.2 Retrofit Requirements

If the fuel flash point is increased over current levels, addition of a fuel heater at the aircraft Auxiliary Power Unit (APU) inlet would be required to maintain the fuel temperature above that corresponding to a maximum viscosity of 12 centistoke, to ensure reliable starting for all ambient conditions. Section 8.2.3.1 provides a detailed explanation of the effects of a fuel flash point increase on APU cold and altitude starting. The cost impact of an APU fuel heater is provided in Section 12.6.2.

Approximately 24 months would be required for development and qualification of a direct current (DC) powered APU fuel heater with BITE (Built In Test Equipment) prior to delivery to the aircraft manufacturer. An additional 12 to 24 months would be required to incorporate the fuel heater in the field. There would be an increase of approximately 4 lb. in APU weight. The fuel heater could be run off the APU battery in-flight, using the existing battery charger powered by the main engine generators.

Additional time and effort would be required to complete any aircraft modifications or flight-testing required. Aircraft changes that may be required include wiring from the APU to the electronic control unit (usually located in a different compartment), modifications to the flight deck display, modifications to the APU battery or charger, modifications to the main engine generators, modifications to aircraft operational procedures, and any airplane manual revisions.

Additional development time, additional weight, and additional aircraft modifications would be required if an AC powered fuel heater were employed.

9.0 TECHNICAL DATA

9.1 Flash Point

9.1.1 Tank Ullage Flammability

Jet fuel has one basic purpose, to burn and release large quantities of heat. Ideally this process would occur only in the engine's combustion system, but jet fuel characteristics can also create a combustible mixture in tankage vapor space or ullage under certain conditions. Three ingredients are needed to cause a fire: fuel vapors, air (oxygen) in proper proportion and an ignition source. It therefore makes sense to first discuss fuel evaporation and then its impact on flammability.

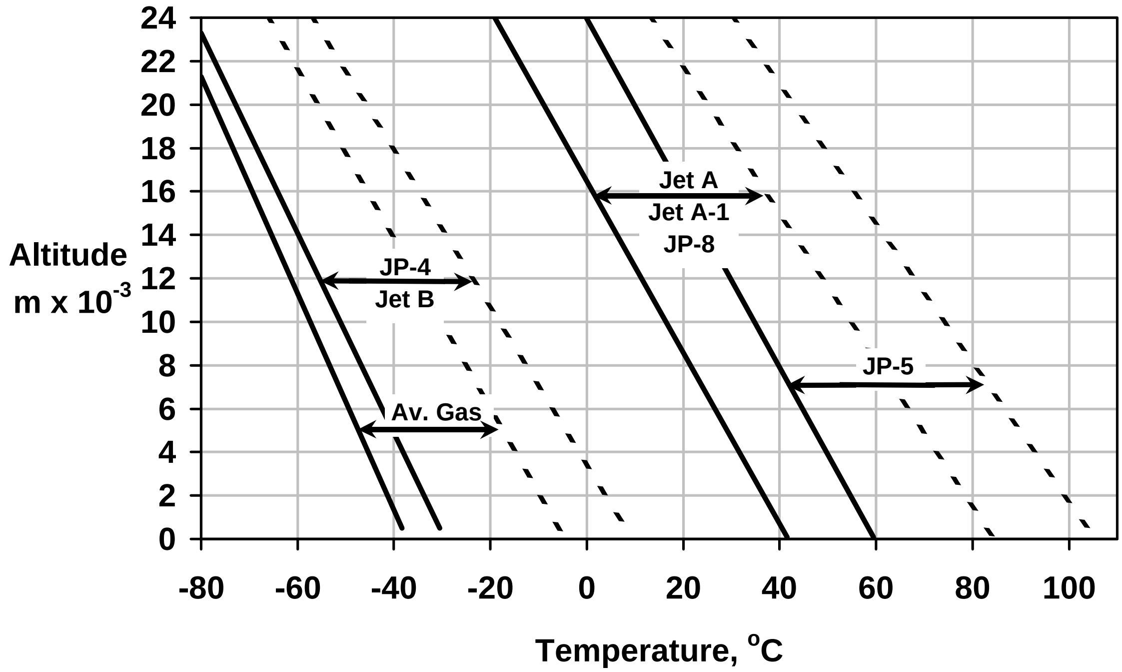
The rate of evaporation and the concentration of evaporated fuel in ullage depend on fuel vapor pressure, fuel temperature and air pressure and temperature. Of these parameters fuel vapor pressure is the most difficult to precisely establish because jet fuel is a complex mixture of hydrocarbons whose vapor pressure is the sum of the partial pressures of all the constituents. Evaporation alters the composition of the fuel and the vapor pressure decreases with the quantity of fuel evaporated. A relatively simple test to measure the vapor pressure of gasoline exists as ASTM D 323, but it only approximates the true vapor pressure of fuel. Vapor pressure measurements of kerosene by this method are further unreliable because they are very near the lower detectable limit of the method. Very specialized equipment is required to measure true jet fuel vapor pressure.

Fuel volatility or its tendency to evaporate, is therefore controlled by other, more empirical means. In the refinery distillate products are separated by boiling range, which is measured by a simple distillation. In this method (ASTM Test Method D 86) product is boiled off, condensed and recovered, while vapor temperature is monitored. The resultant temperature vs. per cent recovered serves as a general characterization, but the test method does not account for up to 1.5% of the most volatile products which are not condensed. However, these constituents determine vapor flammability, so they are characterized by determining the temperature at which the vapor first becomes flammable. This temperature is called the flash point. Details and limitations of flash point methods are discussed in the remainder of this section.

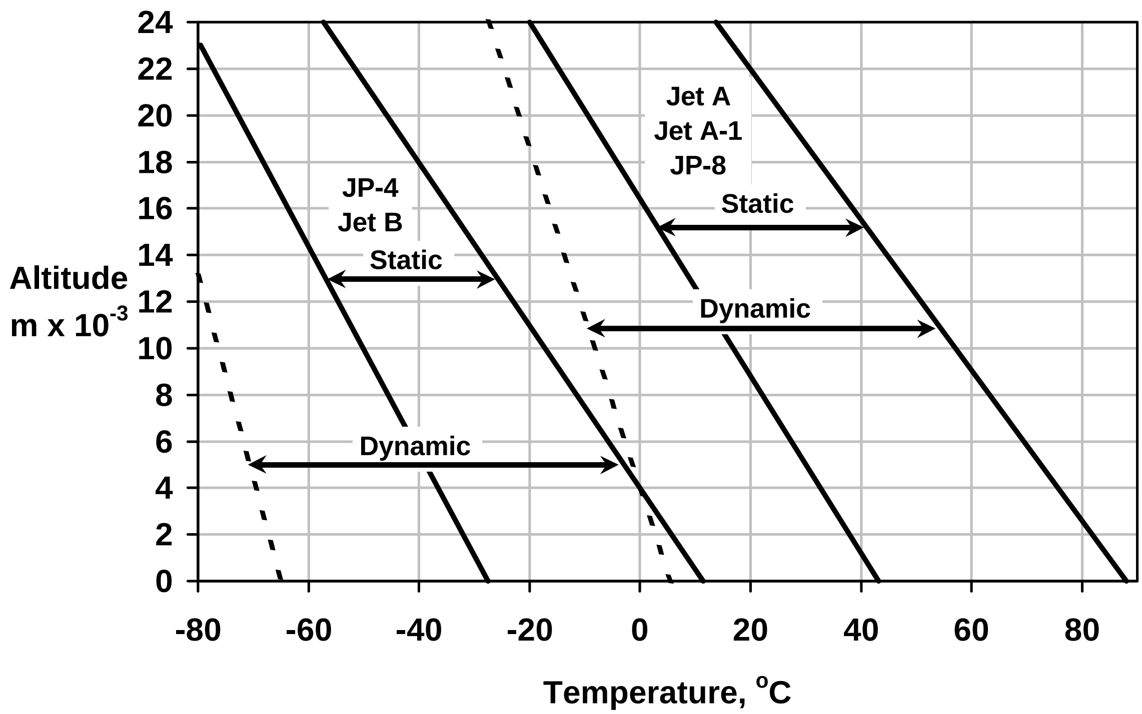
Relating jet fuel characteristics to ullage flammability is complex. Aside from the imprecise characterization of volatility, ullage vapor concentrations do not reach equilibrium when fuel is withdrawn from tanks vented to atmosphere. Air flows out of the tanks as air pressure decreases during climb, and dissolved gases can evolve from the fuel. Possible tank agitation resulting in sloshing or misting adds to the complexity. In the simplest test case, a tank is partially filled with fuel and the fuel is allowed to evaporate as temperature is increased in steps at constant pressure. In letting all conditions come to equilibrium at each temperature, a temperature is reached when enough fuel is evaporated to first form a flammable mixture. This temperature is called the lower flammability limit (LFL) or lean limit. As the system temperature is increased, the vapor space remains flammable until so much fuel is evaporated that there is insufficient oxygen to permit combustion. This temperature is the upper flammable limit (UFL) or rich limit. Conducting these experiments at reduced air pressures – increasing altitudes – results in curves such as are contained in Figure 1[(1)]. Because of decreasing air density less fuel vapor is needed at altitude to maintain a constant fuel/air ratio and a lower system temperature will maintain the LFL.

Figure 1 also illustrates the difference between different fuel grades. Adding factors such as outgassing shifts the limits as does misting or sloshing. The large effect on flammability limits resulting from extreme sloshing is illustrated in Figure 2. Unfortunately this effect depends entirely upon the conditions under which the tests were conducted and will differ greatly in real life situations. In tankage the vapor concentration will be highest just above the liquid level and lowest at the top surface. At very low fuel levels the non-homogeneity of fuel vapors becomes even greater because of uneven fuel warming and the cooling effects of vertical tank members. As a result, the relationships between existing fuel tests and tank flammability are not precise and not directly related on a one-to-one basis. Therefore, flammability conditions can be difficult to predict. In fact, the Executive Summary of the recently published FAA Final Report *A Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks* (DOT/FAA/AR-98/26) states the following:

> “In addition to finding a need for more data on the flammability of Jet A fuel, the task group found present methods for predicting in-flight fuel temperatures to be inadequate. The development of reliable heat transfer models and the ability to calculate the flammability of the ullage space in an aircraft fuel tank under different environmental and operational conditions are in the early stages. Therefore the ability to reliably evaluate different strategies to reduce the flammability of jet fuel in the center wing tank of a B747 has not been proven.”



<u>**Section 9.1.1, Figure 1--Fuels Flammability Limits vs. Altitude**</u>



<u>Section 9.1.1, Figure 2--Effect of Tank Dynamics on the Relative Flammability Limits of Jet Fuels</u>

9.1.2 Flash Point Methods and Significance

Liquid fuels all exhibit an equilibrium vapor pressure that is dependent on the temperature of the fuel. As the temperature of the fuel is raised, the fuel vapor in equilibrium with the liquid fuel reaches a sufficient concentration to ignite when mixed with air and exposed to a strong ignition source such as a flame. The temperature of the fuel at this point is known as the *lower flash point temperature*. If the temperature of the fuel is increased, the equilibrium vapor pressure increases to a point where the air-vapor mixture contains so much vapor that it is above the upper flammable limit for the fuel. The temperature at which combustion will not occur is known as the *upper flash point temperature.* For kerosene-based jet fuels such as Jet A and Jet A1, the relevant temperature is the *lower flash point temperature* and is commonly referred to as the *flash point.* This convention is used in this report.

In actual practice, the flash point is measured in several standardized pieces of apparatus. The most reproducible are "closed" cup methods. In these methods a sample is placed in a closed sample container and stirred. The temperature is increased at a prescribed rate. Periodically, the vapor is exposed to a flame and observation of whether combustion occurs is made. The lowest temperature at which the vapor ignites with a distinct flash is taken as the *flash point*. This observed measurement is then corrected for pressure by the equation:

Flash Point (^oF) = Observed Flash Point (^oF) +0.06 [760-Ambient Pressure (mm Hg)]

While the methods all measure the Flash point, the actual value measured and the test reproducibility can differ. There are four closed cup methods that are used commonly in aviation fuel specifications. These are shown in Section 9.1.1, Table 2. "Repeatability" is the maximum expected difference in two test results by the same operator and instrument; "Reproducibility" is the maximum expected difference in two test results by different operators in different laboratories. At the current flash point specification the reproducibility and repeatability are given in Section 9.1.1, Table 2. Section 9.1.1, Table 3 gives the flash point as measured by each apparatus for n-decane and n-undecane. As seen from this table, slightly different results are obtained with each method. In this study, flash point results are measured or adjusted to be the same as measured by ASTM D56. In specifications, ASTM D 1655, the commercial specification, uses D56 as the referee method, MIL-T-5624N and MIL-T-83133D, the United States Military Specifications use D 93 as the referee method, and DEFStan 91-91, the British specification uses IP 170 as the referee method. Care needs to be taken when reporting data to understand which method was used.

Method	**Title**	**Repeatability for 100^{o}F &140^{o}F Fl.Pt.**	**Reproducibility 100^{o}F &140^{o}F Fl.Pt.**
ASTM D 56	Standard Test Method for Flash Point by Tag Closed Tester	2.0^{o}F/2.0^{o}F	8^{o}F/8^{o}F
ASTM D 93	Standard Test Method for Flash Point by Pensky-Martens Closed Cup Tester	2.4^{o}F/3.8^{o}F	5.1^{o}F/8^{o}F
ASTM D 3828	Standard Test Methods for Flash Point by Small Scale Closed Tester	0.9^{o}F/0.9^{o}F	3.7^{o}F/3.7^{o}F
ISO 170	Petroleum Products – Determination of Flash Point – Abel Closed Cup Method	1.8^{o}F	2.7^{o}F

Section 9.1.2, Table 1–Closed Cup Flash Point Temperatures

Method	Flash Point °C	
	n-Decane	n-undecane
D56	50.9	67.1
D93	52.8	68.9
D 3828	49.8	65.9
IP 170	48.9[a]	65.1[a]

[a] *Result inferred from DefStan 91-91 Specification Limits; Calibration procedure not listed in standard*

<u>Section 9.1.2, Table 2–Flash Point Differences in Test Methods</u>

The flash point results can vary substantially from the actual lower flammability limit. While a definite difference has not been defined, ignition as much at 8-10°F below the actual flash point have been observed. Actual ignition of fuel vapors can be affected by factors such as:

- Direction of flame propagation – vertical upward flame requires less hydrocarbon to ignite than downward propagation induced in these methods.

- Non-equilibrium effects -- vapor concentration may not be uniform throughout a container, and time is needed for liquid to evaporate or for vapor condensation as conditions change.

- The ullage to liquid volume ratio -- the amount of hydrocarbon vapor differs and hence composition of the vapors can be different- this effect is particularly significant for fuels such as kerosene, which are mixtures of hydrocarbons with different volatility, not pure compounds.

- Liquid mass transfer --can determine the rate of vaporization and other diffusional effects which can have an effect on the flash

- Mixing in ullage space -- can determine when ignition can occur.

Thus, while the flash point adjusted for actual conditions can be used as a surrogate for the temperature at the lower flammability temperature, it should be understood that actual ignition can occur several degrees above or below this value.

While slightly different results can be obtained from the several test methods which are commonly used, these differences are small compared to the range of flash points found for kerosene as sold in the marketplace. Practices established for use and application must generally be based on an expectation that kerosene has the minimum allowed flash point; survey data shows that is improbable. It might be advisable to harmonize on a single method for use in all specifications, and consideration of that is underway and will likely occur if flash point requirements for jet fuel are changed to a higher minimum value.

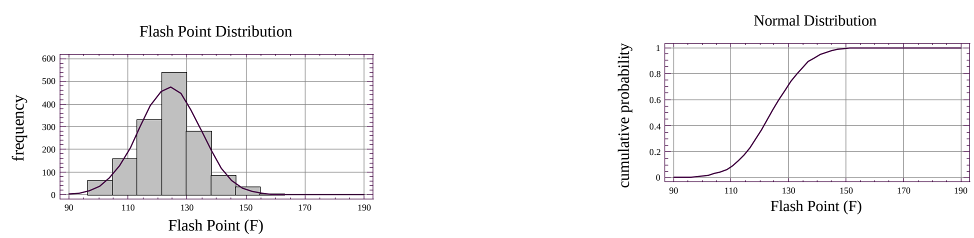
9.1.3 Flash Point Distributions

Flash point distributions are subject to some variation depending on the source and timing. In this study we attempt to find a sufficiently large database which would be meaningful, and test it where possible against other data or databases. However, because of the nature of the data, the results are presented as numerical averages -- they have not been weighted on a volume basis or other possible schemes. In fact, there can be significant debate as to which average is best for this study. The numerical data presented in this study should be sufficient to provide necessary data for further analysis.

9.1.3.1 United States Data

One of the largest readily available databases on flash points at United States Airports is provided by measurements by the U.S. military at commercial airports. This database[2] provides measurements of flash point at all contract commercial airports. These samples were taken from a period of August 1994 to September 1996.

A summary of the data is shown in Section 9.1.3, Figure 1.



<u>Section 9.1.3, Figure 1--Flash Point Distribution in U.S.</u>

Based on these data and other survey, results indicate that the average flash point in the United States would be between 124^{o}F and 127^{o}F with a standard deviation of 10 to 12 ^{o}F.

9.1.3.2 United Kingdom Defense Research Agency Flash Point Data[3]

The Defense Research Agency publishes survey data annually. One thousand four hundred forty four (1444) samples were analyzed for flash point. A summary of the 1997 data is shown in Section 9.1.3, Figure 2. The mean flash point was 111.6^{o}F with a standard deviation of 4.5^{o}F, when the flash point is adjusted to be equivalent to ASTM D56.

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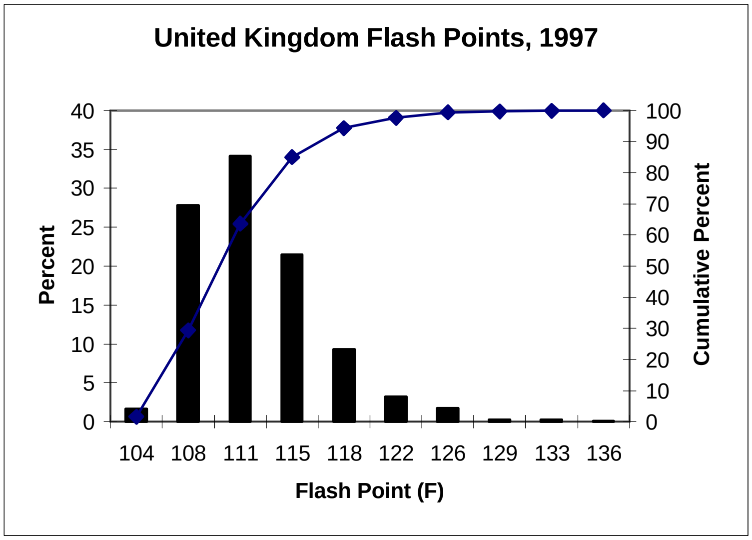
[2]**Into Plane Contract Testing** Air Force Directorate of Aerospace Fuels, Technical Division (SFT) Kelly Air Force Base, Texas (January 15, 1997)

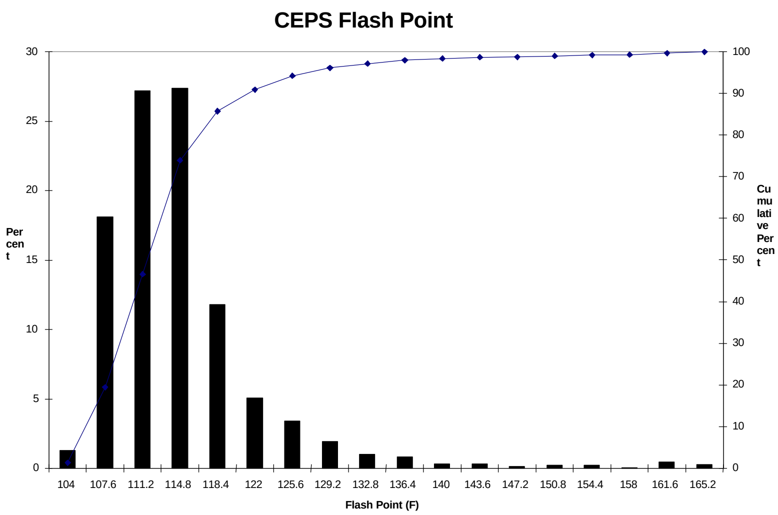
[3] ***The Quality of Aviation Fuel Available in the United Kingdom Annual Survey, 1997*** Defence Research Agency, Land Systems, Fuels & Lubricants Centre (1997 - to be published)



Section 9.1.3, Figure 2--Flash Point Data for Fuels Available in United Kingdom

9.1.3.3 European Flash Point Distributions

The Central Europe Pipeline System[4] publishes survey data annually. The data is compiled from 15 different sources located in the Netherlands, Belgium, France, and Germany. One thousand five hundred twenty three (1523) samples were analyzed for flash point. A summary of the 1996 data is shown in Section 9.1.3, Figure 3. Assuming a normal distribution, the mean flash point was 114.8^{o}F with a standard deviation of 8.0^{o}F, when the flash point is adjusted to be equivalent to ASTM D56.



Section 9.1.3, Figure 3–Flash Point Distribution in Europe

[4] Central Europe Pipeline System *Characteristics of Aviation Fuel within the CEPS 1996*

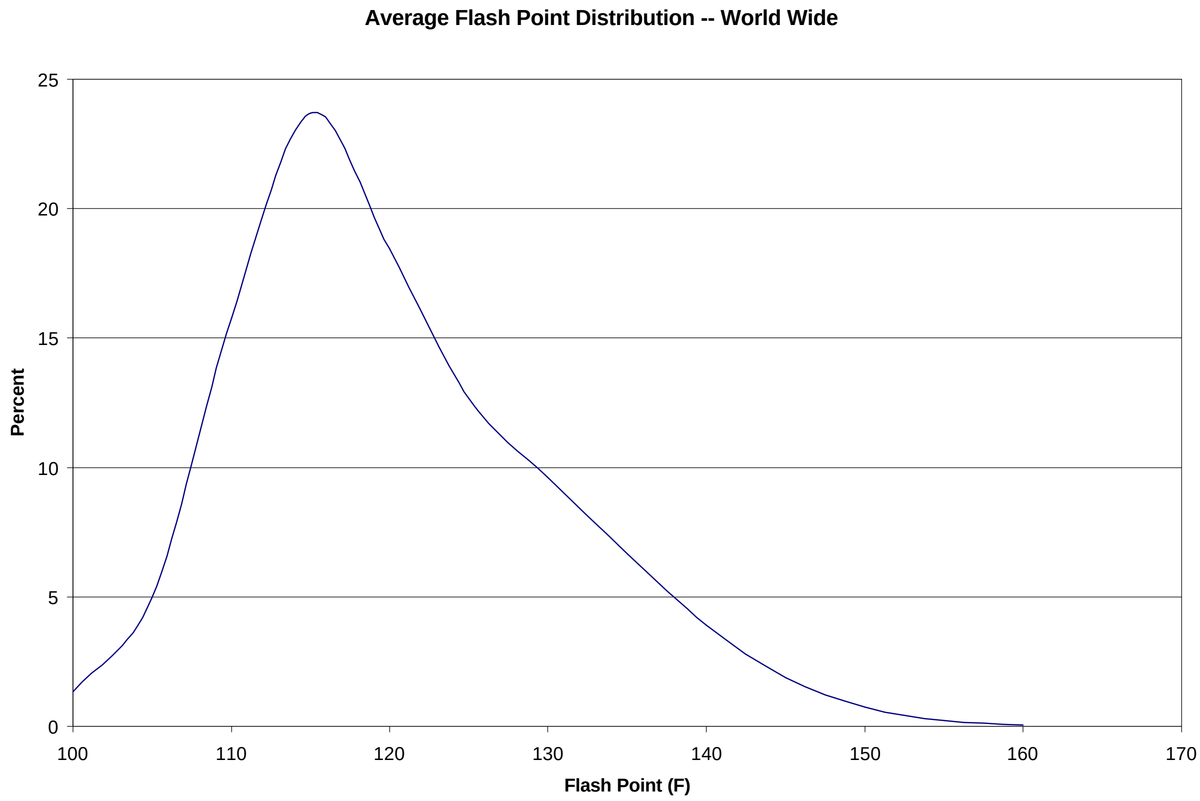
9.1.3.4 Average Flash Point Distribution Curve Worldwide

To simulate an average flash point distribution worldwide, the flash point distributions from the United States, United Kingdom, and CEPS (Europe) were weighted in the following way:

- The United States flash point distribution was weighted by the percent of jet fuel consumed in the United States and 1/3rd the jet fuel consumption in Central and South America. Weighting Factor = 45%

- The United Kingdom flash point distribution was weighted by the percent consumed in the United Kingdom, the Middle East, Africa, and the Far East and 1/3rd the jet fuel consumed in Central and South America. Weighting factor = 34%

- The CEPS flash point distribution was weighted by the percent consumed in the Western Europe and 1/3rd the jet fuel consumed in Central and South America. Weighting factor = 21%



Section 9.1.3, Figure 4–Flash Point Distribution –Worldwide Average

Lack of data precluded assignment of weights to production in Mexico, Canada, China, and C.I.S. Thus the flash point distributions are for Jet A and Jet A-1 only. Other fuels are not included in this averaging, but the average of 13 samples taken in Russia and the C.I.S is 95.7 ^{o}F (35.4 ^{o}C). Based on this calculation, the distribution of worldwide flash points is given in Section 9.1.3, Figure 4. The actual values are in Section 9.1.3, Table 1.

Flash Point F	**Cumulative Percent**
100	1.3
105	6.3
110	22.1
115	45.7
120	64.2
125	76.9
130	86.5
135	93.1
140	97.1
145	99.0
150	99.7
155	99.9
160	100.0

Section 9.1.3, Table 1--Flash Point Distribution – Worldwide Average

A summary of the flash points given in Section 9.1.3, Table 2.

PADD	**Mean Flash Point (^{o}F)**	**Std. Deviation (^{o}F)**	**# of Samples**
U.S.	124.1	10.5	1497
PADD 1	127.5	10.0	446
PADD 2	126.0	9.1	405
PADD 3	120.0	11.4	357
PADD 4	123.3	10.4	109
PADD 5 ex California	119.2	8.6	91
California	121.1	8.1	86
United Kingdom	111.6	4.5	1444
Central Europe Pipeline System	114.8	8.0	1523

Section 9.1.3, Table 2--Statistical Summary of Flash Point Data

9.1.4 Flash Point Margins

In the United States, the average value of flash point is approximately 19-27^{o}F above the specification limit. This is not entirely product give-away, i.e., higher flash resulting from inefficient and/or most economical operating point for a refinery. Increasing the flash point specification will not permit producers operating above the new specification to maintain status quo. The producer will have to increase his production limit commensurably. Section 9.1.4, Figure 1 shows a schematic of the factors involved in producing on-spec fuel at the airport. The components going into the flash point produced are as follows:

- Pipeline Specification -- .... 8°F
- Test Tolerance -- .... 4.9°F
- Process Control -- .... 3-8°F
- Product Give-away -- .... ??

As a check on this model, the United Kingdom data (Section 9.1.3, Figure 2) can be examined. Here, the producers are trying to maximize middle distillate. It is highly likely that they are attempting to optimize Jet A-1 operations. Since they do not have to meet pipeline specifications, the flash point produced at the refinery should be 7-13°F over the specification value. The observed average is 11.6°F -- within the estimate proposed.

Assuming product give-away is eliminated, one can make an estimate of the variance for delivery of fuel through a pipeline. The variance is the sum of the individual variances, i.e.,

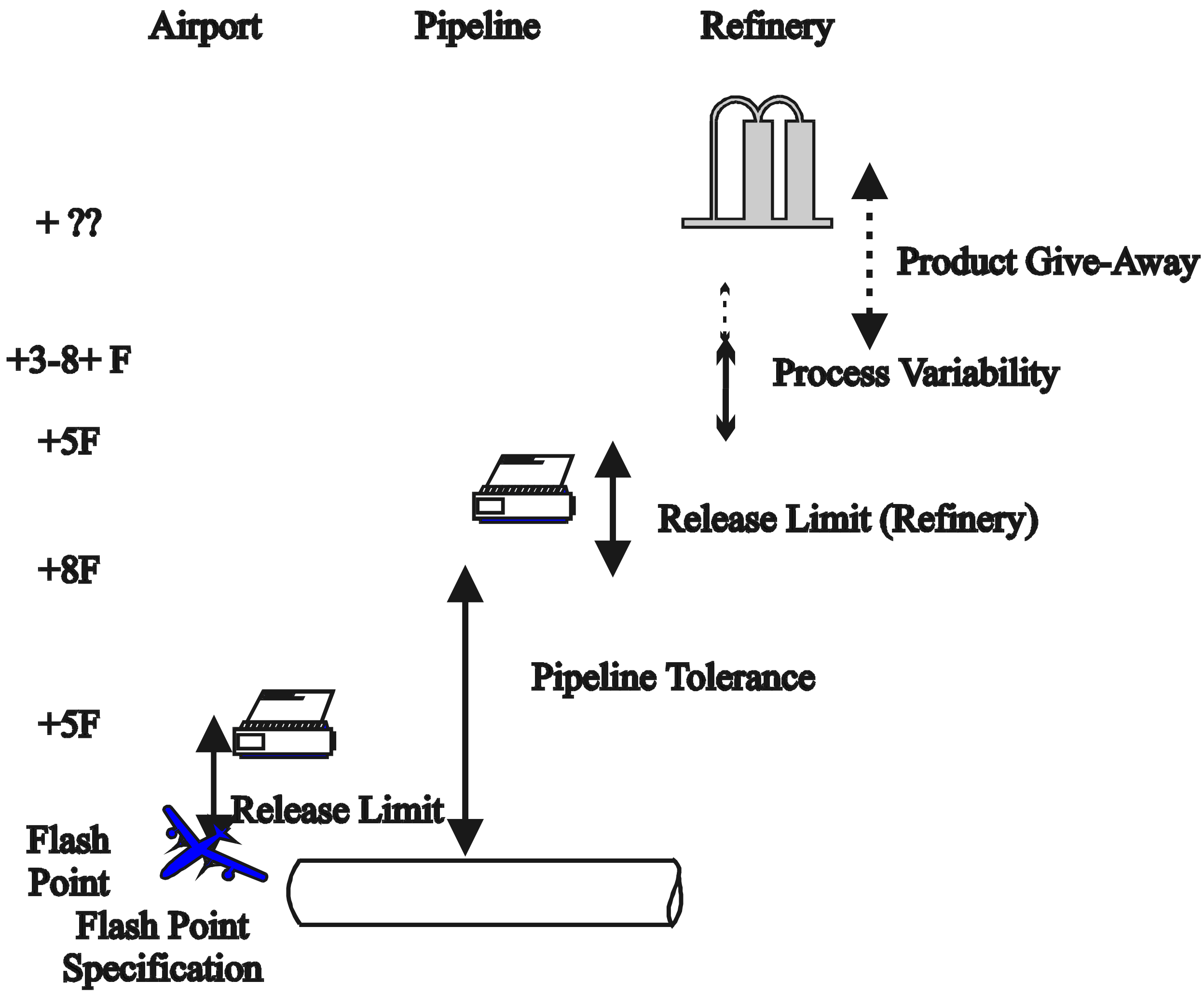
$$s^2 = \sum s_i^2$$

If one assume 95% confidence in test tolerance at airport and into pipeline as well as a 2 degree process control limit at 95% confidence limits, the standard deviation could be as low as 4.3°F. If the pipeline maintains its requirement of specification plus test reproducibility into pipeline the standard deviation can be as high as 5.8°F. This assumes no product give-away.

As the flash point specification is raised, the flash point will also rise commensurately (approximately12 - 15°F) at the refinery to assure on-spec product is delivered to the airport in the United States. Where pipelines are not involved, i.e., where there is a single transfer, the flash point on average can be as low as 8°F higher than the specification. The standard deviation could be as little as 3.13°F for this case. This will result in an additional cost to most, if not all refiners, to achieve any increase in specification.

For the purpose of this study, σ = 5.8°F for fuel consumed in the United States and 3.13°F for fuel consumed in the rest of the world. Future changes such as the NATO pipeline becoming a multi-product pipeline typical of the pipelines in the United States would change the standard deviation to be more like the United States.

A final option could be to carry out multiple flash point tests at each transfer. For example if four flash point tests were done at transfer, the reproducibility would be 4°F rather than 8°F for a single measurement. This would reduce the standard deviation to 3.1°F for the United States and 2.7°F for the rest of the world. This case is also presented in Section 9.1.5.



Section 9.1.4, Figure 1--Achieving Flash Point Specification Versus Flash Point at Refinery

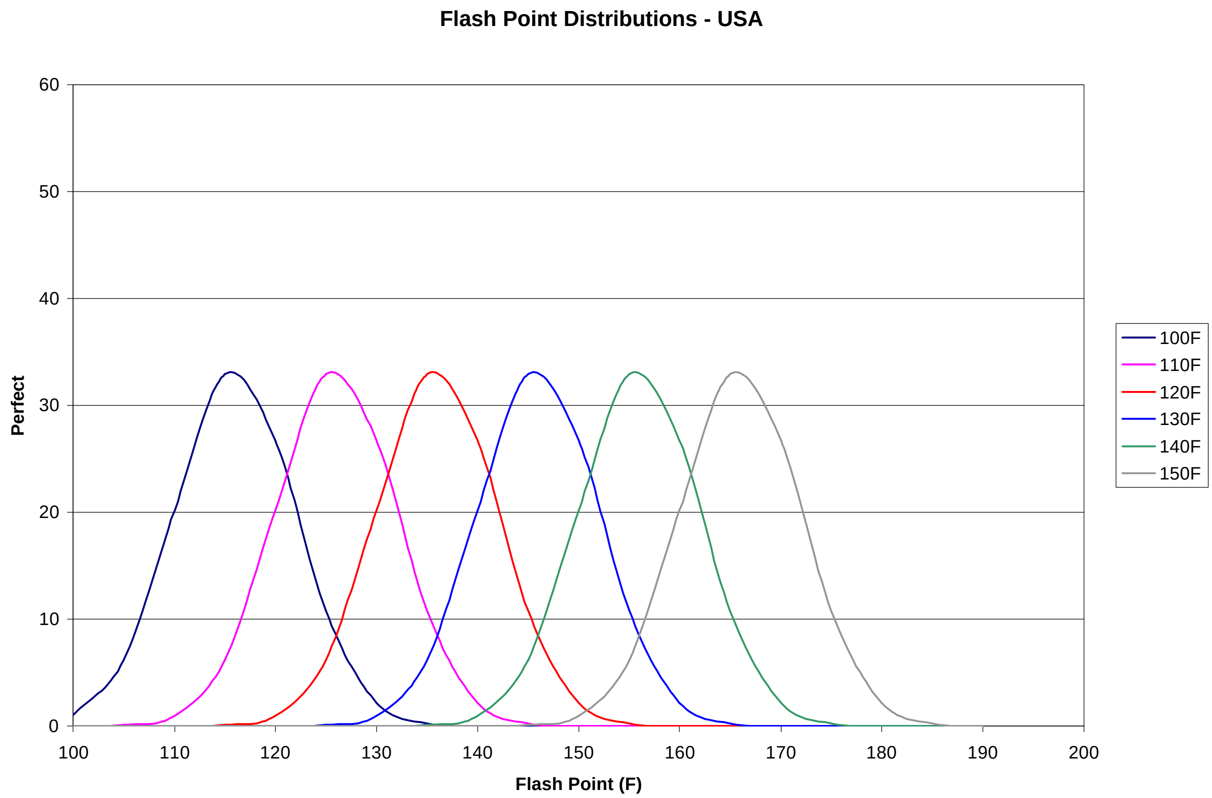
9.1.5 Flash Point Predictions

For the future, it is assumed that the manufacturer will not give product quality away. While this assumption is inevitably true for high flash, e.g., flash points greater than 130-140^{o}F, the amount of give-away for lower level of flash point is debatable. It is assumed that for the United States the standard deviation of the product will be 5.8^{o}F and that 99% of the product will be meet specification. The United Kingdom and European will have a standard deviation of 3.13^{o}F.

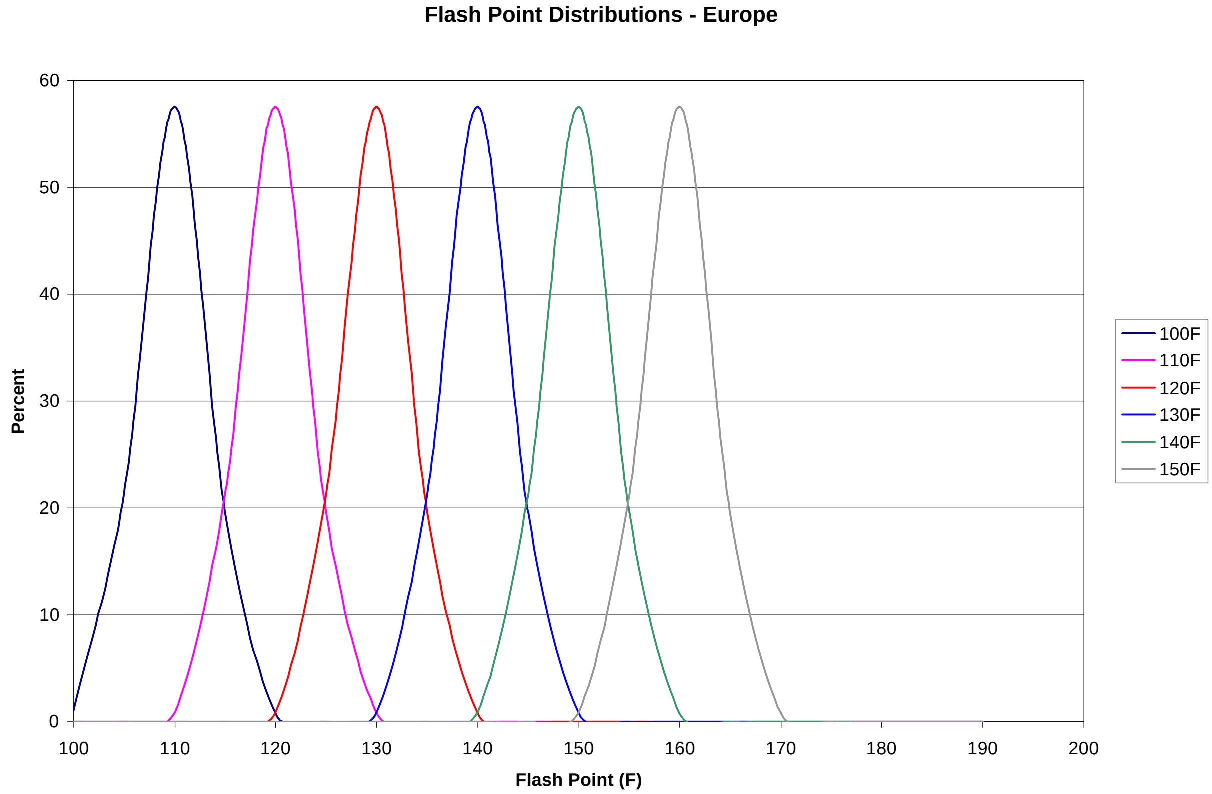
An average worldwide distribution was obtained by adding 45% of the United States flash point distribution to 55% of the European flash point distribution.

The results of these calculations are shown in Section 9.1.5, Figures 2 to Section 9.1.5, Figure 4. For the United States the flash point is 13.5^{o}F higher than the specification, the European is 7.4^{o}F higher than the specification.

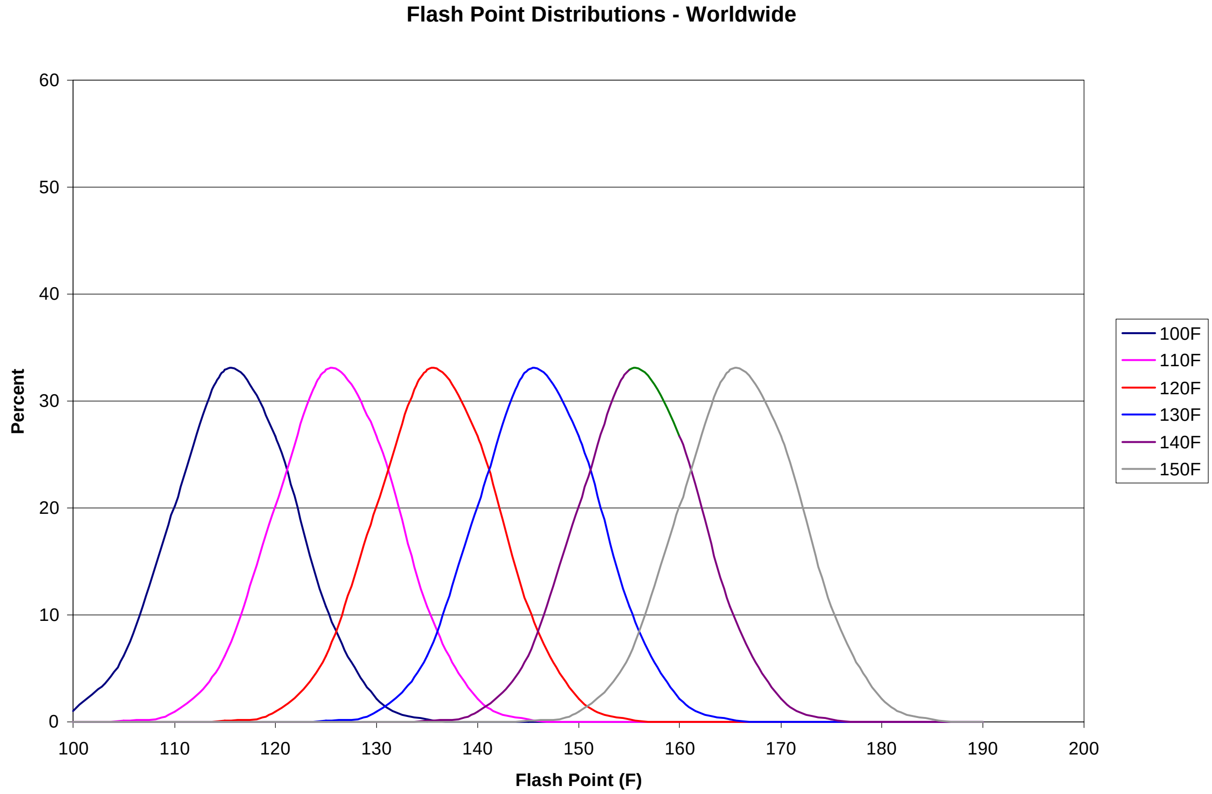
If four flash point measurements were taken at each transfer, the mean temperature for the United States would be about 7.4°F above the specification and worldwide would be about 6.4°F.



Section 9.1.5, Figure 2–Predicted Flash Point Distribution in United States with No-Give-Away



<u>Section 9.1.5, Figure 3–Predicted Flash Point Distribution in Europe with No-Give-Away</u>



Section 9.1.5, Figure 4–Average Worldwide Predicted Flash Point Distribution with No-Give-Away

9.1 Fuel Property Effects

9.2.1 Fuel Property Effect Predictions

9.2.1.1 Introduction

An increase in the jet fuel flash point specification can be expected to affect the properties of jet fuel in three ways:

1. By causing refiners to modify jet fuel distillation properties in conventional refinery processes to meet the new specification.

2. By increasing the probability that refiners will extend yield by modifying jet fuel processing schemes. Both the greater use of conventional processing such as severe hydrocracking and the implementation of unconventional refinery processing may occur

3. By causing significant property shifts in the jet fuel made by conventional refinery processing in some areas that rely on unique refinery configurations or atypical crude oils.

It is important to note that a higher flash point Jet A is a new jet fuel specification. Experience gained with JP-5 [140°F (60°C) flash point, -51°F (-46°C) freeze point] is not relevant because:

- JP-5 is a niche product made by few refiners (who presumably are well situated to produce it). A fuel made in commercial quantities, where maximizing yield is an issue, will have different properties.

- The higher freeze point [-40°F, (-40°C)] of a high flash point Jet A results in significantly changed properties, such as higher viscosity, versus JP-5.

9.2.1.2 The Impact of Modified Distillation Properties: Jet Fuel Properties Survey

Task Group 6/7 reviewed the literature and developed a number of cases to predict the fuel properties that would result from changes in the distillation profile if the flash point specification were raised from 100°F (38°C) to a higher limit. A survey was conducted where selected properties were calculated (by participants' proprietary analysis/predictive systems) for a number of crudes as function of flash point and freeze point. The feedback from the various participants was collected and regressed to calculate average values. The crude oils included in this analysis are shown in Section 9.2.1, Table 1.

1. Nigerian Light	6. Arab Light (Saudi Arabia)	11. Brent North Sea
2. Arabian Light	7. Maya (Mexico)	12. Sumatran Light Waxy
3. North Sea	8. Cano Limon (Colombia)	13. Arab Light
4. Alaska North Slope	9. Alaska North Slope	14. Mexico Maya Heavy
5. Maya	10. California LA Basin	15. Venezuela Merey Export Blend

Section 9.2.1, Table 1--Crude Oils Included in the Jet Fuel Property Survey

The crude oils were chosen to represent a broad range of those currently refined. No effort was made to balance the selection of crudes to match the "average" slate commercially refined to produce jet fuel. Thus, the current jet fuel pool average for any given property is expected to be offset from the average from this study. The changes in jet fuel properties found in this study are expected to be substantially more predictive than average values. The changes in distillation properties are shown in Section 9.2.1, Table 2. The non-distillation property changes are presented in Section 9.2.1, Table 3.

Flash Point °F (°C)	Freeze Point °F (°C)	Change in Flash Point °F (°C)	Change in Initial Boiling Point °F (°C)	Change in 10% Boiling Point °F (°C)	Change in 50% Boiling Point °F (°C)	Change in 90% Boiling Point °F (°C)	Change in Final Boiling Point °F (°C)
120 (49)	-40 (-40)	20 (11)	38 (21)	24 (13)	12 (7)	-3 (-2)	-14 (-8)
140 (60)	-40 (-40)	40 (22)	76 (42)	49 (27)	24 (13)	-7 (-4)	-28 (-16)
150 (66)	-40 (-40)	50 (28)	94 (52)	60 (33)	30 (17)	-9 (-5)	-35 (-19)
100 (38)	-53 (-47)	0 (0)	8 (4)	0 (0)	-15 (-8)	-31 (-17)	-36 (-20)
120 (49)	-53 (-47)	20 (11)	65 (36)	24 (13)	-3 (-2)	-35 (-19)	-51 (-28)
140 (60)	-53 (-47)	40 (22)	123 (68)	49 (27)	9 (5)	-38 (-21)	-67 (-37)
150 (66)	-53 (-47)	50 (28)	152 (84)	60 (33)	15 (8)	-40 (-22)	-15 (-8)

Section 9.2.1, Table 2--The Change in Distillation Properties versus Base from the Jet Fuel Properties Survey

Flash Point °F (°C)	Freeze Point °F (°C)	Change in Freeze Point °F (°C)	Change in Viscosity at –4°F (-20°C) (centistoke)	Change in Smoke Point (mm)	Change in Density (kg/m^3)	Change in Aromatics Contents (%)	Change in Heat of Combustion (mJ/kg)
120 (49)	-40 (-40)	0 (0)	0.6	-1.4	8	0.4	0.0
140 (60)	-40 (-40)	0 (0)	1.2	-2.8	17	0.7	-0.1
150 (66)	-40 (-40)	0 (0)	1.5	-3.4	21	0.9	-0.1
100 (38)	-53 (-47)	-13 (-7)	-1.1	0.7	-7	0.0	0.1
120 (49)	-53 (-47)	-13 (-7)	-0.5	-0.6	2	0.4	0.0
140 (60)	-53 (-47)	-13 (-7)	0.1	-2.0	10	0.8	-0.1
150 (66)	-53 (-47)	-13 (-7)	0.4	-2.7	14	1.0	-0.1

Section 9.2.1, Table 3--The Change in Average Non-Distillation Properties versus base from the Jet Fuel Properties Survey

Participants provided property predictions and yields at specification flash points of 100°F (38°C), 120 °F (49°C), 140 °F (60°C), 150°F(66°C) and freeze points of -40°F(-40°C) and -53°F (-47°C). The averages of the results are shown in Section 9.2.1, Table 4 and Section 9.2.1, Table 5. Note that the properties are a function of the distillation cut, crude type and other factors which causes significant scatter in the data.

Flash Point °F (°C)	Freeze Point °F (°C)	Yield Loss (%)	Initial Boiling Point °F (°C)	10% Boiling Point °F (°C)	50% Boiling Point °F (°C)	90% Boiling Point °F (°C)	Final Boiling Point °F (°C)
100 (38)	-40 (-40)	0	279 (137)	344 (173)	402 (206)	481 (249)	555 (291)
120 (49)	-40 (-40)	25	317 (158)	368 (187)	414 (212)	478 (248)	541 (283)
140 (60)	-40 (-40)	50	355 (179)	393 (201)	426 (219)	474 (246)	527 (275)
150 (66)	-40 (-40)	62	373 (189)	404 (207)	432 (222)	472 (244)	520 (271)
100 (38)	-47 (-53)	28	287 (142)	344 (173)	387 (197)	450 (232)	519 (271)
120 (49)	-47 (-53)	53	344 (173)	368 (187)	399 (204)	446 (230)	504 (262)
140 (60)	-47 (-53)	78	370 (188)	393 (201)	411 (211)	443 (228)	488 (253)
150 (66)	-47 (-53)	90	391 (199)	404 (207)	417 (214)	441 (227)	540 (282)

Section 9.2.1, Table 4--Average Yields and Distillation Properties from the Jet Fuel Properties Survey

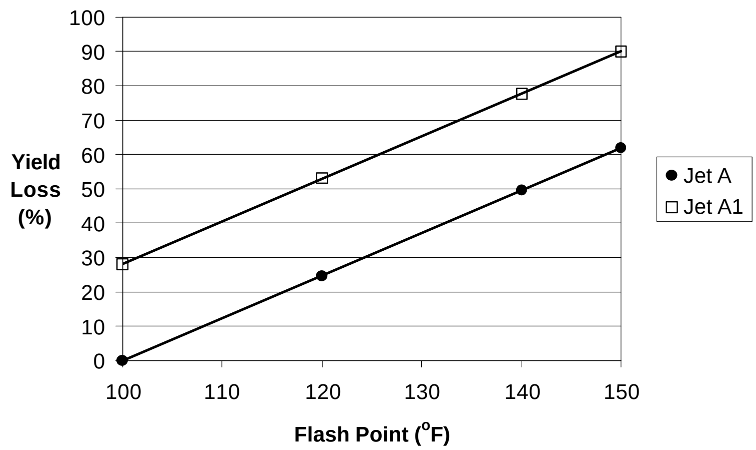
Flash Point °F (°C)	Freeze Point °F (°C)	Viscosity at –4°F (-20°C) (centistoke)	Smoke Point (mm)	Density (kg/m^3)	Aromatics Content (%)	Heat of Combustion (mJ/kg)
100 (38)	-40 (-40)	5.7	22.0	815	18.0	43.1
120 (49)	-40 (-40)	6.3	20.6	823	18.4	43.1
140 (60)	-40 (-40)	6.9	19.2	832	18.7	43.0
150 (66)	-40 (-40)	7.2	18.6	836	18.9	43.0
100 (38)	-53 (-47)	4.6	22.7	808	18.0	43.2
120 (49)	-53 (-47)	5.2	21.4	817	18.4	43.1
140 (60)	-53 (-47)	5.8	20.0	825	18.8	43.0
150 (66)	-53 (-47)	6.1	19.3	829	19.0	43.0

Section 9.2.1, Table 5--Average Non-Distillation Properties from the Jet Fuel Properties Survey

The loss in yield from any increase in the flash point specification is significant (>1% yield per °F flash point) as shown in Section 9.2.1, Figure 1. The "yield loss" in Section 9.2.1, Table 4 and Section 9.2.1, Figure 1 is calculated versus the Jet A base case [100°F (38°C) flash point, -40°F (-40°C) freeze point]. It represents the production lost when distillation cut points are changed to keep the fuel within specification limits. At the higher flash points and lower freeze point, many crude oils would produce no jet fuel at all. [This leads to the apparent anomaly in Section 9.2.1, Table 4 where the final boiling point for the 150°F (66°C) flash point Jet A-1 of 540°F (282°C) seems higher than expected from the other final boiling points. This is caused by most of the crude oils dropping out leaving only those with intrinsically good freeze point performance remaining to average properties.]

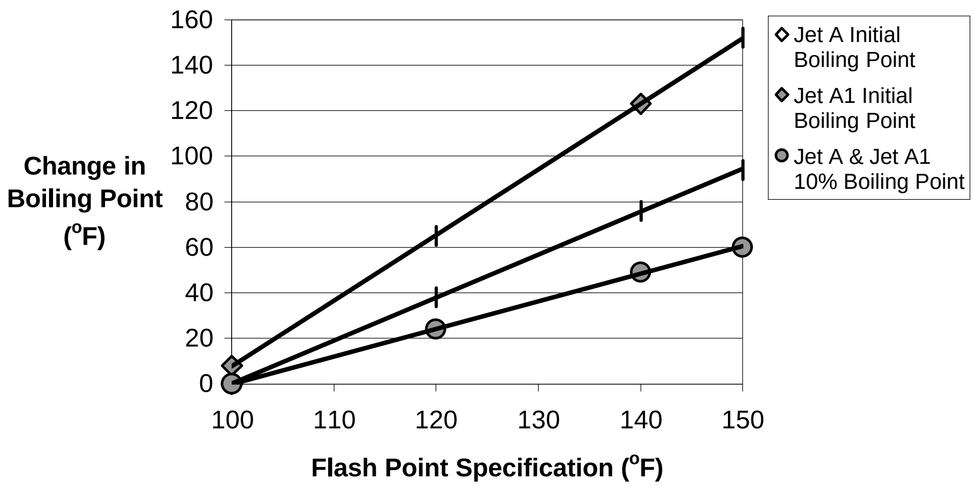
Note that the higher growth rate of jet fuel production and use versus other fuels, described in Section 12.2.4, is expected to apply pressure to future jet fuel availability.

The loss in jet fuel yield associated with an increased flash point specification should exacerbate this situation.



Section 9.2.1, Figure 1--The Loss in Jet Fuel Yield (from the Distillation of Crude Oil) as a Function of the Flash Point Specification

The 10% boiling points (temperature at which 10% of the material has distilled) and initial boiling points vary linearly with the flash point specification temperature as shown in Section 9.2.1, Figure 2.



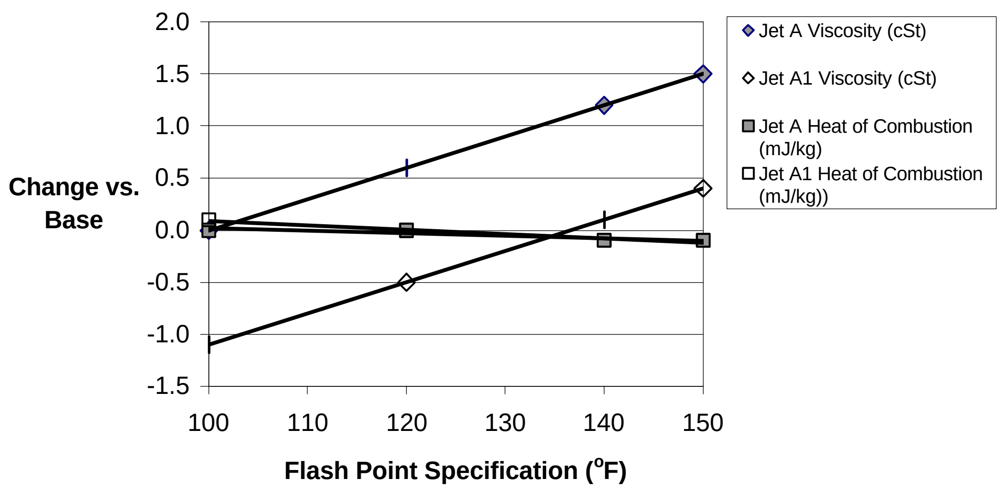
Section 9.2.1, Figure 2--The Linear Relationship between the Front End Distillation Parameters and the Flash Point Specification Temperature Found in the Jet Fuel Properties Survey

These distillation results (Section 9.2.1, Table 2) provide insight concerning why jet fuel properties change when the flash point is raised. Material is excluded from the "front end" (more volatile end) of jet fuel to meet the flash point specification resulting in increased initial boiling and 10% boiling points. The front end of jet fuel helps to dissolve straight chain paraffin molecules that can crystallize at low temperatures to form wax. The loss of the front end material requires the back end to be reduced (resulting in lower 90% and final boiling points) to remove large straight-chain paraffin molecules to maintain freeze point performance.

The difference in Jet A [-40°F (-40°C) freeze point] and Jet A-1 [-53°F (-47°C) freeze point] is mostly the reduced back end fraction in Jet A-1 (lower 90% and final boiling points). This acts to reject more of the large straight-chain paraffin molecules that can form wax.

The jet fuel property most impacted by a change in flash point specification appears to be viscosity. Viscosity increases are linear with flash point (Section 9.2.1, Figure 3). The results demonstrate the role that the back end material plays in jet fuel viscosity: the viscosities for Jet A-1 fuels [–53°F (-47°C) freeze point] were significantly lower than those for Jet A were [–40°F (–40°C) freeze point].

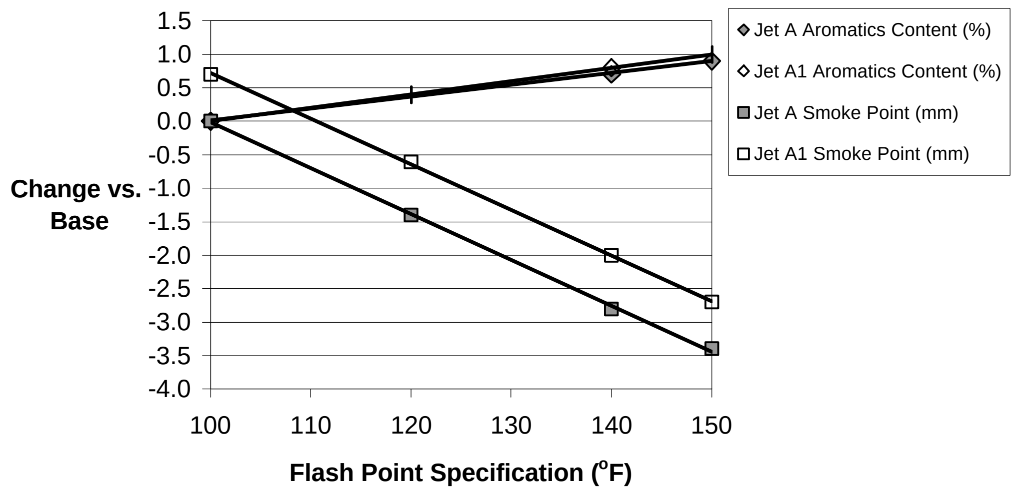
The results indicate that a flash point specification of 120°F (49°C) could result in an increase to 5.77 centistoke for the jet fuel pool viscosity at -4°F (-20°C). This is based on an estimate of 5.17 centistoke for the current jet fuel pool viscosity at -4°F (-20°C).



Section 9.2.1, Figure 3--The Changes in Jet Fuel Viscosity [at -4°F (-20°C)] and Heat of Combustion versus Flash Point found in the Jet Fuel Properties Survey

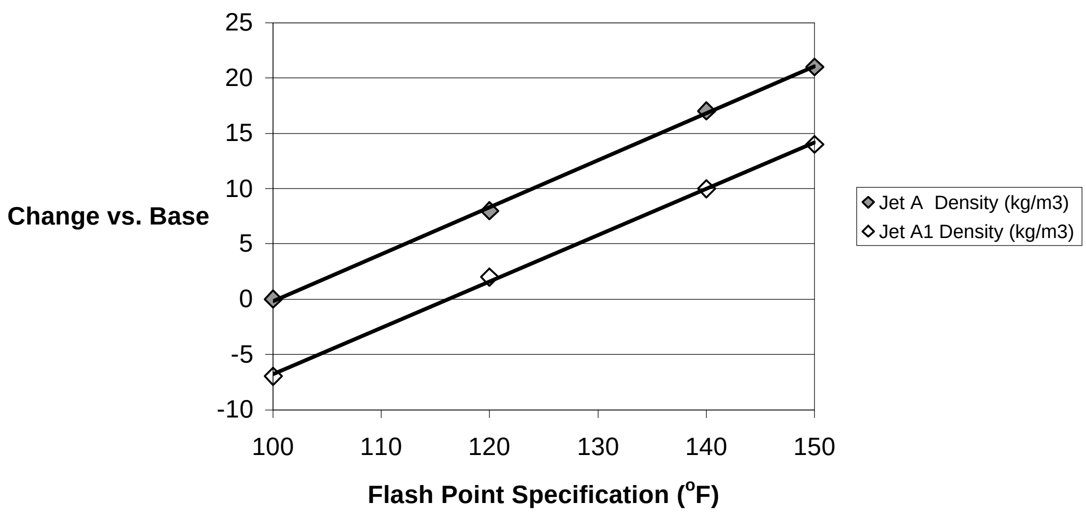
The combustion properties (aromatics content and smoke point) showed degradation in high flash point fuels (Section 9.2.1, Figure 4). The results were linear with smaller flash point changes showing smaller property changes.

These results indicate that a flash point specification of 120°F (49°C) could result in an increase of the average jet fuel aromatics content to 19.0% and a reduction in the average smoke point to 20.3mm. This is based on current jet fuel pool estimates of 18.6% for aromatics content and 21.7mm for smoke point.



Section 9.2.1, Figure 4--The Changes in Jet Fuel Aromatics Content and Smoke Point versus Flash Point Specification found in the Jet Fuel Properties Survey

The density shows a small, linear increase as the flash point specification increases (Section 9.2.1, Figure 5). Based on an estimate**Error! Bookmark not defined.** of the current jet fuel pool density of 814 kg/m^3, a flash point specification of 120°F (49°C) would increase the average jet fuel density to about 822 kg/m^3.



Section 9.2.1, Figure 5--The Changes in Jet Fuel Density versus Flash Point Specification found in the Jet Fuel Properties Survey.

The heat of combustion was slightly negatively impacted by increased fuel flash point specifications (Section 9.2.1 Figure 3).

On average, jet fuel sulfur content was essentially unaffected by the changes in distillation.

9.2.1.3 The Impact of Modified Jet Fuel Refining

An increased flash point specification could cause more jet fuel to be produced to the smoke point, aromatics content, or JFTOT specification limits but the magnitude of this change cannot be estimated with current knowledge. The scenario is that an increased flash point specification could cause reduced jet fuel availability. Reduced availability could invite refiners to maximize jet fuel yield by blending refinery streams, not normally used for jet fuel, as jet fuel. For example, kerosenes from catalytic crackers and coker units have high aromatics contents, low smoke points, and poor thermal oxidative stabilities. If hydrotreated to improve stability, these can be blended as jet fuel but generally are not because the increased yields are small compared to the effort required to maintain compliance with the limiting smoke point, aromatics, and JFTOT specifications. A shortage of jet fuel could result in incentives for using these streams in jet fuel with the result that the jet fuel pool would shift towards the specification limits with regard to these properties.

Another possibility that cannot be quantified on the short time scale of this study is that an increased flash point specification is likely to cause more jet fuel to be produced by severe hydroprocessing. In general, severe hydroprocessing improves jet fuel thermal stability. However the pressure to maximize productivity may lead to increased catalyst run life with resultant degradation in thermal stability in localized situations. Another issue with severe hydroprocessing is that the produced jet fuel can have poor lubricity properties. Lubricity is usually restored by blending with good lubricity fuel or corrosion inhibitor/lubricity additives.

9.2.1.4 Local Impacts

The average overall shifts in jet fuel properties resulting from an increased flash point specification, described above, may be magnified in some locations. A specific example is that the increased flash point specification may cause a high proportion of jet fuel in some local areas to be produced to the viscosity limit. The issue, here, is that some naphthenic crude oils produce jet fuels that have low freezing points and relatively high viscosities. If the initial boiling points of these jet fuels are raised to increase flash points, the viscosities will increase because the light material is removed but not much of the heaviest material. (Little change is needed in the distillation final boiling points to meet the freeze point specification.) Depending upon the extent of a flash point specification change, refineries processing primarily these naphthenic crude oils (for example some California refineries) may find the viscosity specification to be yield constraining. The result is that some jet fuel batches may have viscosities at -4°F (-20°C) very close to 8 centistoke instead of the 5.2-6.7 centistoke range predicted from the results shown above.

Another example of a possible local impact results if the increased use of severe hydroprocessing to produce jet fuel leads to a locality having predominately low lubricity jet fuel.

9.2.1.5 The Impact of Uncertainty in Fuel Properties

The uncertainty concerning the performance-related properties of a high flash point jet fuel should be viewed as a risk.[5] The impacts cannot be quantified at this time, but greater flash point specification changes increase the significance of the concerns raised above.[6] This uncertainty brings the risk that properties may shift sufficiently to impact equipment operation.

9.2.2 Fuel Property Effects on Airframes

9.2.2.1 Material Compatibility

Aircraft materials are evaluated for compatibility with jet fuels. Metals, coatings, seals and sealants are tested with a representative fuel and with a fuel that contains 30% toluene and 0.4% sulfur. Any high flash point fuel would not exceed the extremes in properties already checked since the fuel must meet the 25% aromatics and 0.3% sulfur limits in the fuel specification. No material compatibility problems in the airframe are anticipated from using high flash point fuels.

9.2.2.2 Heat Content and Density

The heat content and density of jet fuel are controlled by the fuel specification. Any higher flash point fuel would meet the current fuel specification requirements. However, on the average, a 140^{o}F(60^{o}C) flash point fuel will have a higher fuel density per gallon but a lower energy per unit weight when compared to delivered Jet A/A-1. There could be a slight benefit for those aircraft that are limited by fuel tank volume and a slight penalty for those aircraft that are limited by gross weight at takeoff. The anticipated aircraft performance change for burning a high flash point fuel (HHF) is shown in Table 1. The performance change is based on a Jet fuel with a density of 6.7 pounds per gallon and a lower heating value of 18,580 Btu per pound as compared with a high flash jet fuel with a density of 6.8 pounds per gallon and a lower heating value of 18,525 Btu per pound.

[5] For more discussion see Section 11.4.
[6] Sections 9.2.1.3 and 9.2.1.4.

	Δ Design Range (nmi) Constant TOGW, Payload	Δ Range at Fuel Volume Limit (nmi) Constant Payload, Fuel Volume	Δ Payload (lbs) Constant TOGW, Range	Δ Block Fuel (%) Constant Payload, Range
Airplane	HFF - Jet A	HFF - Jet A	HFF - Jet A	(HFF - Jet A) / Jet A
737-300	-6	40	-52	0.3%
737-700	-7	60	-48	0.3%
747-400	15*	85	-753	0.4%
757-200	-9	50	-114	0.3%
767-300	60**	60	-347	0.4%
777-200	-23	100	-539	0.4%

*   Fuel volume limited with Jet A
** Fuel volume limited with both Jet A and High Flash Fuel (HFF)
TOGW - Takeoff gross weight

Section 9.2.2.2, Table 1--Delta Change in Airplane Performance with High Flash Point Fuel.

The changes identified in Table 1 would result if the flash point was increased by 20°F(11°C). [See section on fuel property effects predictions for property changes versus flash point increase.] For the U. S., 120°F(49°C) minimum flash point fuel will not differ significantly in heat content and density from the currently delivered Jet A fuel and no impact to range or payload is expected.

9.2.2.3 Freezing Point

The requirement for freezing point of jet fuel is independent of flash point. The requirement is to deliver to the engine fuel with a temperature 5.4°F(3°C) above its freezing point. For Jet A, the pilot must initiate action to keep the fuel from getting any colder if the fuel temperature reaches -35°F(-37°C). A high flash point fuel is not expected to behave differently from other kerosene fuels. Currently the freezing point of delivered Jet A in the U. S. averages well above the specification minimum of -40°F (-40°C). Although airlines do not take advantage of the better than specification minimum fuel, aircraft have operated with additional margin as a result of the product quality give away.

The freezing point of Jet A is becoming an issue for the new routes opening up over the Northern latitudes. The fuel temperature in wing tanks can get as low as -44°C(-47°F) during long range flights on polar and Siberian routes in the winter. A Jet A type of fuel may not be satisfactory for commercial aviation operations on these routes in the winter. Some aircraft dispatched from the U. S. may require a lower freezing point fuel. The need for a low freezing point fuel is currently being assessed by the airlines. Implementing a high flash point fuel is likely to end the freezing point quality give away currently being provided to the airlines and end all efforts to identify the actual fuel freezing point at the time of refueling.

9.2.2.4 Viscosity

Viscosity at low temperatures is an engine and APU concern and not an issue in the airframe fuel system (see Section 9.2.3).

9.2.3 Fuel Property Effects on Engines and Auxiliary Power Units

9.2.3.1 General

This section describes how the predicted changes in fuel properties, as flash point requirement is increased, could affect gas turbine engine operability and performance. This information is presented as a consensus view based analysis of fuel property information provided by API in its survey and model reported in 9.2.1 and inputs from engine and APU manufacturers within Task Groups 6 and 7. The engine manufacturers considered a wide range of engine types, thrust ratings and aircraft applications (turboprop, turbojet and turbofan designs have been included in the deliberations).

Engine and APU aerothermal and fuel delivery system performance, integrity and durability are affected in many complex ways by the properties of fuel being used. Section 9.2.3, Table 1 which is included as Appendix 4, summarizes the potential impact changes in fuel properties can have on engine and APU operation. The proposed increase in flash point would, if achieved without change to other fuel properties, have minor effects on engine/APU operability but would not improve the overall safety of these units. However, the API model calculations clearly indicate that in order to achieve production that meets the current demand for jet fuel there would be a significant shift in several important fuel properties. It is therefore important to consider the impact of all these property changes when assessing the overall risks and benefit of increasing fuel flash point.

Since most civil engines and APUs are approved to run on both JetA/A-1 and military high flash point JP-5 it would appear that if the proposed fuel fell within these bounds there would be no problems or risks associated with its use. This is, however, a gross over-simplification.

As the flash point requirement rises, predicted fuel properties and combinations thereof increasingly depart from current experience of either Jet A/A-1 or JP-5 both in-service or used in validation testing. Further, API input clearly indicates the use of alternative raw materials and processes to recover yields to current levels may result in hitherto unknown changes in fuel properties by, for instance, the introduction of new molecule types/species.

The following paragraphs highlight the most important implications of operating on the fuel types predicted by the API model calculations described in Section 9.2.1.2. The predicted effects on engine and APU operation are our best judgment at this time given there is no operating experience for a civil flash point modified fuel and only very limited documented experience of extended civil operation with military JP-5 fuels. It is also important to note that the model only provides predicted mean values; no population data is available to indicate value distribution around the mean or variations between geographic locations. The full range of possible scenarios cannot therefore be addressed.

Testing to evaluate the effects and provide quantitative data would be required to assess the impact on the engine/APU in many instances. Such testing would have to be carried out on referee fuels manufactured specifically to represent examples of the fuels likely to be encountered in service. The type of testing which may be required is described under the fuel property headings below and may include laboratory, rig or full engine testing. (In service monitoring may also be required to determine long term effects). An internationally coordinated and funded program would be an appropriate way forward.

9.2.3.2 Flash Point and Distillation

Progressive increases in flash point and the associated change in distillation will by definition reduce fuel volatility. This makes combustion initiation more difficult under adverse conditions such as altitude relighting and cold starting. The potential impact becomes increasingly severe as the flash point increases. Task Group 6/7 is concerned that high flash point fuels could adversely impact both ignition performance and/or engine start times at the extremes of the relight envelope and on the ground during cold temperature starting.

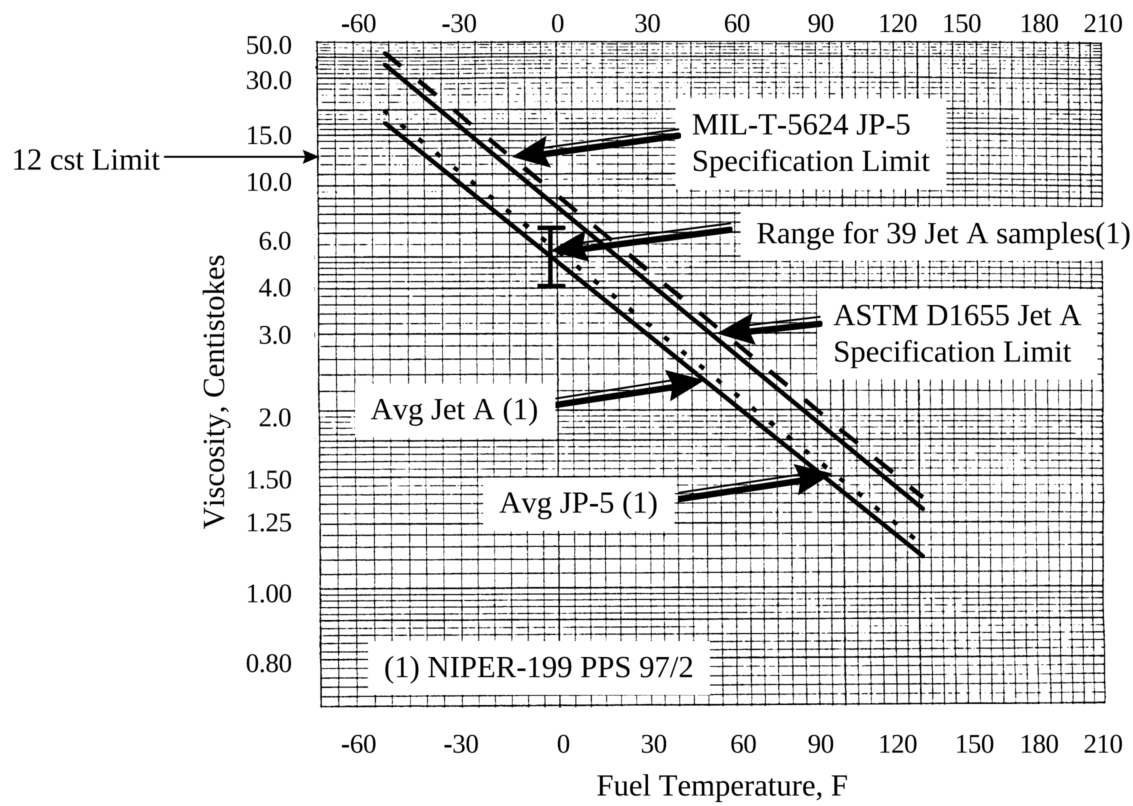
The requirement to fully evaluate the actual impact on ignition and relight performance would be a serious consideration for the higher reference flash point fuels.

Mitigating actions include re-scheduling of fuel control systems, or revision of the engine relight envelopes.

9.2.3.3 Viscosity

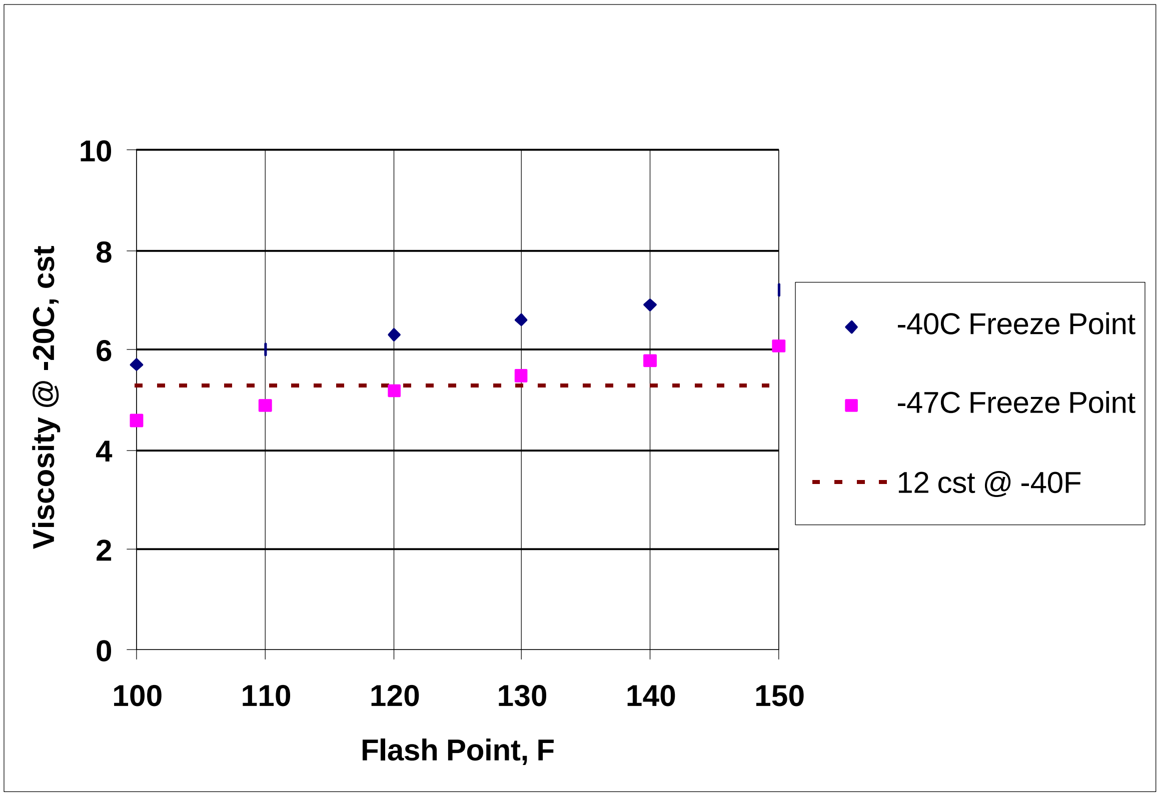
Main engines and APUs are designed to start and operate using a variety of kerosene and wide-cut fuels, up to a maximum fuel viscosity of 12 centistokes (cSt). At extreme cold start conditions the viscosity becomes the prime limiting factor. With the current pool of jet fuels, engine cold starting has not presented a significant problem in the continental United States (U.S.) or Europe. However, engine cold starting is an operational concern in extreme cold conditions (see Section 11.2).

Section 9.2.3.3, Figure 1 shows fuel viscosity as a function of temperature for Jet A and JP-5 fuels. As shown, the current ASTM D1655 specification maximum Jet A fuel (8 cSt max. at –20°C) can reach the 12 cSt viscosity limit at approximately –20°F, However, the viscosity range for current jet fuels is well away from the specification limit. For reference, the U.S. mean jet fuel viscosity is approximately 5 cSt at –20°C (Section 9.2.3.3, Reference 1) and the United Kingdom (UK) mean viscosity is approximately 3.8 cSt at –20°C (Section 9.2.3.3, Reference 2). Note that Europe and the UK use Jet A-1 fuel, which has a lower freeze point than Jet A fuel (usually accompanied by lower fuel viscosity).



<u>Section 9.2.3.3, Figure 1--Fuel Viscosity as a Function of Temperature</u>

The API survey has indicated that an increase in the commercial jet fuel flash point would result in an increase in fuel viscosity. A high flash point fuel will therefore reach the 12 cSt maximum viscosity limit at a higher temperature than current commercial jet fuels. Section 9.2.3.3, Figure 2 shows the API predicted fuel viscosity at –20°C as a function of the fuel flash point. As seen in Figure 2, any increase in flash point will increase the average viscosity above current levels for Jet A (-40°C freeze point) fuel, and for any increase above approximately 130°F for Jet A-1 (-47°C freeze point) fuels.



Section 9.2.3.3, Figure 2--Predicted Fuel Viscosity as a Function of Fuel Flash Point

As the fuel viscosity exceeds the 12 cSt point, there will be an increasingly deleterious effect on fuel atomization. The combination of increased viscosity and reduced fuel volatility with the high flash point fuels could result in slow and difficult engine starting, or a no-start. An increase in engine ground start problems in cold weather would be a major operability concern. Engines that currently have a reduced operating envelope (higher minimum operating temperatures) when using high flash point JP-5 fuel, may need to also restrict cold weather operation with a commercial high flash point fuel.

An additional concern would be APU starting during or after a long flight, or after extensive time on the ground in extreme cold conditions. APU ground start problems could result in an increase in flight delays while backup ground start carts are brought up. Cancellations of some flights (ETOPS) may occur if there is significant risk of the APU failing to start after long flights. See Section 9.2.3.10 for additional information on the effect of fuel property changes on APU operation and mitigating actions.

The risk of engine and APU cold starting problems could be mitigated by revising the viscosity limit to a maximum of 12 cSt at -40°C. Based on a viscosity correlation provided by the petroleum industry, a fuel viscosity of 5.3 cSt at -20°C corresponds to a viscosity of 12 cSt at -40°C (-40°F). Further study on reference fuels would be required to finalize this value.

Comparison of the U.S. data (Jet A -freeze point -40°C) and European data (Jet A-1 -freeze point -47°C) also shows that to some extent the higher viscosity levels are avoided when a -47°C freeze point is specified. The downside of changing U.S. production to -47°C would introduce further yield limitations over and above the levels already predicted by the API/EUROPIA survey (see Section 12.2, Appendix 14.1 and 14.2).

Increased viscosity would also slightly reduce the heat transfer efficiency of fuel/oil heat exchangers, and cause increased oil temperatures. Fuel injector cooling by the fuel will also be reduced slightly by the same effect. These effects need to be modeled or tested using the target properties of the proposed high flash point fuels to determine the ultimate impact (if any) on component or system operation and durability.

9.2.3.4 Aromatics and Smoke Point

The relatively small increase in aromatics levels from 18.0 (for 100°F flash) to 19.0% (for 150°F flash) are not of concern per se. The decrease in smoke point which is closely related to aromatic content and type does however change significantly, falling from 22-23 mm for 100°F flash point fuel to 19 mm for 150°F flash (current minimum is 18 mm). Based on established relationships between aromatics level and smoke point, this data implies that either the aromatic types would be changing with potentially increased multi-ring species, or, there is inaccuracy in the smoke point prediction. Assuming the model is correct the changes have two potential impacts:

1. Aromatics content and type influence swell of certain elastomer types. Significant change from current swell levels could cause seal problems leading to potential additional corrective maintenance actions.

2. Lower smoke point fuels have lower combustion quality. Such fuels increase the potential for smoke and flame radiation reducing overall hot-end durability. The magnitude of these effects and impact on operating costs are likely to be engine type specific.

Laboratory testing on reference fuels to evaluate elastomer compatibility and impact on emissions and hot-end durability may be appropriate when the revised specification is finalized. Increasing the minimum smoke point specification requirement is an option that should be given serious consideration to offset combustion-related problems.

Given the predicted downward shift in combustion properties the current requirements for certification emissions testing reference (see Section 9.2.5.1) may need to be redefined for future engine certifications.

9.2.3.5 Total Sulfur Content

The API model did not predict any impact on the sulfur level of the final product. Any increase in sulfur level from the initial distillation would be offset by the use of hydroprocessing. No significant effect of fuel sulfur content on engine operation is expected.

9.2.3.6 Thermal Stability

No quantitative data is available on the impact of the proposed changes in flash point on thermal stability. The API survey identifies that there will be an increasing incentive to use less desirable streams and processes to offset the reduction in yield. This has the potential to reduce both storage and thermal stability of the fuel pool. Conversely, there are indications that increased use of hydrogen-based processing will be used, which could improve thermal stability.

A significant reduction in the stability of the fuel pool would increase deposition and consequent fouling of fuel control units and injectors, increasing operating costs due to the increased maintenance. The magnitude of this effect cannot be estimated with the current data, which is only qualitative. Laboratory and rig scale testing would provide a quantitative prediction on the long-term impact of using these fuels.

At this stage removal of the two tier thermal stability limit present in the ASTM D1655 specification and introduce a single requirement of 260°C, or higher, could mitigate thermal stability related problems.

9.2.3.7 Freeze Point (Cold Flow Properties)

Freeze point (the point at which wax-like crystal disappears when warming the fuel) is one of the primary yield limiting parameters. To maximize jet fuel yield, high flash point fuels may be much nearer to the freeze point than at present (less margin). Also, the increased use of hydrocracked product will lead to a much sharper transition between liquid and almost solid phases. Pour points of the fuel (the temperature at which the fuel will not flow) are likely to be much closer to the freeze point and potentially there will be changes in crystal size distribution compared to existing fuels.

Engine fuel systems are designed on the assumption that fuel is free from wax and water crystals at the entry to the low pressure (LP) fuel filter, so filter element blockage will not occur under normal circumstances. Most engines use a fuel/oil heat exchanger to heat the fuel prior to entering the LP filter, which will prevent filter blockage during operation (not during cold starting on the ground however). For engines without an upstream fuel heater or a filter bypass, LP filter blockage is considered a hazard to engine safety. However, low pressure filter blockage by wax crystals would normally only cause bypass flow warnings and require subsequent maintenance action.

Given the potential changes in cold flow properties of the high flash point fuels, evaluation is required to ensure heat input to fuel is sufficient to ensure that very cold fuel will un-freeze prior to the low-pressure fuel filter.

9.2.3.8 Lubricity (Lubricating Quality)

Pressure on the producers to maintain yield will almost inevitably result in increase the use of hydrocrackers, hydroprocessors and the possible blending of synthesized product. These types of processes reduce fuel lubricity significantly. Low lubricity fuels can cause increased wear rates in pump and control system components. This is primarily a component life limiting issue and hence operating cost would increase if lubricity reduced significantly. However, recent isolated incidents have demonstrated that with a continuous diet of poor lubricity fuel sudden component failure can occur.

Lubricity is not currently a specification test requirement. Inclusion of a lubricity requirement in the specification would significantly reduce the risks described. However, further debate is required to define the limit to be imposed and how it would be applied. An alternative option is to increase the use of lubricity improving additives. If it became necessary to use these additives on a regular basis this would incur cost and logistics penalties.

9.2.3.9 Heat of Combustion and Density

Predicted changes in both heat of combustion and density are not expected to adversely impact engine performance. Lower heat of combustion will increase fuel consumption (on a weight basis). A significant shift in the population of density or heat of combustion or the established relationship between these two parameters may necessitate re-calibration of fuel control units and flowmeters. Note that flowmeters may also be sensitive to viscosity changes.

9.2.3.10 APU Operational Impact

The Auxiliary Power Unit (APU) is a small gas turbine engine used on all major transport aircraft and on most regional and executive aircraft. The APU is typically used as a power source for the aircraft air-conditioning units and electrical systems during ground taxi and gate operations, and as a power source for main engine starting during rollback from the gate. The APU is only used in-flight as an alternate electrical source in the event of a failure of a main engine generator.

Under normal conditions the APU is considered non-essential equipment. Non-essential equipment may be non-operational without jeopardizing safe operation of the aircraft either on the ground or in-flight. There are certain conditions however, when the APU is considered essential equipment on the aircraft minimum equipment list. Essential equipment is necessary for maintaining safe operation of the aircraft either on the ground or in-flight. For example, the APU may be considered essential equipment for ETOPS (Extended Twin Operations) flights, where a twin-engine aircraft is more than a specified flight time away from an airport (such as on most overseas flights). To obtain and maintain an ETOPS rating, an APU must demonstrate reliable altitude and cold starting capability, usually up to the maximum aircraft cruise altitude (some ETOPS APUs must be operating prior to entering the ETOPS flight leg). This is significantly different than main engine relight requirements, which are typically only up to 20 to 25 thousand feet altitude.

Since the APU compartment is usually not heated, the APU and the fuel are cold soaked at the prevailing total air temperature conditions in-flight. Some regional and executive aircraft do not have an APU inlet door, resulting in increased airflow through the engine during flight with a corresponding decrease in time to stabilize at the cold soak temperature. Even with a closed APU inlet door, the APU and fuel are usually stabilized at the cold soak conditions after three to four hours in-flight. Typical APU cold soak temperatures for a long range flight would be in the -20°F to -40°F range, but they can be significantly lower for extreme cold or arctic conditions. The combination of the high altitude and extreme cold soak requirements make APU starting a major design consideration. APU usage varies considerably depending on the operator, the aircraft type, and any local airport restrictions, but the APU is frequently started after landing and prior to arriving at the gate.

APUs are designed to start and operate using a variety of kerosene and wide-cut fuels, up to a maximum fuel viscosity of 12 centistoke. The refinery survey has indicated that an increase in the flash point of commercial jet fuel would result in an increase in fuel viscosity. The combination of reduced fuel volatility and increased viscosity with the high flash point fuels could result in slow and difficult APU starting, or a no-start. Of particular concern would be APU starting during or after a long flight, or after extensive time on the ground in extreme cold conditions. APU ground start problems could result in an increase in flight delays while backup ground start carts are brought up, or cancellations of some flights (ETOPS).

If the fuel flash point is increased over current levels, addition of a fuel heater at the APU inlet may be required to maintain the fuel temperature above that corresponding to a maximum viscosity of 12 centistoke, to ensure reliable starting for all ambient conditions. Detailed measurement of fuel temperatures at the APU fuel control inlet for various aircraft would be required to fully evaluate the impact of a fuel flash point change on APU starting. The fuel heater could be run off the APU battery in-flight, using the existing battery charger powered by the main engine generators. The fuel heater could only be used on the ground when the electric power was provided by the gate in order to prevent the APU battery from being discharged too low for subsequent starts. Retrofit requirements for an APU fuel heater are provided in Section 8.2, with cost information provided in Section 12.6.2.

9.2.4 Ground Infrastructure & Fungibility

Raising the minimum flash point of jet fuel would not impose significant constraints on the U.S. fungible pipeline system. However, this is based on the assumption that this constitutes a change in the current fuel specification as opposed to adding an additional grade of jet fuel. (See Section 6.3 for additional information on pipeline transportation).

There are significant differences in the operation of multiproduct pipelines between Europe and the U.S. Traditionally, Europe has adopted a process of recertification after any movement of jet fuel where contamination with the products can occur. In this process, contamination sensitive properties such as distillation, flash point, freeze point, existent gum are measured after the operation and results compared with the original values. If any of the values have changed by more than permitted amounts (based on reproducibility of the test method), contamination is suspected and an investigation is conducted.

In the corresponding U.S. process, the fuel is simply tested against the specification. Provided that the values still meet the specification, all is well. Traditionally, pipeline companies set specifications for entry into their systems which exceed the product specification by a considerable margin to give them a buffer to absorb the effect of cross grade contamination.

Entry specifications for flash point in the U.S. are significantly higher than the flash point minimum, probably reflecting the potential for contamination with gasoline. In Europe, jet fuel is usually buffered between gas oil or diesel tenders (no likelihood of a flash point decrease even if contamination occurs). In the U.S., the lower demand for gas oil/diesel increases the likelihood that jet fuel will be buffered by gasoline tenders thereby increasing the risk of flash point reduction from interface mingling. The net effect of this is that jet fuel is normally produced much closer to the minimum flash point specification than in North America.

9.2.5 Environmental Effects

9.2.5.1 Aircraft Emissions

Since the 1980's, gas turbine engine emissions have been regulated by the U.S. Environmental Protection Agency (EPA) as defined by 40CFR Part 87, Control of Air Pollution from Aircraft and Aircraft Engines; Emission Standards and Test Procedures. Within this regulation visible emissions (smoke) are regulated on all turbo-prop engines with a shaft horsepower of 1000 kW (1340 HP) or greater, and all gas turbine engines, Class T3, T8, and TF, of a rated output of 26.7 kN (6000 # Fn) thrust or greater. The invisible emissions (unburned hydrocarbons, carbon monoxide and oxides of nitrogen) are regulated for all gas turbine engines, Class T3, T8, and TF, of a rated output of 26.7 kN (6000 # Fn) thrust or greater. The <u>current</u> regulatory levels are:

Unburned Hydrocarbons	-	19.6 grams/ kilonewton
Carbon Monoxide	-	118.0 grams/kilonewton
Oxides of Nitrogen	-	(40 + 2 (Rated Pressure Ratio))g/kN
Smoke For T3, T8 & TF Class	-	83.6 (Rated Output, kN)^ -0.274 SN

The engine manufacturer's approach to meeting emission regulations has been by careful design of both the fuel injectors, and the combustors into which these fuel injectors fit. Because of this, most modern gas turbine engines have emissions levels which are well below the regulatory values noted above, and the slight influence of fuel properties has not been considered that important. It is considered unlikely that the changes in fuel's properties will drive any engine over the regulatory limits. If some particular engine model is required to recertify, there will be some cost to the manufacturer, in as much as three engine tests are required plus the cost of the report.

If and when a higher flash point commercial fuel is selected, the engine manufacturers will have to emissions test their engines to determine how emissions levels have changed. This is necessary because stationary facilities, such as airports, are required to do an emissions inventory (including aircraft emissions) and report the results of these surveys to the EPA. Any increase in emissions must be reported.

Based on the fuel properties extrapolations done by API, and for a significant (+40 degrees F) increase in fuel flash point, increases in fuel viscosity, density and surface tension will generally result in slightly larger fuel droplets from the fuel injectors at the engine idle operating condition. This in turn reduces the initial vaporizing rate of the fuel, which can result in local fuel rich pockets in the combustor primary burning zone. These rich pockets, when burned, produce fractionally higher levels of unburned hydrocarbons and carbon monoxide. Further, if the increase in fuel flash point does result in higher aromatics for the pool of fuels available, then it is possible that smoke emissions will increase slightly for some engine models. But for many engine models this increase will be so small as to lie within the ability to measure smoke level.

Relative to fuel properties, there is insufficient information to analytically quantify how emissions would change. Studies of fuels effects done by the Air Force in the late 1970's and early 1980's, were done on combustor and fuel nozzle designs that have been superseded by the technology used in today's engines. The only way to determine the fuel property change effects on engine emissions would be to test today's engines.

In summary, it is felt that increasing fuel flash point could cause some, very minor, increases in gas turbine emissions levels, depending on how large a flash point change is selected. Up to about a 15 degree increase in flash point it is unlikely that the change in important fuel properties would be sufficient to cause measurable change. As the selected value of flash point increases away from the current fuels, it becomes more likely that engine manufacturers will have to run emissions tests on their engines to (1) quantify the increases in emissions levels for airport operator's reports to the EPA and (2) assure that engine models did not exceed EPA regulatory values for those engines which might now be marginal in a particular contaminant.

9.2.5.2 Jet Fuel Manufacturing Emissions

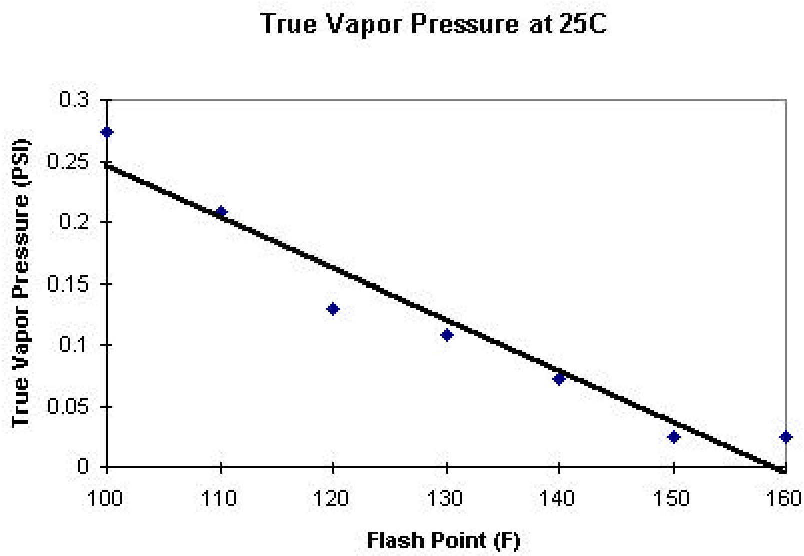
CONCAWE, the European oil industry organization for environmental, health, and safety, examined the effects of changing the jet fuel flash-point specification in the range of 100°F to 140°F. The study involved an assessment of the effects on distillation yields and an assessment of an EU refining simulation evaluating the overall impact and remedial actions to restore the specified future demand quantity.

CONCAWE determined that restoring the jet demand would involve substantial European investments in hydrocracking of approximately 25 million tons per year (Mtpa) additional capacity with associated investments in hydrogen generation facilities. The additional energy use in hydrocracking as well as the extra hydrogen consumption leads to an increase in CO2 emissions estimated at 7-8 Mtpa.

The Task Group recommends that a linear interpolation of this data be used, which leads to an estimated increase in CO2 emissions of 1.75-2 Mtpa per 10°F increase in jet flash-point for the EU-15 countries. The increase in CO2 due to a 10°F increase in jet fuel flash point would add about 1% to the total CO2 emissions from EU-15 refineries. However, as a result of the Kyoto conference, there is a worldwide pressure to reduce overall CO2 emissions.

9.2.5.3 Evaporative Emissions

Evaporation of fuel from tanks at airports, terminals, and refinery storage tanks depends on the vapor pressure of fuel at ambient temperatures. Because jet fuel is a mixture, the amount of fuel that can evaporate varies as a function of ullage to fuel volume, the amount of weathering of the fuel, and other factors. One way to obtain an estimate of the amount of evaporative emissions that can occur is to examine changes in the true vapor pressure with flash point. The true vapor pressure is the pressure exerted by vapors of a fuel in equilibrium at a specific temperature when the ullage to liquid volume ratio tends to zero. Using the data of Section 9.2.1 and ASTM D2889, the true vapor pressure at 25^{o}C as a function of flash point for jet fuel with a freezing point of -40^{o}C can be determined as shown in Section 9.2.5.3, Figure 1. Fuel with a freezing point of -47^{o}C should have comparable values.



Section 9.2.5.3, Figure 1--True Vapor Pressure of High Flash Jet A Fuel

Evaporative emissions should be reduced with increasing flash point as the ratio of the true vapor pressure. Section 9.2.5.3, Table 1 shows the approximate reduction in evaporative emissions anticipated.

Flash Point (^oF)	**% Reduction in Evaporative Emissions**
100	0
110	24
120	53
130	60
140	73
150	91

Section 9.2.5.3, Table 1--Reduction in Evaporative Emissions with Increasing Flash Point

Since its initial boiling point and T10 distillation point largely drive a fuel's vapor pressure, raising the minimum flash point will lower the vapor pressure of jet fuel, further diminishing its already low evaporative emissions.

9.2.6 Additives in High Flash Jet Fuels

Additives are used in jet fuel to affect its properties. In general, additives are effective when used to control minor constituents in the fuel, or when they are used to affect some property, which is sensitive to minor constituents. Additive concentrations, with one exception, are in the parts-per-million range. Bulk properties are not normally affected. Hence, it is not anticipated that an additive could be found which could affect flash point, freezing point, distillation, or other compositional properties.

A variety of optional and mandatory additives are used in jet fuels. The probable changes in performance, and any increased need for these additives are discussed in the following paragraphs.

9.2.6.1 Antioxidants

These additives are used to prevent the formation of peroxides during storage of fuels that have been hydrogen-treated. Use of 17-24 parts per million (ppm) is mandatory in hydrogen –treated fuels outside the U.S. and in U.S. Military jet fuels. Use is optional in jet fuels meeting ASTM D 1655. The performance of these additives is unlikely to show any dependence on the flash point of the fuel; they have been used effectively in JP-5 high flash fuel for many years.

While the need for antioxidants is not affected by flash point, a somewhat larger fraction of jet fuel outside the U.S. might require them if hydrocracking or other hydrogen-treating processes are used to maximize the availability of jet fuels.

9.2.6.2 Metal Deactivator Additive

Metal deactivator additive (MDA) is used in jet fuel to counter-act the tendency for dissolved trace metals to reduce stability of jet fuel during storage and during high temperature exposure in the turbine engine. A small proportion of jet fuel is treated with MDA, mainly when minute traces of copper could be dissolved in fuel during refining or during transportation. Use of 2 – 5.7 ppm of this additive is optional. No change in performance or the frequency of use for this additive is expected based on flash point considerations.

9.2.6.3 Static Dissipator Additive

Static dissipator additive (SDA) use is optional in U.S. civil jet fuels meeting ASTM D 1655, but is mandatory in some military jet fuel requirements and in most other civil jet fuel specifications. This additive increases the fuel conductivity and hence aids in dissipating electrostatic charge that has been generated by the fuel passing through filters used during fuel transportation and at airports. Minimizing the static charge is necessary to prevent the possibility of a spark that could ignite fuel vapors or mists. Increasing the flash point may not change the need for this additive, especially if lower flash point jet fuels (TS-1 and Jet B) may still be present in aircraft tanks.

An increase in the minimum flash point of jet fuel would require an increased concentration (normally 0.5 to 1.5 ppm) of SDA to give the necessary conductivity increase, but will not otherwise affect performance. Studies (see 9.2.1) show that jet fuels with higher flash point will have a higher average viscosity, and the performance of SDA will be slightly reduced since response is, in part, determined by this property.

9.2.6.4 Corrosion Inhibitor/Lubricity Additives

These additives are required at concentrations of 9-15 ppm in military jet fuels to improve the lubricity of jet fuel in engine parts such as pumps and engine controls, and can be used in civil jet fuels with the permission of the purchaser. Currently, a very small portion of civil jet fuel contains lubricity improver additive. Lubricity of hydrogen treated fuels is variable and may be poor; lubricity of non-hydrogen treated jet fuel is normally adequate. A steady diet of poor lubricity fuel can cause component failure in flight. It is known that only a few percent of fuel with good lubricity needs to be commingled to give satisfactory performance. Military aircraft operating from fixed bases may not benefit from commingling and wear problems have been eliminated by use of lubricity additives.

Except in very rare circumstances, civil aircraft receive an adequately varied fuel diet to ensure good performance, and these rare circumstances are being managed satisfactorily. However, the current equilibrium might be disturbed by significant changes in fuel production methods and distribution, and the potential for serious lubricity problems in a rapidly changing situation should not be taken lightly. Lubricity properties are a current concern in jet fuel specification activities.

Corrosion inhibitor/lubricity additives may be added at any point during distribution. Currently, broad use of this additive in civil fuels is inhibited by specification requirements, which usually require acceptance by purchasers. These additives have a negative effect on the performance of filter coalescers used to remove particulates and water from jet fuels. Improved coalescers being developed for military use have increased resistance to these and other additives, and might reduce the risks of using lubricity improvers. At this time, however, broad use of lubricity improver is strongly inhibited by water separation concerns.

9.2.6.5 Fuel System Icing Inhibitor (Anti-icing Additive)

This additive, diethyleneglycol monomethyl ether (DiEGME) is used in high concentrations (0.10 to 0.15 volume percent) relative to other additives. It dissolves in water, which may precipitate from the fuel and prevents freezing in cold climates or at high altitude. Large commercial aircraft with filter heaters do not require this additive, but many small aircraft need it. Because this additive has been used successfully in JP-5 for many years, there is no reason to expect any change in efficacy, or to expect any change in the need for its use.

9.2.6.6 Miscellaneous Additives

- Biocides are used intermittently in some aircraft to inhibit microbiological growth. There will be no change in the need for or the performance of these additives.

- Tracer A is a new additive being developed for intermittent use to detect leaks in airport fuel hydrant systems. There will be no change in the need for or performance of this additive.

- JP-8+100 Stabilizer is a new additive being developed for use in military aircraft, to improve the thermal stability of jet fuel. While not yet approved for use in civil fuels, this additive is likely to be used in the future. There is no likely change in performance of this additive based on flash point alone, but these additives have performed differently in different fuels. If unusual components are more commonly used to meet flash point and availability, the need for the additive could increase or new formulations may have to be developed. Improved filter coalescers, under development for military use of this additive, would probably be required. Use concentrations are 100 ppm or higher.

9.2.6.7 Research Opportunities for Additives

Freezing point is a property that is a strong function of the types of molecules present in the fuel. It is highly unlikely that wax solubility could be affected by an additive. However, pour point depressants could affect flow properties at low temperature. These work by altering the size of the wax crystals formed. While this has worked well in diesel fuels, there are occasionally times when agglomeration of the wax occurs, causing operational problems. This would not be tolerated in aircraft. However, if the jet fuel specifications were changed to a minimum pour point instead of freezing point, and better additives were developed, increases in productivity would occur. It is unlikely that this research effort and related no-harm testing could be completed in less than five years.

10.0 AIRWORTHINESS REQUIREMENTS

Based on the API model predictions, a higher flash point fuel is likely to depart from the current engine and API test and service experience in terms described previously. The magnitude of changes is increasingly severe as flash point increases.

Possible mitigating actions to off-set adverse impacts on engine and APU operation (where available) were discussed in Section 9.2.3. These include:

- Hardware modifications, adjustments and re-calibrations
- Revisions to the fuel specification requirements in additions to the increase in flash point
- Revised aircraft operational limits

The influence on airworthiness may be initially modest with respect to main powerplant considerations for minor increases in flash point, to requiring significant corrective actions for the highest flash point fuels. Moreover, there is the potential for the APU to be significantly affected by relatively small increases in the flash point.

Dependent on the magnitude of changes in fuel properties, specification limits, and hardware changes, further actions may be required by the engine, APU, hardware (e.g., fuel system unit and component) manufacturers and airworthiness agencies to ensure that civil airworthiness requirements continue to be met.

11.0 SAFETY

11.1 Operation on Low/High Flash Fuels

Commercial airlines make frequent flights to other parts of the World and it is unknown if some parts of the World will, or will be able to change to a high flash point fuel. Therefore aircraft will continue to uplift low flash fuels particularly in Russia and the Commonwealth of Independent States (C.I.S.). Defueling and the transfer of fuel between tanks is not practical for commercial operations. In today's global market, there is no practical way to avoid mixing fuels from different parts of the world.

European airlines with a high number of flights to Russia and the C.I.S will have the greatest exposure, uplifting approximately 35% of the fuel required in these States.

Aircraft manufacturers will also need to continue to certify aircraft for safe use of these fuels particularly when sold to an operator in these regions.

11.2 Operation in Cold Climates

11.2.1 Canada

From the Canadian point of view, an increase in flash point of kerosene-type aviation fuels would be a move in the wrong direction. Increasing the flash point would reduce the more volatile, low-boiling components of the fuel, which in turn leads to an increase in viscosity and exacerbates an already tenuous cold starting situation. Cold starting problems and "hung starts" are currently not uncommon during cold weather operations at major Canadian airports such as Winnipeg and Edmonton, even though these airports operate on Jet A-1 fuel. In the far north, commercial operations are mostly on Jet B / JP-4 although some Jet A-1 is in use.

Additionally, the Air Element of the Canadian Forces, despite a total conversion to kerosene-type fuels by all its allies, continues to use wide-cut JP-4 as its standard fuel for all land-based operations in order to insure starts under all conditions at any time of the year. A one-year trial of JP-8 at a Canadian Forces base located near Vancouver proved unsuccessful due to starting problems, particularly with rotary aircraft. The base reverted back to JP-4 following the trial period.

In the Canadian view raising the flash point of kerosene fuels will, in all likelihood, create more problems than it will solve and is not viewed as an improvement to flight safety.

11.2.2 Scandinavia and the Baltic States

Scandinavian and Baltic States operators are similarly concerned with the proposal to raise the flash point of the fuel and the resulting effect on the fuel viscosity and subsequent cold starting problems which would severely disrupt their operation in winter months.

11.2.3 Russia and the C.I.S.

Russia and the C.I.S use a kerosene fuel whose properties are controlled by the Russian specification GOST 10227 Grade RT and TS-1. The distillation range, viscosity and freeze point limits of Russian fuels is designed to allow operation, cold starting and engine re-light at very cold temperatures experienced in Siberia. These fuels are more volatile than Jet A/A-1 with a minimum flash point of 28°C (82.4°F).

The Chinese also specify two grades of fuel, RP1/2 with similar characteristics and flash points to the Russian fuels but state that they now only deliver Jet Fuel No.3 (RP3) to specification GB 6537-94 at all major International airports which meets International Specifications including ASTM D1655 for Jet A-1.

11.3 Russian and C.I.S. Aircraft Operation on High Flash Fuel.

Russian aircraft and engines have not been designed to operate on high flash fuel. Impacts on their operability and airworthiness have not been determined.
In the past they have experienced problems operating on Jet A from the U.S. and Merox treated fuels resulting in lacquering of engine components.

11.4 Changing the Experience Database

The aviation fuel community is by nature very conservative. It has a high confidence level with currently produced fuel because of a long experience base. Collectively, we cannot readily measure the existing margin to alter the nature of the fuel for all aircraft engine types. Effects from changes at a single source are difficult to determine because they are usually lost in the pool fuel volume, so that continuous operation at the extremes of the property limits is infrequent. Conversely, changes to the jet fuel pool as a whole must of necessity be viewed with concern. The concern level for a change in minimum flash point to 110-120ºF is significant. The concern level for a change to 140ºF is many times higher because refiners can be expected to change production methods and reduce specification margins on a broad scale.

Possible mitigating actions to off-set adverse effects on engine and APU operation might include hardware modifications, adjustments and re-calibrations. There is a potential that increased viscosity may require measures to moderate low temperature extremes in the APU environment, or a change in the viscosity requirement. Other revisions of fuel specification requirements might be necessary in addition to the increase in flash point, and aircraft operational limits might require consideration. The current effort has not included evaluation of impact on availability from other possible specification changes.

Conceptually, an increase in only the flash point should not markedly affect the properties or suitability of jet fuel for its intended purpose. Some high volatility components would be eliminated to increase flash point, and some low volatility components would be eliminated to assure jet fuel still meets freezing point requirements. Thus it would appear that all of the fuel would remain within the criteria bounded by the previous requirements. This view, however, is an over-simplification. API review (see

Section 9.2.1.1) of likely changes indicates the propensity to produce fuel with properties and molecular composition outside current experience increases significantly with increasing flash point requirements. This raises concerns about departure from current engine and APU test and service experience for key specification limits and actual property values in the population. This is true for individual key properties and combinations thereof.

The vast majority of the world's airline fleet operates on a varied diet of jet fuels as they refuel at each destination. Major destinations in turn receive their fuel from more than one refinery. Because most planes are exposed to an "average" diet of fuels, they experience an averaged exposure to fuel property extremes. Changes to flash point are likely to cause drift for several fuel properties, especially viscosity at low temperature, aromatics content, thermal stability, and smoke point.

Jet fuel properties are largely determined by four variables: the initial and final boiling points (together these define the boiling range), processing, and the type of crude oil feedstock. Currently, nearly all jet fuel is either a boiling range fraction from the crude oil distillation column (with further mild processing to improve properties without significantly changing the hydrocarbons present) or a mixture of this fraction with hydrocarbons of a similar boiling range obtained from a hydrocracking unit. Use of hydrocracker component is more recent, and was introduced slowly; a few jet fuels now contain only this component but most of the time it is blended with the kerosene boiling range product from crude distillation.

A complex issue for further consideration, however, is that changes to increase the minimum flash point may cause abrupt shifts in refinery process components which are used to make up jet fuel, to maintain the current product volume. The motivation for such shifts is proportional to the increase in minimum flash point. At 110-120F, motivation would be light to moderate for Jet A production in the U.S., and moderate for Jet A-1 elsewhere. At 140ºF flash point pressure to include non-conventional streams would be strong in the U.S., and can only be described as extreme elsewhere. Stated differently, at a 140ºF flash point a large enough proportion of jet fuel refiners could be expected to include presently atypical components that the pool composition of fuel could be changed outside of the current experience base.

For example, a component with a similar boiling range to kerosene can be obtained from a fluid catalytic cracking unit, present on most refineries. This material is not normally used in jet fuel because it has poor thermal stability, very high aromatics content and very low smoke point. It can be expected that many refiners will need to produce at the extremities of the specification by including such marginal streams, to meet fuel demand. This will result in a reduction of the margin for these properties in the overall jet pool, proportional to the increase in flash point.

Overall, at the extremes of contemplated flash point increases, such changes have a characteristic unparalleled in aviation fuel history. Up until now, changes in fuel composition and properties could be described as carefully measured and controlled, slowly evolving over time. Changes brought about by a significant change in minimum flash point, it is feared, are likely to be rapid and uncontrolled, driven by urgent needs to make up shortfalls in product volume, especially at refineries maximizing jet fuel production. In the past, small adjustments have been agreed to after lengthy debate and after gathering data on the suitability of the revised fuel specifications. For example, the maximum freezing point of Jet A-1 was changed from –50º to –47ºC after several years of in-flight measurements and development of detailed climatic data. Maximum aromatics content of fuel has slowly increased from a maximum of 20% to 22% to 25% over a period of years, during which time refiners were required to report to customers when fuels had aromatics content higher than 20% (later 22%). Inclusion of small volumes of Fischer-Tropsch liquids sparked healthy debate and investigations over a period of two years that have not yet been concluded.

Most of the jet fuel was totally unaffected by these changes, but by expanding the envelope of allowed properties slightly, adequate fuel supplies were assured in select areas. The average effect on jet pool quality was minor, and difficult to measure. Because the increase in flash point will, for the first time, significantly **restrict** availability, nearly all refiners, rather than a few, will be changing their production methods and thus the properties of the most of the jet fuel pool could be modified. Again, the magnitude of these changes is proportional to the change in minimum flash point.

12.0 COST AND AVAILABILITY IMPACT OF HIGH FLASH JET FUEL

The API/NPRA survey results are included as Appendix 1. Seventy-eight refiners completed the survey, which represented nearly 87% of the refining crude capacity and practically 100% of jet fuel production, based on Department of Energy (DOE) weekly production figures.

The survey was designed to assess the industry's ability to manufacture jet fuel with a higher flash point and estimate the impact on manufacturing costs associated with a range of property changes. Respondents were asked to complete a questionnaire for each refinery in which they currently produce commercial aviation Jet A fuel. The first question requested general information regarding the capacities of each refinery. The second set of questions (2a through 2g) assumed a series of revised minimum flash points and asked the respondents to determine:

a. Changes in jet fuel production volume
b. Total short term cost resulting from potential specification changes
c. Other product volume reductions or increases
d. Amount of reduction from (a) that could be made up in the short term
e. Total cost in (d) resulting from potential specification changes
f. Capital investments to make up as much of the lost production as feasible
g. Total cost of long term changes in (f) to recover this jet fuel production

The third set of questions (3a through 3g) assumed a series of revised minimum flash points and a reduction of the freeze point minimum specification as a basis for determining the same information (a through g) as above. The fourth question asked whether any of the changes to the flash point specification would create difficulties in complying with gasoline parameters.

The API/NPRA Survey was also distributed internationally. Survey responses from 33 European refineries were submitted by EUROPIA, the European Petroleum Industry Association (Appendix 2) representing more than two thirds of the jet fuel production and 50% of the crude distillation capacity in Europe. The Petroleum Association of Japan also submitted data from 24 refineries representing 85% of the jet fuel production and 72% of the crude distillation capacity in Japan (Appendix 3).

All survey results address jet fuel demand at 1998 levels. The survey does not address long-term changes in jet fuel demand or changes that could result from environmental regulations on other fuels. However, increases in demand or environmentally driven fuel changes are likely to amplify the difficulties predicted for the 1998 level (see Section 12.2.4).

Further, anticipated growth in jet fuel demand will put pressure on jet fuel availability even without a flash point change. Any increase in flash point will further complicated this situation.

12.1 Fuel Cost Estimates

All cost estimates reported are the estimated manufacturing costs to produce the new fuels. *The actual price for these fuels will be set by the marketplace.* In addition, refiners reported that these costs do not provide for 100% replacement of jet fuel production lost as a result of the higher minimum flash points (see Section 12.2).

12.1.1 United States

The API/NPRA survey results indicated that requirements for higher flash point jet fuels could result in United States refinery short-term (up to 24 months) production cost increases of 2-3 cents per gallon at 120 degrees F up to 5-7 cents per gallon at 150 degrees F. These short term costs do not include capital investments, but include incremental operating costs and economic losses through downgrades or changed product slates.

Long-term (up to five year) cost estimates, which include potential capital investments, ranged from 1.5-2.2 cents per gallon at 120 degrees F to 6-7.5 cents per gallon at 150 degrees F. Long term costs assumed 1998 dollars, 7% ROI for capital investment decisions and 10% return on capital. Based on current U.S. jet fuel demand, this translates into annual costs of $350-520 million at 120 degrees F to $1.4-1.7 billion at 150 degrees F.

U.S. refiners estimate their required capital investment to produce 120 degree F jet fuel at about $3 billion up to about $9 billion for 150 degree F fuel.

12.1.2 Europe

The EUROPIA survey results indicated that the requirements for higher flash point jet fuel could result in European refinery short-term (up to 24 months) production cost increases of 9 cents per gallon at 120 degrees F to more than 15 cents per gallon at 150 degrees F. Long term cost increases were 8 cents per gallon at 120 degrees F to more than 20 cents per gallon at 150 degrees F. European refiners estimate their capital investment to produce 120 degree F jet fuel at about $5 billion for 120 degree F fuel up to over $17 billion for 150 degree F fuel.

EUROPIA indicated that the impact in Europe is greater than the U.S. due to:

- The manufacture of the lower freeze point Jet A-1 grade in Europe which additionally reduces the potential jet fuel yield on crude;

- The demand barrel shape in Europe differs with less motor gasoline and more middle distillates required from a barrel of crude oil. This tends to produce higher front end cut points and flash points for U.S. jet fuel;
- Europe has a stronger demand for diesel fuel for which kerosene is also required. Environmental pressures in Europe are likely to require a lighter diesel fuel containing more kerosene in the near future.

12.1.3 Rest of the World

Survey results submitted by the Petroleum Association of Japan were consistent with data submitted by EUROPIA for the three reasons given in 12.1.2. Further, the Japanese reported that in order to manufacture a new specification of jet fuel, most of their refiners would have to give up their current refinery slate and install new facilities to produce jet fuel possibly including hydrocracking units. However, installing new units, or facilities in Japan is difficult due to space limitations and environmental/safety regulations so their report concluded that it would be economically infeasible to attempt to recover the lost volume.

12.2 Availability of Fuel

It was generally agreed that worldwide, higher flash points would result in less availability of jet fuel, and would require longer lead times for industry to meet demand. It is impossible to speculate on the future business plans of refiners regarding their decision to ensure that there would be an adequate supply of jet fuel.

12.2.1 United States

The API/NPRA survey results indicate that requirements for higher flash point jet fuel will result in U.S. refinery shortfalls of up to five percent at 120 degrees F and up to approximately 20 percent at 150 degrees F (assuming 1 to 2 years lead time and the required short term investments are made.). Actual shortfalls will vary considerably by refinery, season and area of the country.

12.2.2 Europe

EUROPIA reported European refinery shortfalls of 12% at 120 degrees F up to 49% at 150 degrees F (assuming 1 to 2 years lead time).

12.2.3 Rest of the World

Similar to EUROPIA, the Petroleum Industry of Japan reported significant short term production losses of 26% at 120 degrees F and 67% production loss at 150 degrees F. They concluded that for reasons discussed in Section 12.1.3, proposed specification changes would create serious availability effect in Japan, not only on jet fuel, but also only on household heating kerosene.

12.2.4 Future Projection of Jet Fuel Demand

The projected demand for jet fuel needs to be viewed in context with that for other refined petroleum products, including gasoline, diesel fuel, and fuel oil distillates. If growth in jet fuel demand is matched by increased demand for other products, there will be no dislocation requiring increased conversion of the crude barrel to jet fuel, and the increased demand can be readily absorbed by overall increases in refining capacity.

In the United States, jet fuel demand has grown at a rate of about 1.8 % per year over the past six years, and was in balance with similar growth in demand for gasoline, diesel fuel, and fuel oil.[1] However, jet fuel demand has been projected to increase 1.7% in 1998, compared to about 1% higher demand for motor gasoline, and 1.2% increased demand for other distillate fuels.[2]

World-wide demand for jet fuel is likely to grow at a rate of about 2.6-4.1% per year.[3] The Pacific Rim, Europe, and many other areas outside the United States will show higher demand growth rates. In the meantime, world-wide refined petroleum product demand is expected to increase at a rate of just under 2.5% per year.[4] On a world-wide basis, demand growth for jet fuel will likely exceed production of other refined transportation fuels by about 0.5 to1% each year. Thus by 2010, world-wide demand for jet fuel is projected to grow 6 to 15% more than other refined petroleum products.

While this appears to be a modest dislocation, other forces are expected to magnify its importance. The composition of gasoline and diesel fuels is increasingly being reformulated to reduce environmental impact. These required changes to other fuels will impact the supply and properties of jet fuel and some of these fuels may in fact compete directly for the same portion of the barrel. For example, the rate of growth of diesel fuel is high in Europe, and regulations may require greater use of “light” diesel fuels, which compete for the jet fuel portion of the barrel.[5]

References

[1] Oil and Gas Journal, week of December 29, 1997.

[2] Oil and Gas Journal, week of January 26, 1998.

[3] ICAO Journal, March 1996, p 9.

[4] SN Crewson, “Oil Markets – Industry Supply and Demand Dynamics”, presented at the IATA Fuel Trade Meeting, Prague, May 7/8, 1997.

[5] EUROPIA report to the ARAC Task Group 6/7, Atlanta, April 15/16, 1998.

12.2.5 Local Situations

From the beginning, members of Task Group 6/7 expressed concerns about the possible reduction of jet fuel supply at some airports if flash point was raised significantly, possibly resulting in localized shortages. Unfortunately the formal surveys by EUROPIA and API, to avoid anti-competitive practices, provided only broad area pictures of how fuel availability would be effected by changes in the minimum flash point requirements.

A few non-petroleum company members of Task Group 6/7 carried out a confidential, informal survey in cooperation with a few U.S. and international airlines, to better define localized supply and demand imbalances, which might result from minimum flash point changes. This effort was not highly successful, mainly because it was not possible to fully develop an overall view of alternate supply feasibility for various airports.

In this survey, airlines asked their suppliers to advise the immediate impact of a change in flash point, and did not request information on recovery of lost capacity (if any).
While it was generally not possible to define effects on specific airports, a review of the responses by individual suppliers revealed tremendous variation in the impact on supply. Availability from a few refiners was unaffected by minimum flash point requirements of 120 or 130ºF. Others were significantly affected at these levels. Thus flexibility of refiners to adapt varied markedly. In addition, those refiners known to be currently maximizing the yield of jet fuel universally suffered significant production losses. Results of the survey also indicated that refiners generally assumed that the current freezing point requirements for their area would remain in place.

An informal Australian/New Zealand survey encompassed all nine refiners in that region. The data again showed significant variation from refinery to refinery. Currently, supply availability and demand are in balance. However, demand for jet fuel has been growing in this area at a rate of 4-5% for the past ten years, while demand for gasoline has been growing at a rate of 1-2%. Refiners were predicting difficulties in meeting jet fuel demand during the next several years, even prior to the high flash jet fuel initiative. Data are shown below in Section 12.2, Table 1 below. These data show immediate impact without investment or other changes to improve jet fuel production, and in general assume the fuel supplied would be Jet A-1 fuel with a maximum freezing point of –47ºC (-53ºF).

Flash Point	**49C**	**54C**	**60C**	**65C**
Region I	10-30%	45-50%	>50%	>50%
Region II	5-10%	10-40%	20-50%	20-100%
Region III	5-50%	5-50%	20-100%	20-100%
Region IV	5-50%	>50%	>50%	>50%
Region V	20-30%	>50%	>50%	100%

Section 12.2.5, Table 1. Percent Reduction in Australian/New Zealand Jet Fuel Availability at Higher Flash Points

12.3 Impact of Availability on Price

Note: The American Petroleum Institute, EUROPIA and member companies did not participate in the analysis in Section 12.3 and do not endorse any conclusions, stated or inferred regarding such impacts.

The proposed flash point changes for jet fuel will increase the cost of production and shrink the available capacity to produce the fuel. Just like any commodity these events will both impact the market price for jet fuel. The extra production costs will raise the market price to the extent the market follows perfectly competitive marginal cost pricing behavior. Given the industry survey results, the cost increase may have some upward price repercussions. The reduction in capacity will create a temporary shortage of jet fuel that will be relieved only when the capacity has been added by the industry. Increasing the capacity will take approximately two years. The capacity shortage has the potential for substantial price increases until the capacity constraint is lifted.

Price elasticity models are used to predict the impact of a decrease in quantity, to the price of a commodity, relative to the demand. For this analysis, we did not assign a specific price elasticity to jet fuel, but we can assume that it is likely very inelastic. Inelastic demand means that the quantity demanded will decrease by less than one percent given a one percent increase in price. A price elasticity of .5 means that a one-percent increase in price will lead to a .5% reduction in quantity.

To demonstrate what possible outcomes would be given a range of possible price elasticities, we calculated the increases in price that could occur for various combinations of capacity reductions and price elasticities. Also for this analysis we assume no substitutions exist for jet fuel. In other words, we have assumed that the consumers would not be able to switch to another petroleum product such as diesel as the jet fuel price increased.

As Table 1 demonstrates, the possible potential impact on price from capacity constraints is dramatic. The price increases will be more substantial the greater the capacity reduction as a result of higher flash points, or the more inelastic the demand for jet fuel.

Cost impact of higher jet fuel flash points

Higher prices due to lowered capacity

Percentage price increase due to capacity reduction

	Capacity	Price elasticity for jet fuel market				
Flash	Reduction	1.0	0.8	0.6	0.4	0.2
120	8.11%	8.11%	10.14%	13.52%	20.28%	40.55%
130	16.74%	16.74%	20.93%	27.90%	41.85%	83.70%
140	24.72%	24.72%	30.90%	41.20%	61.80%	123.60%
150	32.13%	32.13%	40.16%	53.55%	80.33%	160.65%

*note: % change in price = % change in quantity / price elasticity**

Base price per gallon: $0.50

Price increase due to capacity reduction

	Capacity	Price elasticity for jet fuel market				
Flash	Reduction	1.0	0.8	0.6	0.4	0.2
120	8.11%	$0.04	$0.05	$0.07	$0.10	$0.20
130	16.74%	$0.08	$0.10	$0.14	$0.21	$0.42
140	24.72%	$0.12	$0.15	$0.21	$0.31	$0.62
150	32.13%	$0.16	$0.20	$0.27	$0.40	$0.80

Base quantity consumed: 23 (Billion gallons)

Years until capacity added: 2

Cost of flash point increase until capacity added

	Capacity	Price elasticity for jet fuel market				
Flash	Reduction	1.0	0.8	0.6	0.4	0.2
120	8.11%	$1,714,024,170	$2,142,530,213	$2,856,706,950	$4,285,060,425	$8,570,120,850
130	16.74%	$3,205,676,520	$4,007,095,650	$5,342,794,200	$8,014,191,300	$16,028,382,600
140	24.72%	$4,280,119,680	$5,350,149,600	$7,133,532,800	$10,700,299,200	$21,400,598,400
150	32.13%	$5,015,525,130	$6,269,406,413	$8,359,208,550	$12,538,812,825	$25,077,625,650

Section 12.3, Table 1—Impact of Availability on Price

Notes:

1. *Costs are not adjusted for inflation*
2. *Costs are calculated using only the gallons still purchased. This analysis does not include any indirect costs of using alternates to jet fuel and air travel.*
3. *These costs also do not include the additional costs of the fuel once the capacity has been added to relieve the capacity constraint.*
4. *This analysis ignores growth in demand for jet fuel that would occur over the time period observed.*

* *Carlton, Dennis W., and Perloff, Jeffrey M., Modern Industrial Organization, 2nd Edition, Harper Collins College Publishers, 1994.*

12.4 Effects on Crude Oil Selection

An increased jet fuel flash point specification may impact the market for crude oils. The mechanism of impact is complex and effects cannot be predicted at this time.

The issue is that crude oils differ with respect to the amount of jet fuel that they produce at higher flash points. To illustrate this, the coded individual crude oil results from the Jet Fuel Properties Survey (Section 9.2.1, Table 1) were used to make Section 12.4 ,Table 1 for Jet A [-40°F (-40°C) freeze point] and Section 12.4, Table 2 [-53°F (-47°C) freeze point]. The Tables show the percentage of the base case [100°F (38°C) flash point specification and -40°F (-40°F) freeze point] that the crude oil could produce at higher flash point specification values. The Tables indicate only “Avail” (jet fuel produced) and “Not Avail” (no jet fuel produced) for the three crude oils (B, N and D) where only qualitative data were supplied.

Coded Crude	100°F	110°F	120°F	130°F	140°F	150°F
L	100	96	92	87	83	79
J	100	94	89	83	78	72
E	100	94	89	83	78	72
G	100	90	79	69	59	48
I	100	87	74	61	49	36
O	100	89	76	63	49	36
A	100	87	74	60	47	34
H	100	84	67	51	35	18
K	100	86	73	59	45	31
F	100	81	62	43	24	5
C	100	77	54	31	8	0
M	100	72	43	15	0	0
B	Avail	Avail	Avail	Avail	Avail	Avail
N	Avail	Avail	Avail	Avail	Avail	Avail
D	Avail	Avail	Avail	Avail	Not Avail	Not Avail

Section 12.4, Table 1-- Relative Jet A yields (%) at selected flash point specification values from the Jet Fuel Properties Survey.

Coded Crude	100°F	110°F	120°F	130°F	140°F	150°F
L	81	76	70	65	60	54
J	74	69	63	57	52	46
E	69	64	58	52	47	41
G	85	73	62	50	38	27
I	85	69	52	35	18	1
O	77	60	44	28	11	0
A	79	60	40	21	1	0
H	67	47	27	7	0	0
K	65	44	24	4	0	0
F	60	41	22	4	0	0
C	60	41	22	4	0	0
M	43	6	0	0	0	0
B	Avail	Avail	Avail	Not Avail	Not Avail	Not Avail
N	Avail	Avail	Avail	Avail	Not Avail	Not Avail
D	Avail	Avail	Avail	Avail	Not Avail	Not Avail

Section 12.4, Table 2-- Relative Jet A-1 yields (%) at selected flash point specification values from the Jet Fuel Properties Survey

The results show that, for the representative crude oils evaluated here, jet fuel production by distillation is greatly reduced at the higher flash point specification values for a number of crude oils.

The impact of this is that if the flash point specification is increased enough to affect availability that:

- The demand may increase for crude oils having higher jet fuel yield coupled with reduced demand for other crude oils.
- Refineries and localities having little flexibility concerning crude oil source may be impacted significantly better or worse than average.

12.5 Effect on Refining

The impact on the manufacturing cost of other fuels (gasoline and diesel) of a higher minimum flash point was not assessed.

The API/NPRA survey results indicate that, as the minimum flash point increases, more refiners could have difficulty producing gasoline and diesel that complies with current state and federal environmental regulations. This impact would be particularly severe in California and the East Coast (PADD 1), where the refiners surveyed reported that even raising the jet fuel flash point to 120°F could severely affect their ability to comply with the aromatics and distillation requirements for gasoline.

12.6 Effect on APU Cost

If the fuel flash point is increased over current levels, addition of a fuel heater at the APU inlet may be required to ensure reliable APU starting for all ambient conditions.

The rough order of magnitude (ROM) cost to develop and certify a direct current (DC) powered APU fuel heater with BITE (Built in Test Equipment) was estimated to be up to $1M per APU model. Approximately 24 months would be required for development and qualification prior to delivery to the aircraft manufacturer. The reoccurring cost was estimated to be approximately $10,000 per engine, with an increase of approximately 4 lb. in APU weight. An additional 12 to 24 months would be required to incorporate the fuel heater in the field. The operator maintenance time to add the fuel heater and implement other necessary changes is estimated to be approximately 8 hours.

Additional time and cost would be required to complete any aircraft modifications or flight-testing required. Aircraft changes that may be required include wiring from the APU to the electronic control unit (usually located in a different compartment), modifications to the flight deck display, modifications to the APU battery or charger, modifications to the main engine generators, modifications to aircraft operational procedures, and any airplane manual revisions.

Additional recurring and non-recurring costs would be involved if an alternating current (AC) powered fuel heater were employed.

13.0 BIBLIOGRAPHY

This Section was not used.

14.0 APPENDIXES

14.1 Final Report API/NPRA Aviation Fuel Properties Survey

14.2 EUROPIA Effect of Jet A-1 Flash Point on Product Availability and Properties

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Final Report
American Petroleum Institute/ National Petrochemical & Refiners Association Aviation Fuel Properties Survey

APRIL 1998

National Petrochemical &
Refiners Association

American
Petroleum
Institute

Brief Review of the Aviation Fuel Survey

As a result of the TWA Flight 800 accident, the FAA is investigating methods to reduce the likelihood of airplane fuel tank ignition. The National Safety Board has made a number of safety related recommendations to the FAA, focusing not only on the elimination of ignition sources within tanks, but also on tank cooling, inerting systems, and raising the flash point of Jet -A aviation fuel.

The American Petroleum Institute (API) was asked to respond to one of these initiatives that may result in the modification of aviation fuel properties. Specifically, the FAA asked the API to assess the ramifications of producing a jet fuel with a higher flash point than the currently used Jet-A and, possibly, a modified freeze point consistent with Jet A-1. In order to provide an accurate assessment of the industry's capability to cope with fuel property changes, API, in conjunction with the National Petrochemical & Refiners Association (NPRA), formerly the National Petroleum Refiners Association, developed an industry-wide survey.

The survey was designed to assess the industry's ability to manufacture jet fuel with a higher flash point and estimate the impact on manufacturing costs associated with a range of property changes. Respondents were asked to complete a questionnaire for each refinery in which they currently produce commercial aviation Jet-A fuel. The first question requested general information regarding the capacities of each refinery. The second set of questions (2a through 2g) assumed a series of revised minimum flash points and asked the respondents to determine:

a. Changes in jet fuel production volume
b. Total short term cost resulting from potential specification changes
c. Other product volume reductions or increases
d. Amount of reduction from (a) that could be made up in the short term
e. Total cost in (d) resulting from potential specification changes
f. Capital investments to make up the lost production
g. Total cost of long term changes in (f) to recover jet fuel production

The third set of questions (3a through 3g) assumed a series of revised minimum flash points and a reduction of the freeze point minimum specification as a basis for determining the same information (a through g) as above. The fourth question asked whether any of the changes to the flash point specification would create difficulties in complying with gasoline parameters.

Committee representatives from both the NPRA and the API distributed the survey to virtually all US refiners. Harold S Haller & Company of Cleveland, Ohio was employed to administer the survey. All responses were sent directly to Haller & Company offices. Only Haller & Company employees viewed the completed survey forms, which will be destroyed after the survey has been completed upon receipt of written authorization from officials at API and NPRA. An Excel™ spreadsheet database was created to store, retrieve, and analyze the survey data.

The surveys were distributed during the week of March 16th. Responders were asked to have the survey completed and mailed or faxed to the Haller offices by no later than Friday, March 27th. Response to the survey was very good. Seventy-eight refiners completed the survey which represented nearly 87 % of refining crude capacity and practically 100% of jet fuel production based on Department of Energy (DOE) weekly production figures.

Review of Jet Fuel Manufacturing in a Typical Refinery

The industry standard for commercial jet fuel is ASTM D1655. This standard specifies values for 16 properties including gravity, freeze, flash, distillation, aromatics content, sulfur and thermal stability (see Appendix, page 50). Because of these stringent specifications, jet fuel production is only possible from a limited number of sources. The most common source occurs naturally in crude oil. It is removed as kerosene in the middle distillate area of the atmospheric crude fractionation column. In order to reduce sulfur to meet Jet-A specifications, kerosene must generally be hydrogen treated in a processing unit called a Hydrotreater. After the Hydrotreater, the product must pass extensive testing before it is sold as Jet -A product. The other source of jet fuel production is hydrocracking. This process converts heavy oil from the bottom of the atmospheric crude column or the middle and top of the vacuum column to lighter products. Hydrogen reduction of heavy oils to lighter oils is accomplished by reacting the heavy oil with hydrogen at high temperatures and very high pressures under the influence of a hydrocracking catalyst. The product slate from a hydrocracker can be adjusted by varying the hydrocracking conditions such as temperature and pressure. Hydrocracking products are equivalent, or in some cases superior, to hydrotreated products and must also pass a rigid testing regimen before being shipped as jet fuel.

While a hydrocracker can produce large quantities of jet fuel, new units generally have very high capital and operating cost. Production from naturally occurring crude oil sources is much more economical but limited by the quantity of jet fuel in crude oil. The refiner has a number of alternative market choices for the jet fuel product fraction. These markets include K1 kerosene, specialty diesel fuel and aliphatic solvents. Most alternative markets do not have the stringent specifications associated with jet fuel.

Survey Comparisons by PADD

Survey analyses were performed in aggregate and by region represented by Petroleum Administration for Defense Districts, PADD. A U.S. map showing the five PADDs is included as Figure 1 on page 17 in the Appendix. PADD 3 is the largest processing PADD. These six southern, Gulf Coast states process nearly 7 million barrels of crude oil per day and produce about 615 thousand barrels per day of jet fuel. The second largest region by processing is the Midwest region, PADD 2. These 15 states process about 3 million barrels per day of crude oil and produce 250 thousands barrels of jet fuel. The West Coast PADD 5 is the third largest processing area. This region processes over 2.5 million barrels per day of crude oil and produces 350 thousand barrels of jet fuel per day. PADD 1 which includes the East Coast states is the fourth largest and processes about 1.5 million barrels per day of crude oil and produces over 100 thousand barrels per day of jet fuel. The Rocky Mountain area, PADD 4, is the smallest. This region processes about 450 thousand barrels of crude oil and produces 25 thousand barrels per day of jet fuel. A complete list of states by PADD is included in the Appendix, page 18. All PADD processing data was taken from the weekly Department of Energy (DOE) petroleum numbers that are posted on the Internet.

To provide data that would assist in the analysis of the impact of possible changes in jet fuel specifications, the data on California refineries were entered separately from the rest of PADD 5 because of California's unique gasoline and diesel requirements.

Survey Procedures

Each survey mailed or faxed to Haller & Company offices in Cleveland, Ohio was reviewed for validity and then either entered into an Excel™ spreadsheet database, or in case of problems, an inquiry was made to the API staff. A few surveys were received during the week ending March 27th. Most were received early in the week ending April 3rd . Calculations and analyses were done during the week ending April 3rd and a draft report was submitted on Friday, April 3rd .

Survey Data

Seventy-eight responses were received and used. This represented 12 million barrels of crude processing and 1.5 million barrels of jet fuel production. This response represented 87% of US crude oil processing and practically all of jet fuel production. Most surveys were well marked and completed in total. Some had inconsistencies and were not fully completed. In some cases the responder was called to resolve questions. In a few cases zero was used for a response that was marked by a comment when it was obvious that zero was intended. Also, questions that were not answered were not included in the survey.

Data Summaries and Survey Analyses

Data Entry

Most of the response categories in the survey that were available for selection by the respondents were given as ranges. In these cases, the midpoint for each category was entered into the Excel ™ database as the response to the question. In this way the estimates for range response categories were unbiased. If the response category indicated "greater than" or "less than" a specific value, this specific value was entered into the Excel™ spread sheet in order to avoid skewing the data without any basis for doing so. Specific values like "zero change" or "zero incremental cost" were recorded as such in the database. Responses to questions on incremental capital expenditures were occasionally "not feasible.". These responses had to be treated in two different ways. If volume changes reported due to specification changes were from zero to five percent, "not feasible" was entered as a zero incremental capital value. If volume changes due to specification changes were greater than five percent, the maximum incremental capital value was entered into the database to reflect the large economic impact to the refinery.

Data Summaries

The survey responses, once quantified for each question as described above, were summarized or aggregated by computing the volume weighted average for each question. For questions related to jet fuel such as percent losses, incremental costs in the short term and overall, and incremental capital required to recover jet volume losses, the weighing factors were the thousands of barrels of jet produced per calendar day (mb/cd) per refiner divided by the total barrels for the group expressed in thousands of barrels per calendar day (mb/cd). The general formula for this was:

Weighted Average Response =

$$\sum \left(\text{jet produced by refinery}\right)\left(\text{refinery response}\right) \div \left(\text{total jet produced in group}\right)$$

where the summation (Σ) is over all refineries in the group. Here the group could be a PADD or all refineries in the United States.

For questions related to a refinery's overall product slate, the weighing factors were based on the crude processed per refinery expressed in thousands of barrels per calendar day (mb/cd) divided by the overall crude processed in the refinery grouping expressed in thousands of barrels per calendar day (mb/cd). The formula in these cases is as follows:

Weighted Average Response =

$$\sum \left(\text{crude processed by refinery}\right)\left(\text{refinery response}\right) \div \left(\text{total crude processed in group}\right)$$

where the summation (Σ) is over all refineries in the group. Here the group could be a PADD or all refineries in the United States.

There is one main reason why volume weighted averages were chosen as the optimum statistic for summarizing the responses relative to the survey questions. With the data aggregated using weighted averages as described above, the total change in a PADD or the overall refining industry caused by a proposed specification change simply can be calculated by multiplying the weighted average response for a refining group by the total product produced or crude processed by the refining group, i.e. PADD or overall US industry. In this way the total impact of proposed specification changes to, for example, the volume loss or incremental capital requirements can be estimated by refining segment. For each question, bar charts were drawn for the weighted averages by PADD and for the overall US refining industry at each flash point.

Survey Analyses

Because the completed survey responses from each PADD that were received by Haller & Company represented a sample from each region, how representative are the weighted averages described above? This question can be answered based on the Analysis of Means. Using

1.) the variation in the responses to each question from each group (PADD or all US refineries),

2.) the fraction of crude processed by each refinery participating in the survey,

3.) the percentage of total crude reported to the DOE from those groups participating in the survey,

maximum and minimum estimates of the weighted averages were calculated for each question. These maximum and minimum estimates provide 95% confidence limits for the weighted averages shown in the charts based on the three uncertainties listed above. Table 1 in the Appendix on pages 46–49 summarizes the maximum, average, and minimum weighted estimates for Questions 2 and 3 (a), (d), and (f) for each flash point, and for each PADD as well as for all US refineries. Only maximum and minimum were summarized for Questions 2 and 3 (b), (e), and (g) for each flash point, and for each PADD as well as for all US refineries.

Survey Detailed Analysis by Question

Question 1
Please indicate the following information regarding your refinery
Crude thruput, mb/cd
Hydrocracking capacity, for jet fuel, mb/cd
RFG & CARB production as a % of total gasoline
Current Jet A/A1 Production, mb/cd
Current JP-5 Production, mb/cd
Current JP-8 Production, mb/cd

	Number of Responses	Crude Runs	Hydro-cracking	RFG & CARB %	Current Jet A/A	Current JP-5	Current JP-8	Total Jet
PADD 1	5	1,100.0	0.0	55.0	87.0	0.0	8.0	95.0
PADD 2	17	2,494.5	29.0	9.8	183.0	0.0	10.9	193.8
PADD 3	34	6,183.1	89.2	13.5	757.1	27.5	41.0	825.6
PADD 4	4	267.1	4.2	8.3	19.6	0.0	0.8	20.4
PADD 5	8	645.4	18.0	13.0	102.6	0.0	2.1	104.7
CALIF	10	1,570.9	207.3	85.0	294.9	15.7	25.7	336.3
TOTAL	78	12,260.9	347.7	24.2	1,444.2	43.2	88.4	1,575.7

Question 2a
If the flash point specification minimum was raised, with no other specification changes, what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.

Listed below is a summary of the responses from Question 2a. All responses are in weighted averages and represent the mid-point of the percentage ranges given in the survey question. As expected, the percent jet fuel losses increase with increasing flash. PADD 5 has the highest averages of the group and PADD 2 has the lowest. All numbers are in percent and represent product loss.

		% Product Loss		
Flash	**120**	**130**	**140**	**150**
PADD 1	6.50	18.11	21.32	27.84
PADD 2	1.70	10.55	17.42	22.66
PADD 3	8.17	16.26	24.02	31.38
PADD 4	3.75	16.37	24.17	39.22
PADD 5	16.85	33.58	45.09	47.20
CALIF	9.65	15.88	25.30	35.50
TOTAL	8.11	16.74	24.72	32.13

Refer to the bar chart on page 19.

Question 2b
What would be the total cost in the short term of these changes in jet fuel production resulting from flash point specification changes, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

The table below is a summary of the analyses of the responses for Question 2b. The entries in the table are the upper (max) and lower (min) 95% confidence limits for the averages of the incremental costs in cents per gallon for added expenses from the changes described in Question 2a. As in Question 2a, the responses that were analyzed were midpoints of the question ranges. The extreme width of the confidence limits for PADDs 1 and 4 reflect the barrels of crude reported by respondents to the survey relative to the DOE reported figures For each PADD, the two line graphs describe the upper and lower 95% confidence limits or max and min, respectively.

Question 2b

Flash		120	130	140	150
PADD 1	Max	2.46	11.42	11.32	12.16
	Min	0.29	0.00	0.00	0.00
PADD 2	Max	0.43	2.46	5.81	8.71
	Min	0.15	0.71	1.51	2.87
PADD 3	Max	1.00	2.33	4.42	6.68
	Min	0.82	1.94	3.81	5.93
PADD 4	Max	5.72	16.62	16.31	18.32
	Min	0.00	0.00	0.00	1.33
PADD 5	Max	4.38	8.40	10.39	15.29
	Min	2.22	5.33	5.86	10.08
CALIF	Max	1.67	5.14	8.58	10.54
	Min	1.13	3.82	6.20	7.88
TOTAL	Max	1.30	3.46	5.62	7.96
	Min	0.94	2.63	4.48	6.61

Question 2c
What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

Gasoline
Kerosene
On-road diesel
Off-road diesel
Heating oil
Exports (naphtha or gasoline)
Other

This question asked for changes in other refinery products as a consequence of the jet fuel specification changes. Charts of the averages are included in the Appendix on pages 21 to 27.

Question 2d
If you indicated a reduction in jet fuel production in question 2a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.

The table below is a summary of the responses to Question 2d. They are expressed as mid-point averages. PADD 2 has responded that they could recover the most fuel of the group, and PADD 5 indicated that they could recover the least.

Question 2d

Flash	120	130	140	150
PADD 1	31.45	27.96	33.87	33.87
PADD 2	63.20	54.74	48.48	51.52
PADD 3	43.51	42.55	32.67	30.92
PADD 4	46.48	36.15	31.99	29.90
PADD 5	28.30	40.96	39.94	41.26
CALIF	41.54	51.30	50.30	48.53
TOTAL	42.03	44.19	38.98	38.23

Refer to the bar chart on page 28.

Question 2e
What would be the total cost in the short term of these changes to recover losses in jet fuel production resulting from flash point specification changes, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

The table below summarizes upper (max) and lower (min) 95% confidence intervals for the weighted average responses from Question 2e. All numbers are expressed as incremental costs in cents per gallon. The extreme width of the confidence limits for PADDs 1 and 4 reflect the barrels of crude reported by respondents to the survey relative to the DOE reported figures. For each PADD, the two line graphs describe the upper and lower 95% confidence limits or max and min, respectively.

	Flash	120	130	140	150
PADD 1	Max	15.63	15.75	15.59	15.59
	Min	2.54	3.26	3.46	3.46
PADD 2	Max	0.28	3.46	5.48	7.52
	Min	0.03	0.55	1.51	3.04
PADD 3	Max	2.64	3.32	4.40	5.72
	Min	2.04	2.73	3.73	5.01
PADD 4	Max	12.84	12.85	13.38	13.74
	Min	0.00	0.00	0.00	0.00
PADD 5	Max	6.88	7.80	9.02	11.73
	Min	2.42	3.39	4.78	7.34
CALIF	Max	3.81	5.58	6.27	7.21
	Min	1.41	2.76	3.47	4.34
TOTAL	Max	3.18	4.23	5.26	6.57
	Min	2.19	3.19	4.15	5.40

Question 2f
If adequate time for capital investments were allowed, what would be the estimated capital investment required in millions of dollars to make up 100% of the lost production. Check one box for each flash point.

The capital cost in Question 2f are expressed as mid-point averages in millions of dollars for recovery of lost jet fuel. PADD 5 is by far the highest cost and PADD 1 is the lowest.

Flash	120	130	140	150
PADD 1	1.63	10.95	10.95	18.53
PADD 2	15.19	49.43	51.96	67.25
PADD 3	35.57	74.72	107.28	124.47
PADD 4	0.74	25.00	20.59	20.59
PADD 5	125.76	136.17	185.26	185.45
CALIF	61.66	81.96	74.09	132.10
TOTAL	42.12	72.75	91.64	115.38

Refer to the bar chart on page 30.

Question 2g
What would be the estimated total cost of these long term changes to recover jet fuel production resulting from flash point changes, including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 15% ROI for capital investment decisions and 10% return on capital for determining per gal capital charges. Check one box for each flash point.

The table below summarizes upper (max) and lower (min) 95% confidence intervals for the weighted average responses from Question 2g. All numbers are expressed as incremental total costs in cents per gallon. The extreme width of the confidence limits for PADDs 1 and 4 reflect the barrels of crude reported by respondents to the survey relative to the DOE reported figures. For each PADD, the two line graphs describe the upper and lower 95% confidence limits or max and min, respectively.

Question 2g

	Flash	120	130	140	150
PADD 1	Max	16.15	17.20	17.74	17.74
	Min	1.80	3.66	4.46	4.46
PADD 2	Max	0.95	3.42	7.20	8.82
	Min	0.29	0.75	1.65	2.78
PADD 3	Max	1.80	3.50	6.23	8.91
	Min	1.44	2.96	5.52	8.03
PADD 4	Max	17.01	17.26	20.42	19.84
	Min	0.00	0.00	0.00	0.00
PADD 5	Max	11.02	13.79	15.71	15.68
	Min	5.75	7.73	9.47	9.57
CALIF	Max	2.66	6.14	11.01	12.46
	Min	1.87	3.15	6.88	8.34
TOTAL	Max	3.00	4.94	7.86	9.77
	Min	2.07	3.75	6.38	8.23

Question 3a
If the freeze point specification minimum was reduced to –53 deg F, in addition to the flash point changes projected above, what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.

The summary below shows the averages of the volume losses expressed as percent. PADD 3 indicates the overall highest losses and PADD 1 indicates the lowest losses.

		% Product Loss		
Flash	**120**	**130**	**140**	**150**
PADD 1	5.13	13.58	18.84	22.42
PADD 2	11.10	16.36	20.71	22.72
PADD 3	20.87	30.13	35.59	39.25
PADD 4	13.43	22.50	32.01	46.57
PADD 5	17.02	27.44	36.12	36.51
CALIF	8.85	15.93	33.89	39.02
TOTAL	15.80	24.13	32.37	36.07

Refer to the bar chart on page 32.

Question 3b
What would be the total cost in the short term of these changes in jet fuel production resulting from flash point and freeze point specification changes, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

The table below summarizes upper (max) and lower (min) 95% confidence intervals for the weighted average responses from Question 3b. All numbers are expressed as incremental costs in cents per gallon. The extreme width of the confidence limits for PADDs 1 and 4 reflect the barrels of crude reported by respondents to the survey relative to the DOE reported figures For each PADD, the two line graphs describe the upper and lower 95% confidence limits or max and min, respectively.

	Flash	**120**	**130**	**140**	**150**
PADD 1	Max	9.75	11.17	12.37	13.72
	Min	0.00	0.00	0.20	2.21
PADD 2	Max	1.77	4.72	7.00	8.64
	Min	0.41	1.04	1.87	2.68
PADD 3	Max	3.89	5.53	6.40	8.49
	Min	3.27	4.82	5.39	7.36
PADD 4	Max	7.80	17.44	18.32	21.72
	Min	0.00	0.00	1.33	5.78
PADD 5	Max	5.91	8.85	9.71	13.17
	Min	1.65	3.75	4.48	7.15
CALIF	Max	5.31	7.06	10.19	11.52
	Min	3.58	5.04	7.52	8.93
TOTAL	Max	3.93	5.71	7.24	9.18
	Min	3.01	4.55	5.77	7.55

Question 3c
What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

Like Question 2c, this question called for estimates of changes to the other refinery products as a consequence of the jet fuel changes. Refer to bar charts of the averages in the Appendix on pages 34 to 40.

Question 3d
If you indicated a reduction in jet fuel production in question 3a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.

The recovery table below is a summary of the volume recoveries expressed as a percent with lowered freeze points. PADD 2 indicated the best recovery and PADD 1 indicated the worst.

Flash	120	130	140	150
PADD 1	27.11	27.89	33.68	33.68
PADD 2	68.31	58.94	53.38	54.98
PADD 3	41.55	33.06	28.55	28.43
PADD 4	57.48	33.70	30.76	21.32
PADD 5	31.20	41.47	40.15	39.49
CALIF	36.81	44.89	47.46	42.58
TOTAL	40.36	38.64	36.93	35.94

Refer to the bar chart on page 41.

Question 3e
What would be the total cost in the short term of these changes to recover losses in jet fuel production resulting from flash and freeze point specification changes, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

The table below summarizes upper (max) and lower (min) 95% confidence intervals for the weighted average responses from Question 3e. All numbers are expressed as incremental costs in cents per gallon. The extreme width of the confidence limits for PADDs 1 and 4 reflect the barrels of crude reported by respondents to the survey relative to the DOE reported figures. For each PADD, the two line graphs describe the upper and lower 95% confidence limits or max and min, respectively.

Question 3e

	Flash	120	130	140	150
PADD 1	Max	20.90	20.90	21.26	22.08
	Min	3.90	3.90	4.89	5.75
PADD 2	Max	4.25	6.72	8.48	9.98
	Min	0.00	1.01	2.08	3.65
PADD 3	Max	4.68	5.10	6.79	7.58
	Min	3.83	4.25	5.85	6.60
PADD 4	Max	17.46	16.74	18.28	20.09
	Min	0.00	0.00	0.00	0.00
PADD 5	Max	8.41	8.41	9.57	11.01
	Min	2.14	2.14	3.58	5.13
CALIF	Max	6.36	6.74	7.88	9.49
	Min	2.76	3.30	4.56	6.21
TOTAL	Max	5.31	5.89	7.38	8.51
	Min	3.85	4.41	5.82	6.90

Question 3f
If adequate time for capital investments were allowed, what would be the estimated capital investment required in millions of dollars to make up 100% of the lost production? Check one box for each flash point.

PADD 5 and California would require the highest recovery capital dollars and PADD 1 the lowest under the proposed specification. All entries in the table are mid-point averages and are expressed in millions of dollars.

Flash	120	130	140	150
PADD 1	7.00	10.95	10.95	18.53
PADD 2	22.38	55.51	67.02	70.50
PADD 3	93.82	73.64	99.41	95.61
PADD 4	7.84	3.43	20.59	20.59
PADD 5	119.68	119.68	119.33	119.33
CALIF	142.90	71.75	81.90	131.75
TOTAL	90.88	69.38	86.66	96.19

Refer to the chart on page 43.

Question 3g
What would be the estimated total cost of these long term changes to recover jet fuel production resulting from flash and freeze point changes, including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 10% ROI for capital investment decisions and 10% return on capital for determining per gal capital charges. Check one box for each flash point.

The table below summarizes upper (max) and lower (min) 95% confidence intervals for the weighted average responses from Question 3g. All numbers are expressed as incremental costs in cents per gallon. The extreme width of the confidence limits for PADDs 1 and 4 reflect the barrels of crude reported by respondents to the survey relative to the DOE reported figures. For each PADD, the two line graphs describe the upper and lower 95% confidence limits or max and min, respectively.

	Flash	**120**	**130**	**140**	**150**
PADD 1	Max	14.55	15.42	15.23	15.82
	Min	4.20	5.46	6.81	7.91
PADD 2	Max	3.33	4.42	6.45	7.30
	Min	0.46	1.09	1.88	2.77
PADD 3	Max	5.63	6.34	8.21	8.81
	Min	4.99	5.68	7.47	8.06
PADD 4	Max	12.89	15.13	15.19	14.61
	Min	0.00	0.00	0.00	2.15
PADD 5	Max	9.69	9.69	9.73	9.73
	Min	5.01	5.01	5.33	5.33
CALIF	Max	6.34	7.64	9.42	11.22
	Min	3.69	5.20	6.63	8.15
TOTAL	Max	5.73	6.58	8.17	9.03
	Min	4.62	5.46	6.97	7.82

Question 4
Would any of the changes to flash point specifications create difficulty with gasoline compliance parameters?

Included in the appendix on page 45 is a table summarizing the responses to Question 4. No conclusions were drawn from the responses, except that a surprising number of refineries did believe that jet fuel changes would impact RFG and CARB production.

Survey Conclusions

The survey has been a very successful attempt to measure the impact of significant jet fuel specification changes on the US refining industry. Given the short time that the refineries had to respond to this request for data, the response rate was excellent. Over 87% of crude processing refineries responded which included virtually all of Jet-A production. In PADD 4 where there was some scatter in confidence levels, volume response was good although the number of responses was somewhat lower. But overall, the results established clear trends about what refiners believe about the impact of the proposed specification changes. The level of response to the survey also showed a great deal of interest and concern for the subject matter.

Appendix

to

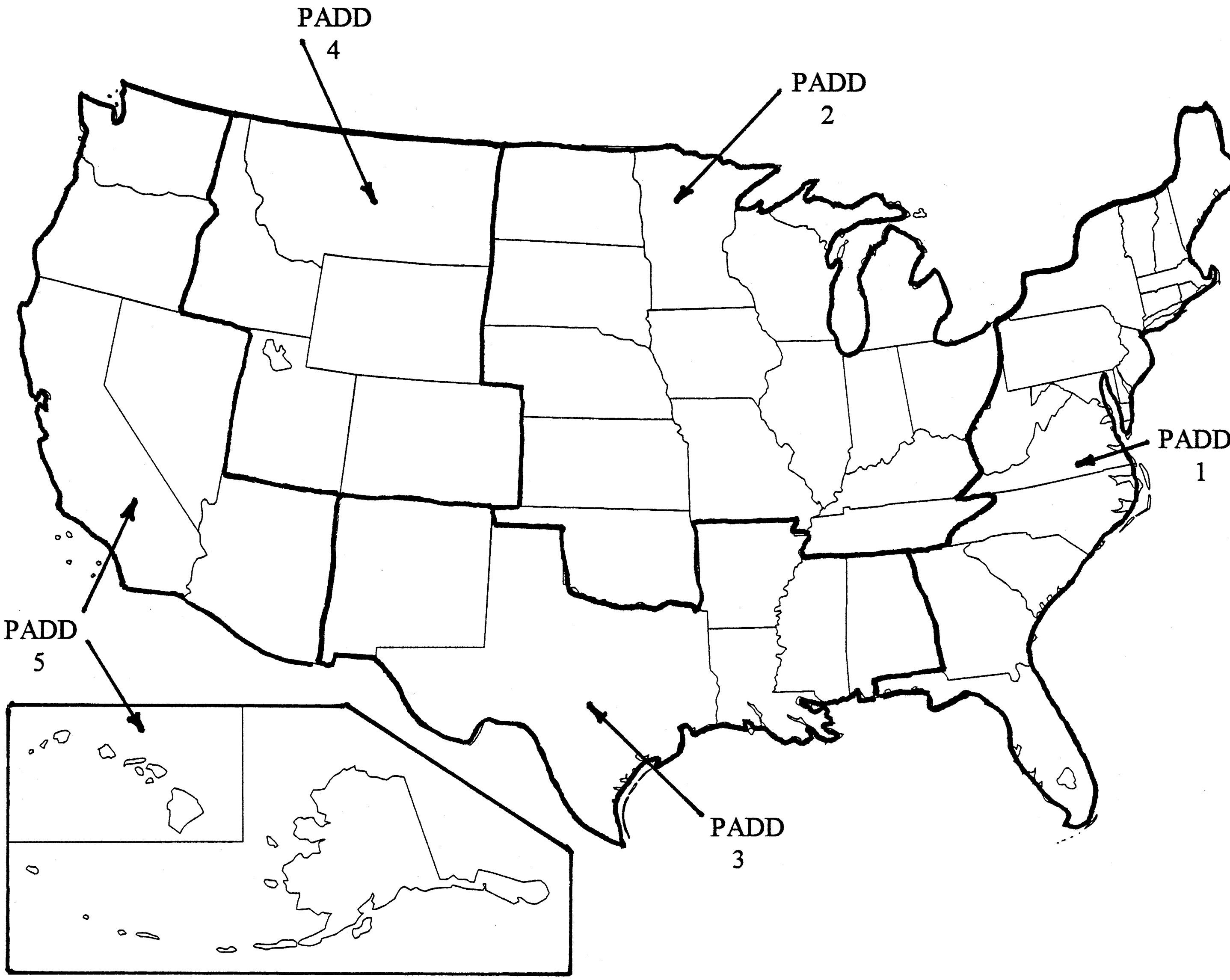
Final Report

on

API/NPRA AVIATION FUEL PROPERTIES SURVEY

Figure 1

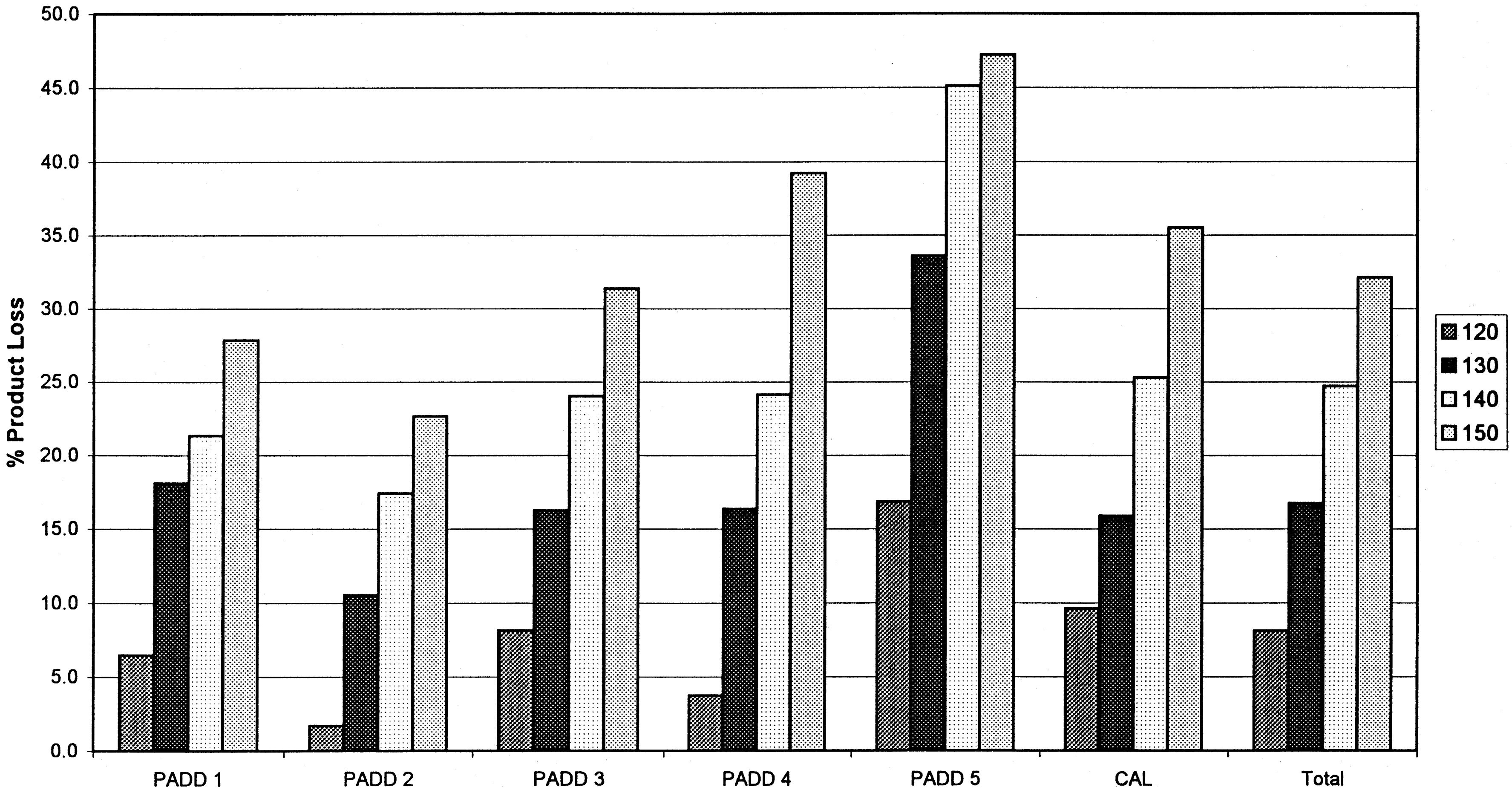
PADD MAP



PADD BY LOCATION

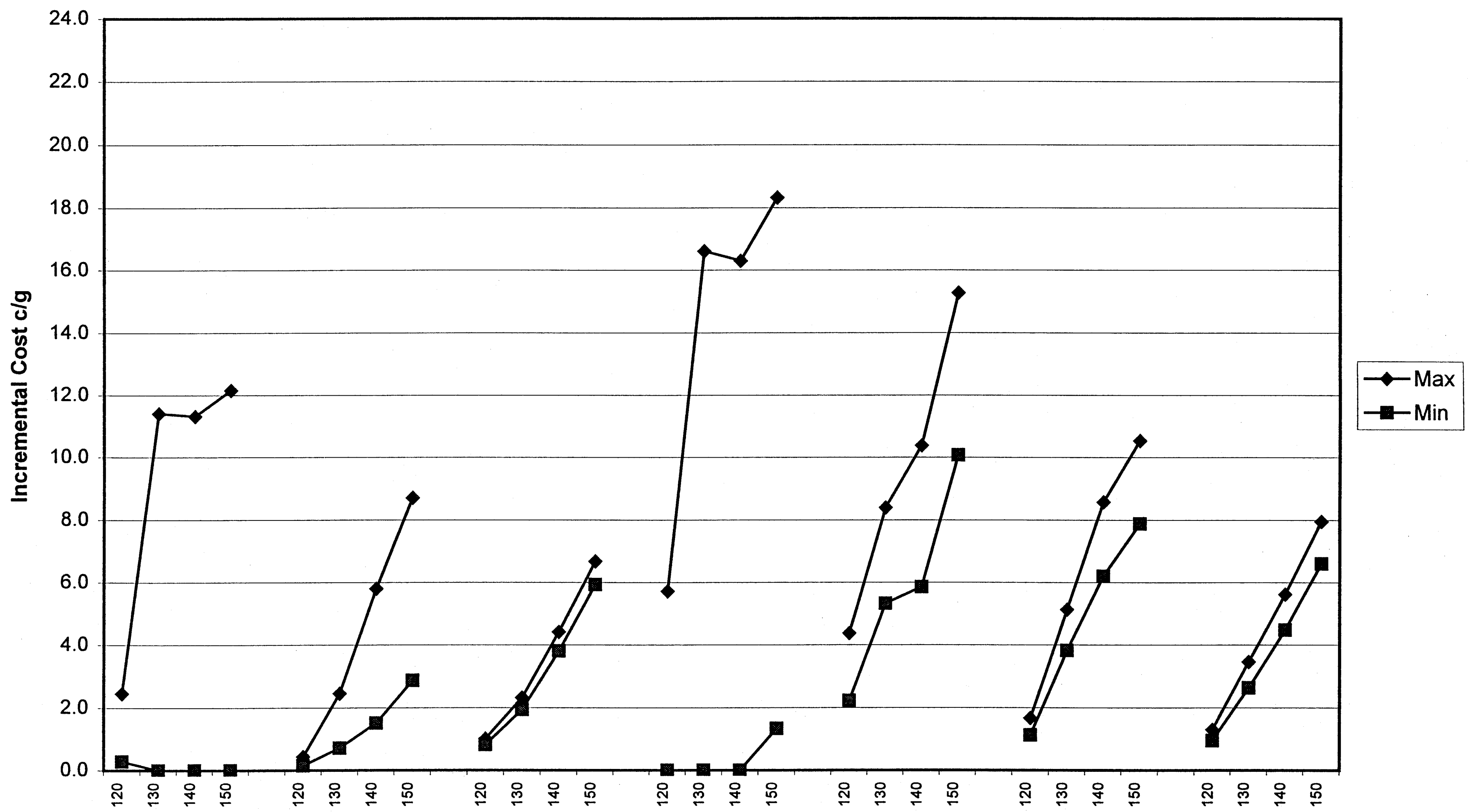
Alphabetical Sort				*PADD Sort*	
States	**PADD**			**States**	**PADD**
Alabama	3			Connecticut	1
Alaska	5			Delaware	1
Arizona	5			District of Columbia	1
Arkansas	3			Florida	1
California	5			Georgia	1
Colorado	4			Maine	1
Connecticut	1			Maryland	1
Delaware	1			Massachusetts	1
District of Columbia	1			New Hampshire	1
Florida	1			New Jersey	1
Georgia	1			New York	1
Hawaii	5			North Carolina	1
Idaho	4			Pennsylvania	1
Illinois	2			Rhode Island	1
Indiana	2			South Carolina	1
Iowa	2			Vermont	1
Kansas	2			Virginia	1
Kentucky	2			West Virginia	1
Louisiana	3			Illinois	2
Maine	1			Indiana	2
Maryland	1			Iowa	2
Massachusetts	1			Kansas	2
Michigan	2			Kentucky	2
Minnesota	2			Michigan	2
Mississippi	3			Minnesota	2
Missouri	2			Missouri	2
Montana	4			Nebraska	2
Nebraska	2			North Dakota	2
Nevada	5			Ohio	2
New Hampshire	1			Oklahoma	2
New Jersey	1			South Dakota	2
New Mexico	3			Tennessee	2
New York	1			Wisconsin	2
North Carolina	1			Alabama	3
North Dakota	2			Arkansas	3
Ohio	2			Louisiana	3
Oklahoma	2			Mississippi	3
Oregon	5			New Mexico	3
Pennsylvania	1			Texas	3
Rhode Island	1			Colorado	4
South Carolina	1			Idaho	4
South Dakota	2			Montana	4
Tennessee	2			Utah	4
Texas	3			Wyoming	4
Utah	4			Alaska	5
Vermont	1			Arizona	5
Virginia	1			California	5
Washington	5			Hawaii	5
West Virginia	1			Nevada	5
Wisconsin	2			Oregon	5
Wyoming	4			Washington	5

Question 2a Comparisons by PADD



2a. **If the flash point specification minimum was raised, with no other specification changes,** what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.

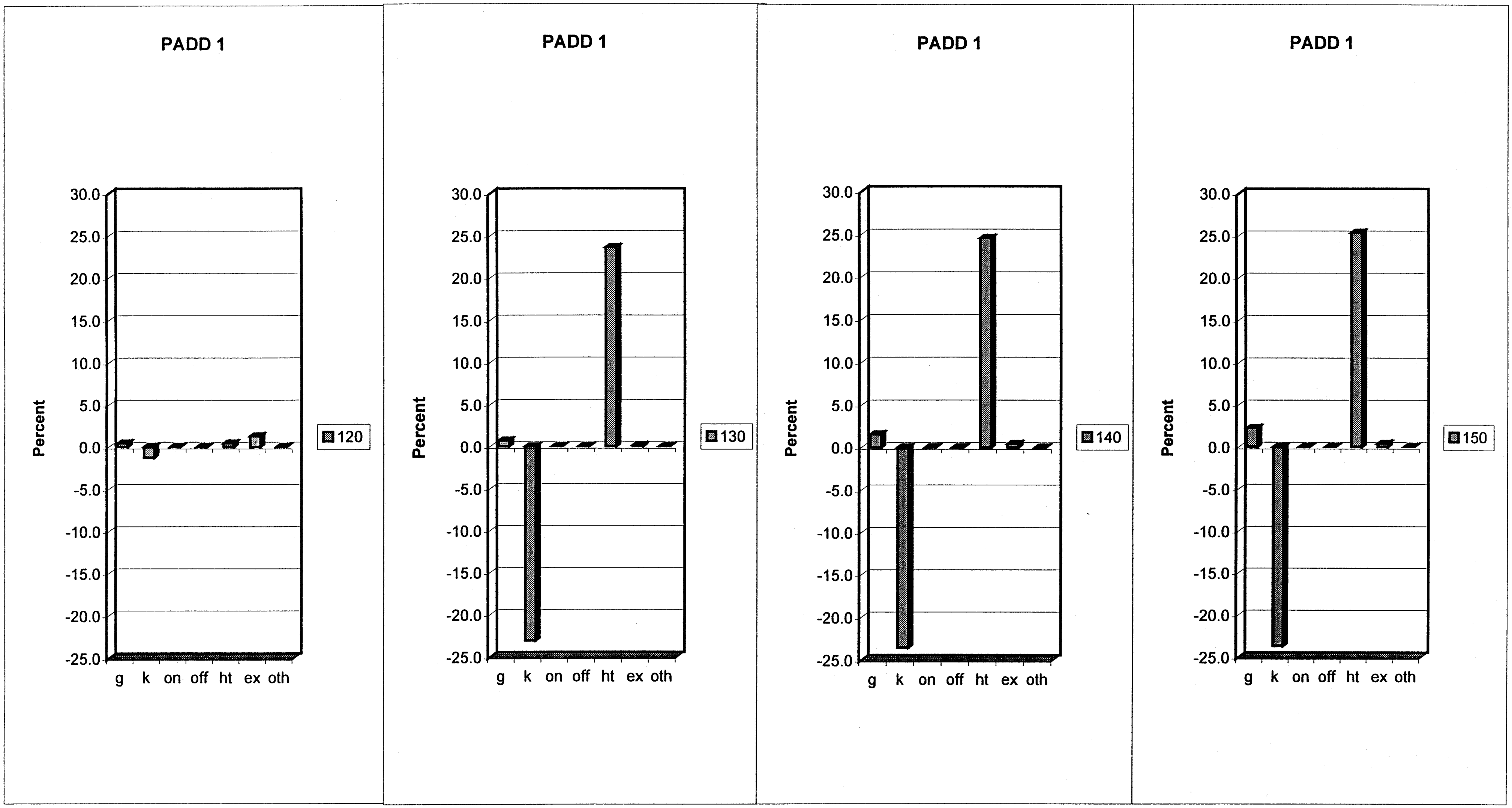
Question 2b Comparison by PADD



PADD 1 PADD 2 PADD 3 PADD 4 PADD 5 CALIF TOTAL

2b. What would be the total cost in the short term of these changes in jet fuel production resulting from **flash point specification changes,** including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point

Question 2C Comparisons for PADD 1

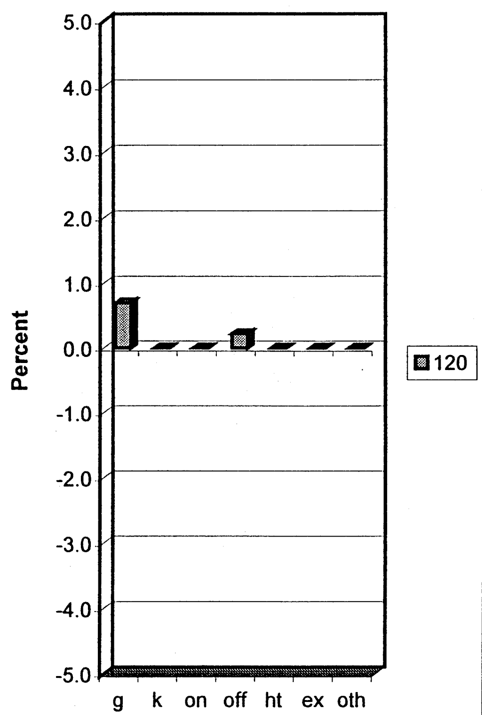


Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

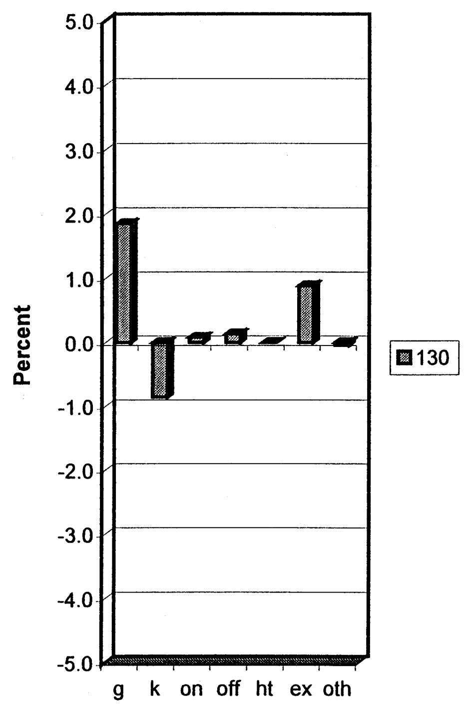
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 2C Comparisons for PADD 2

PADD 2



PADD 2



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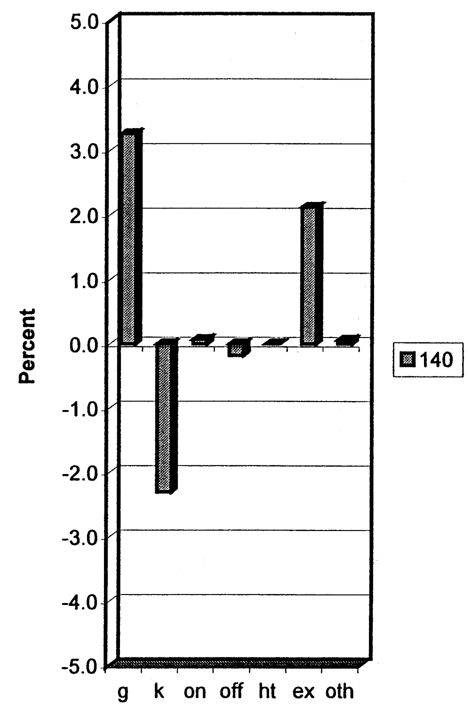
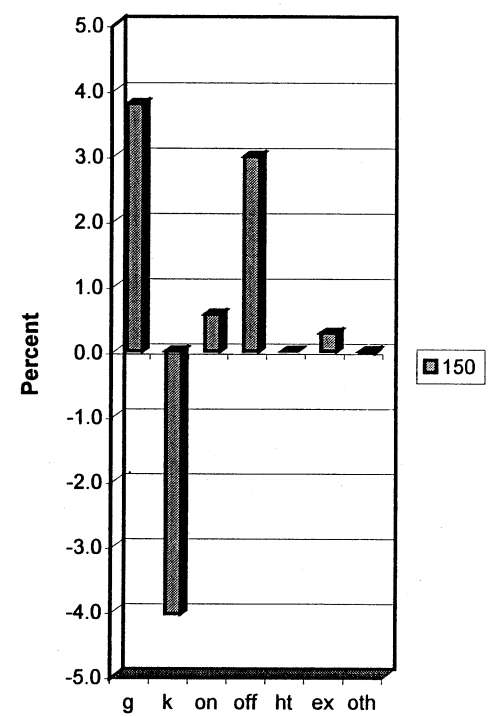


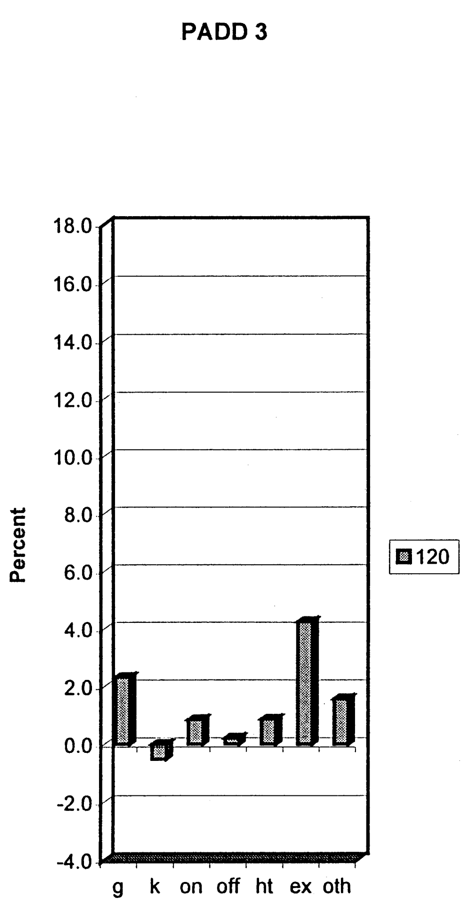
PADD 2

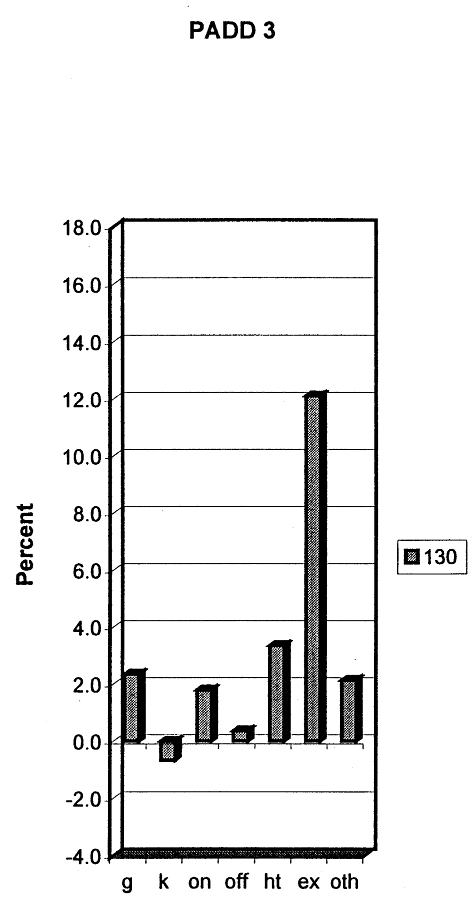


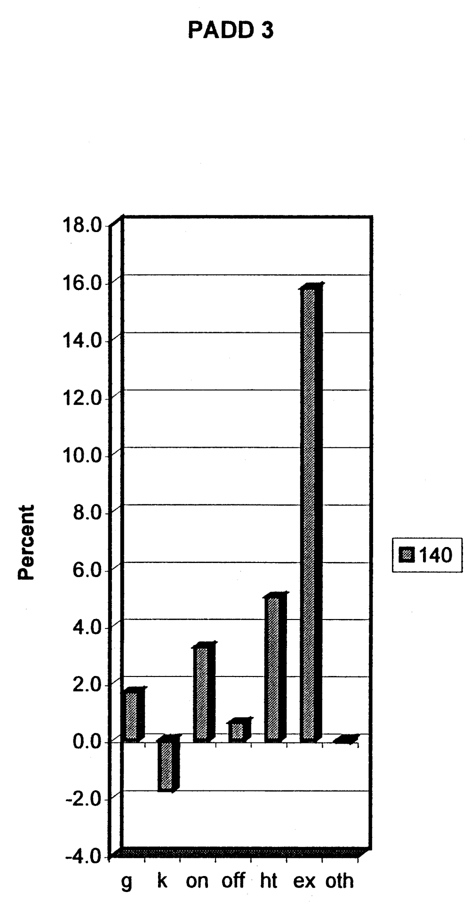
Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

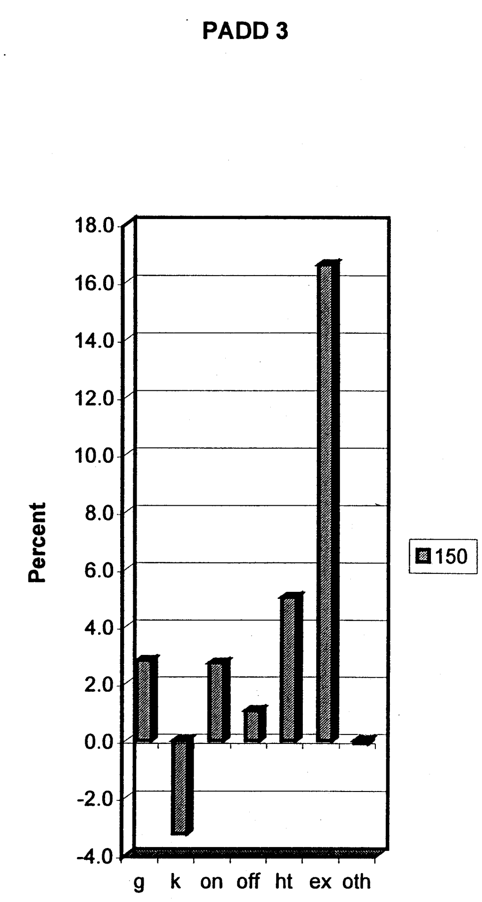
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 2C Comparisons for PADD 3



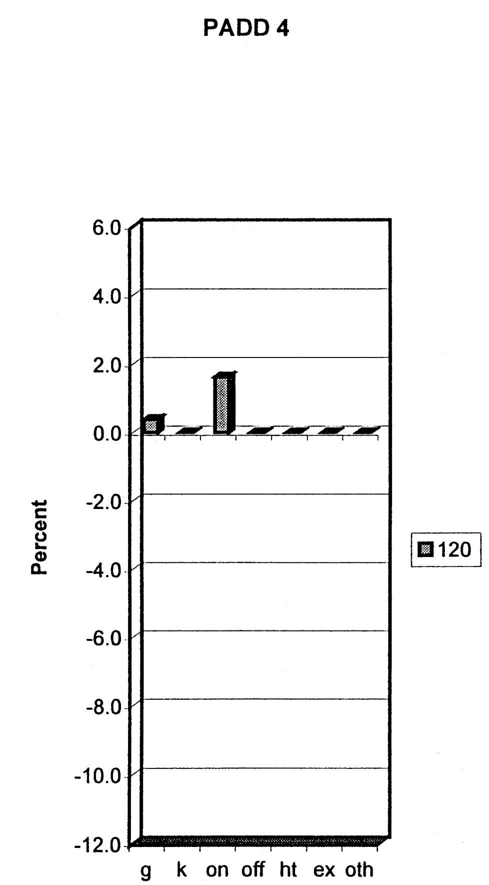


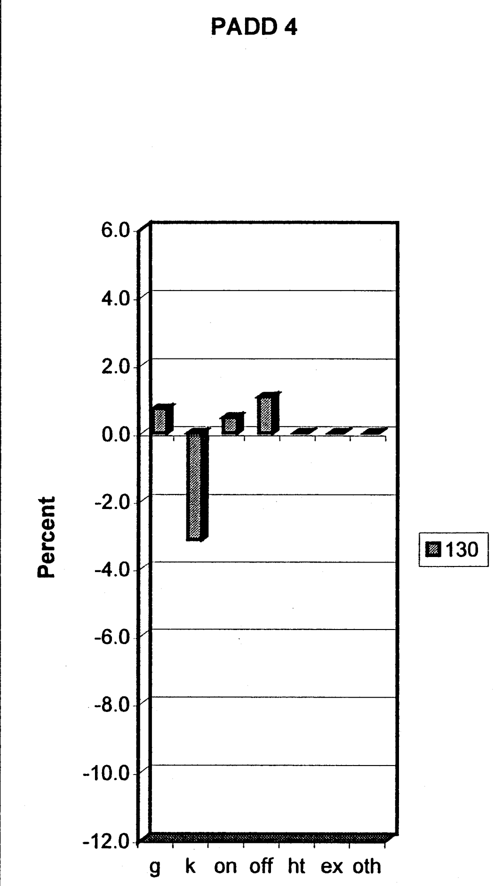


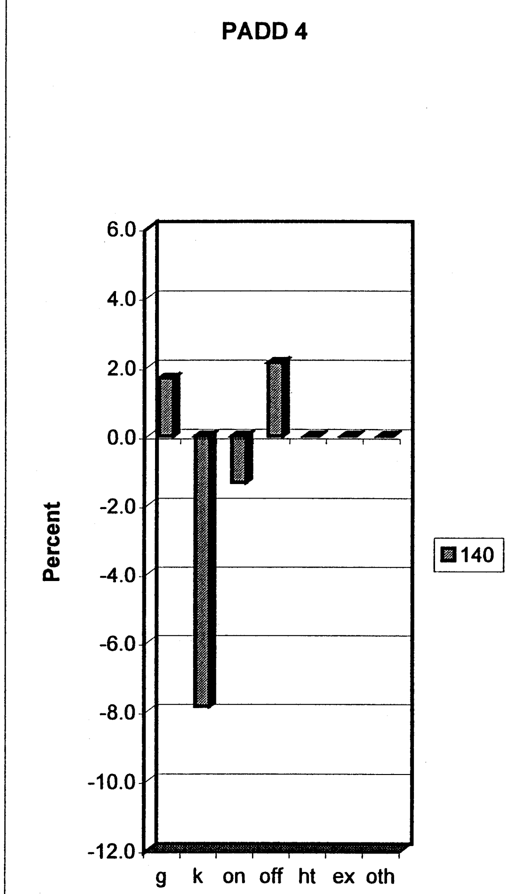


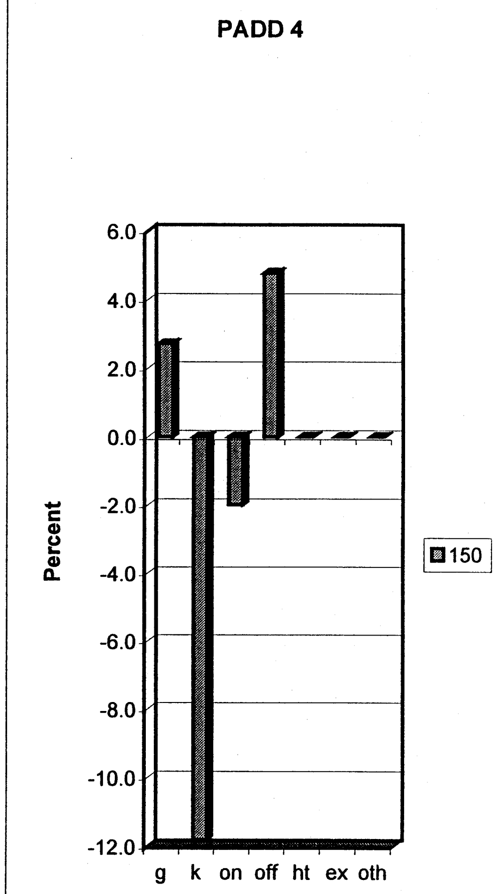
Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 2C Comparisons for PADD 4



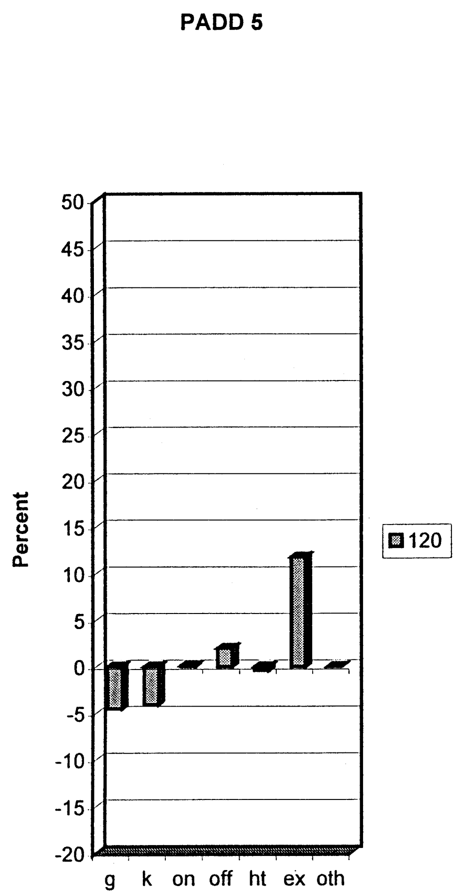


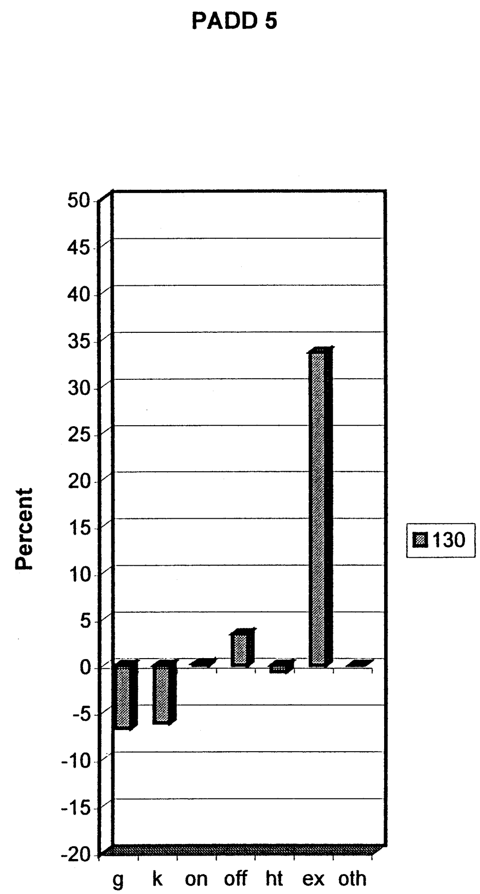


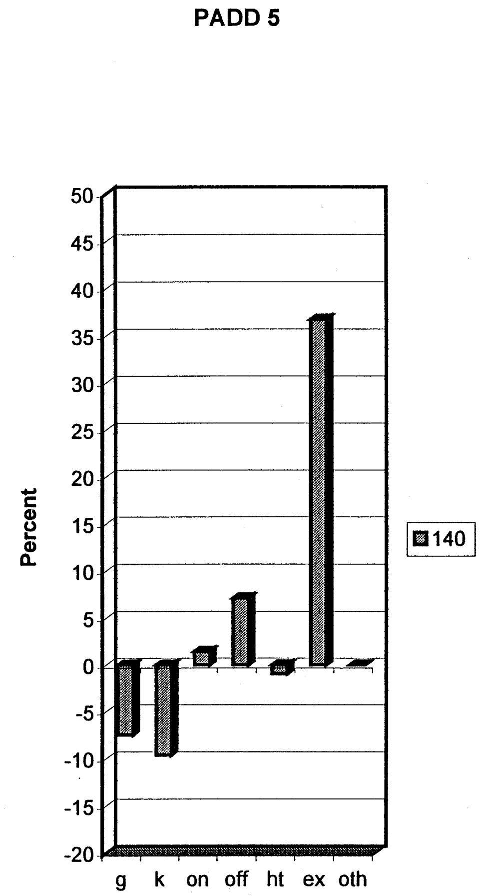


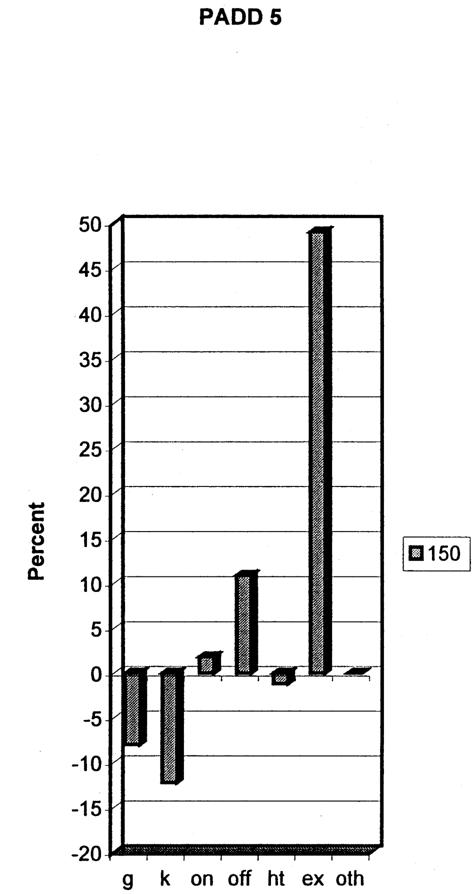
Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 2C Comparisons for PADD 5



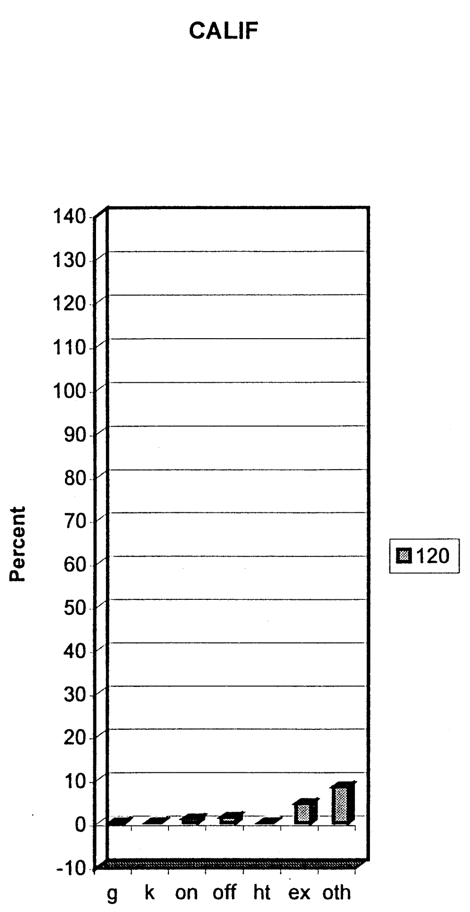


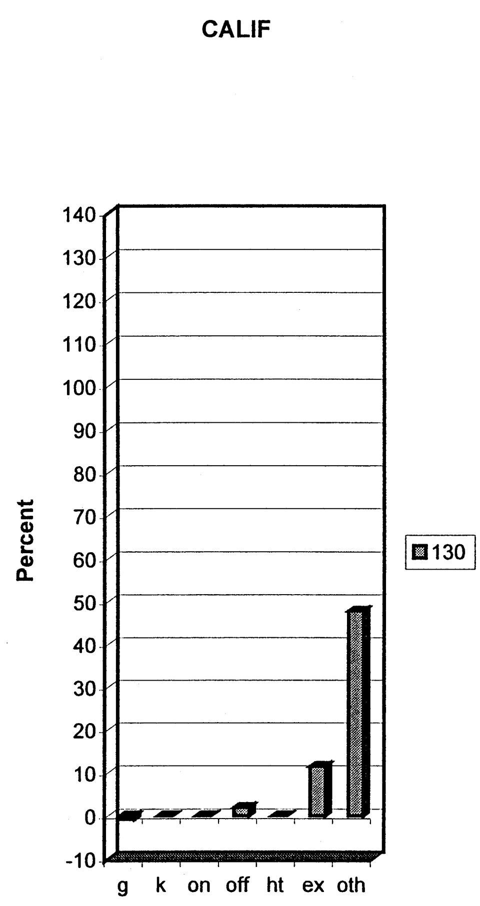


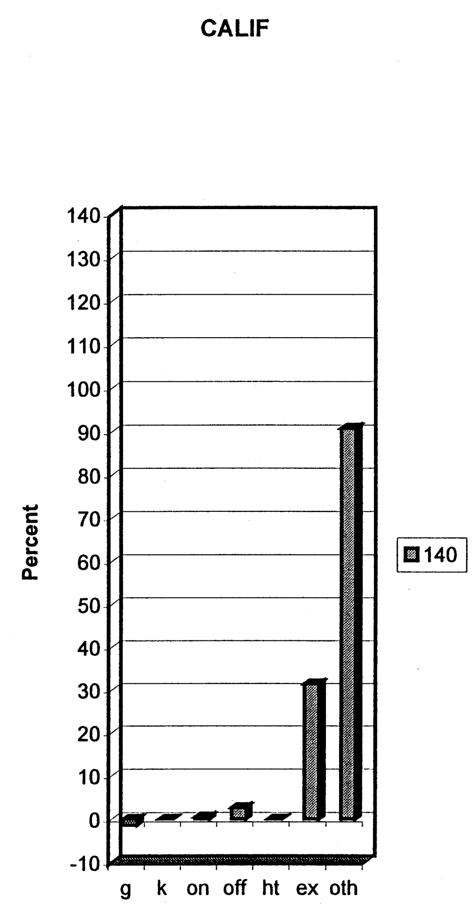


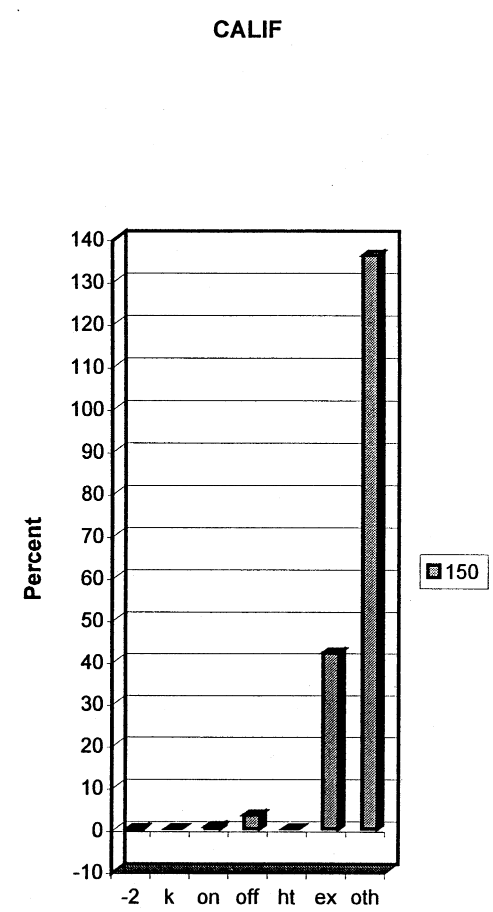
Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 2C Comparisons for CALIF





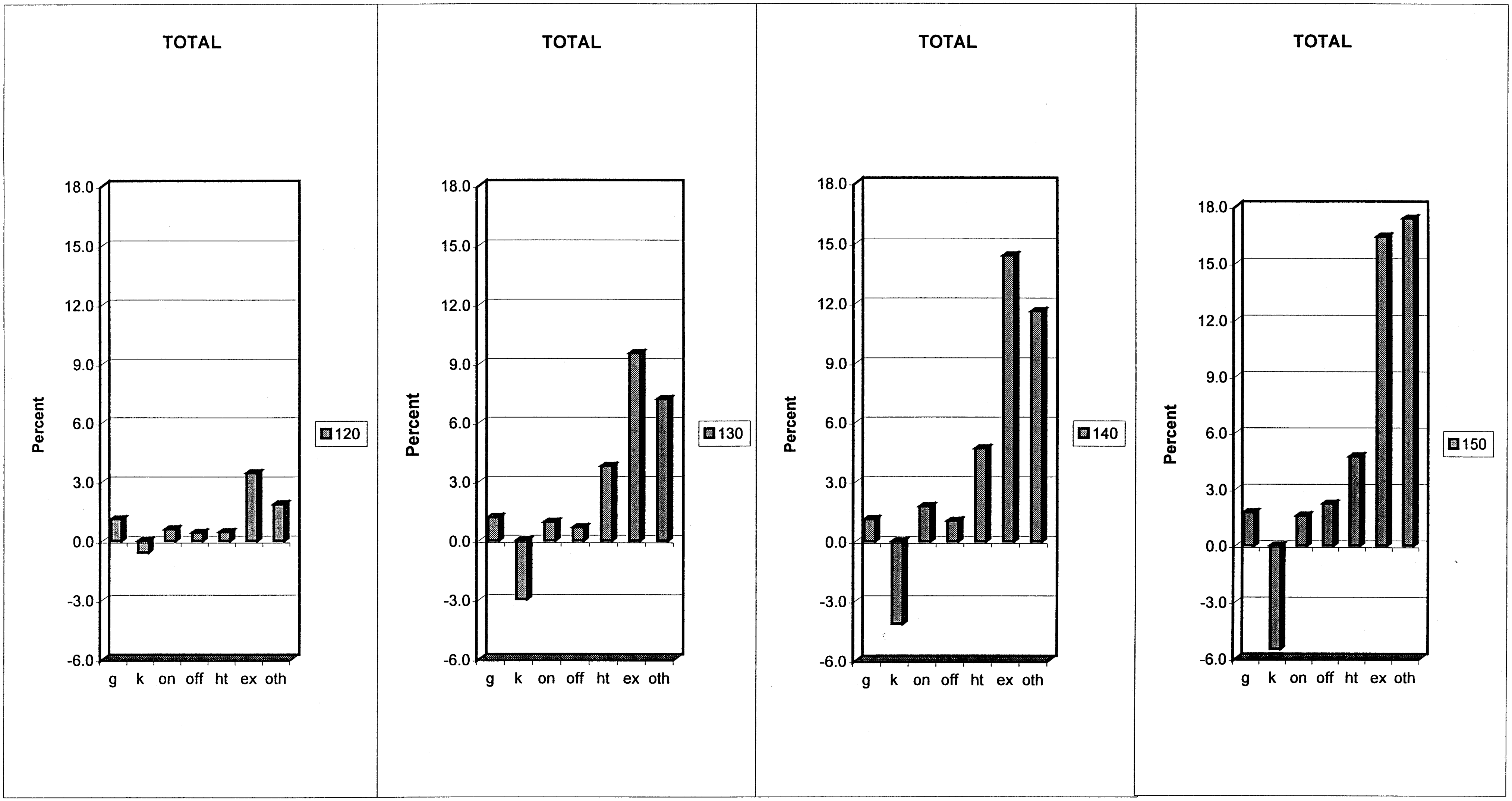




Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

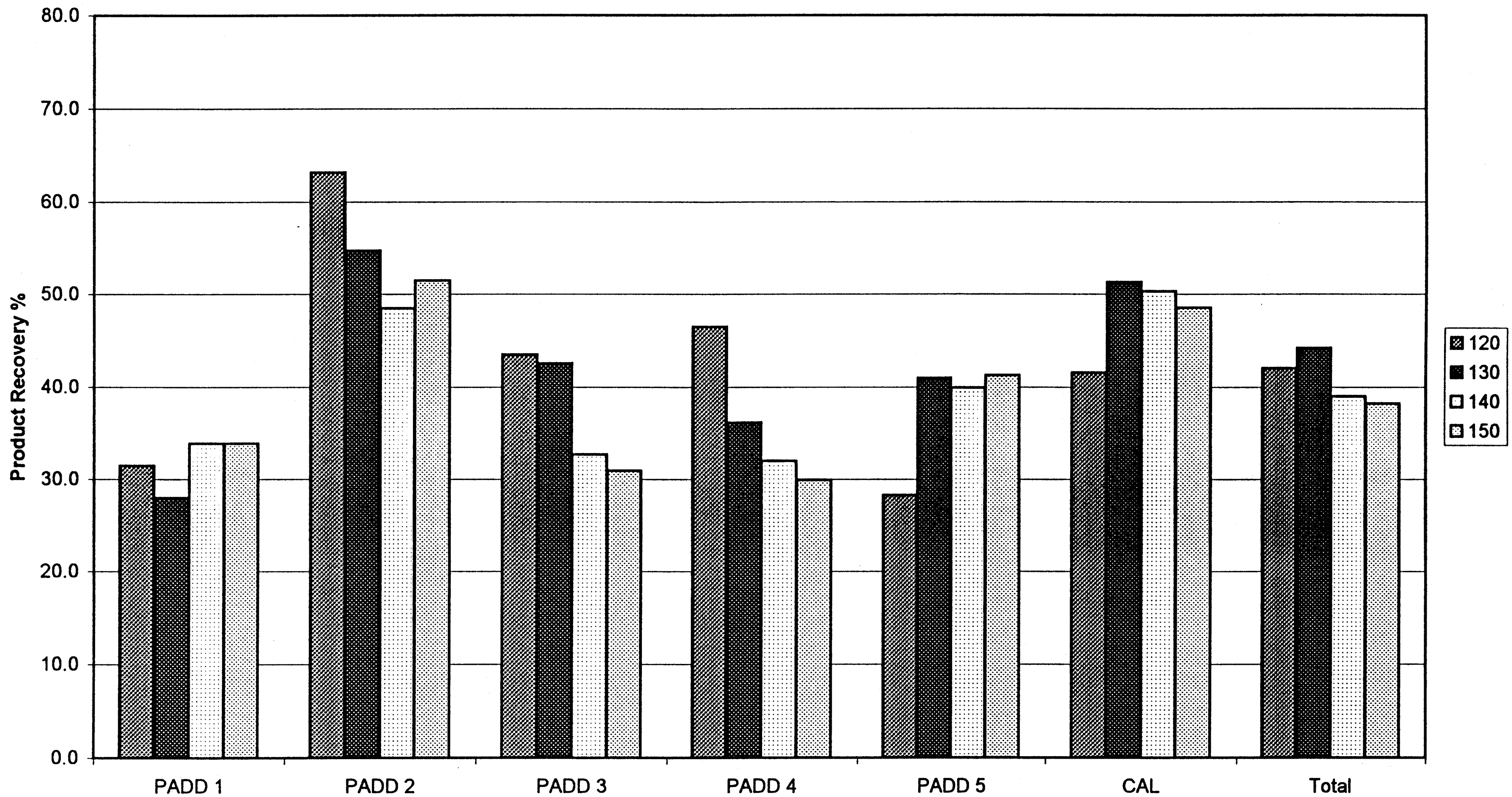
Question 2C Comparisons for TOTAL



Question 2c. What other product volume reduction/increase (-/+) would result by the changes to the flash point specification and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

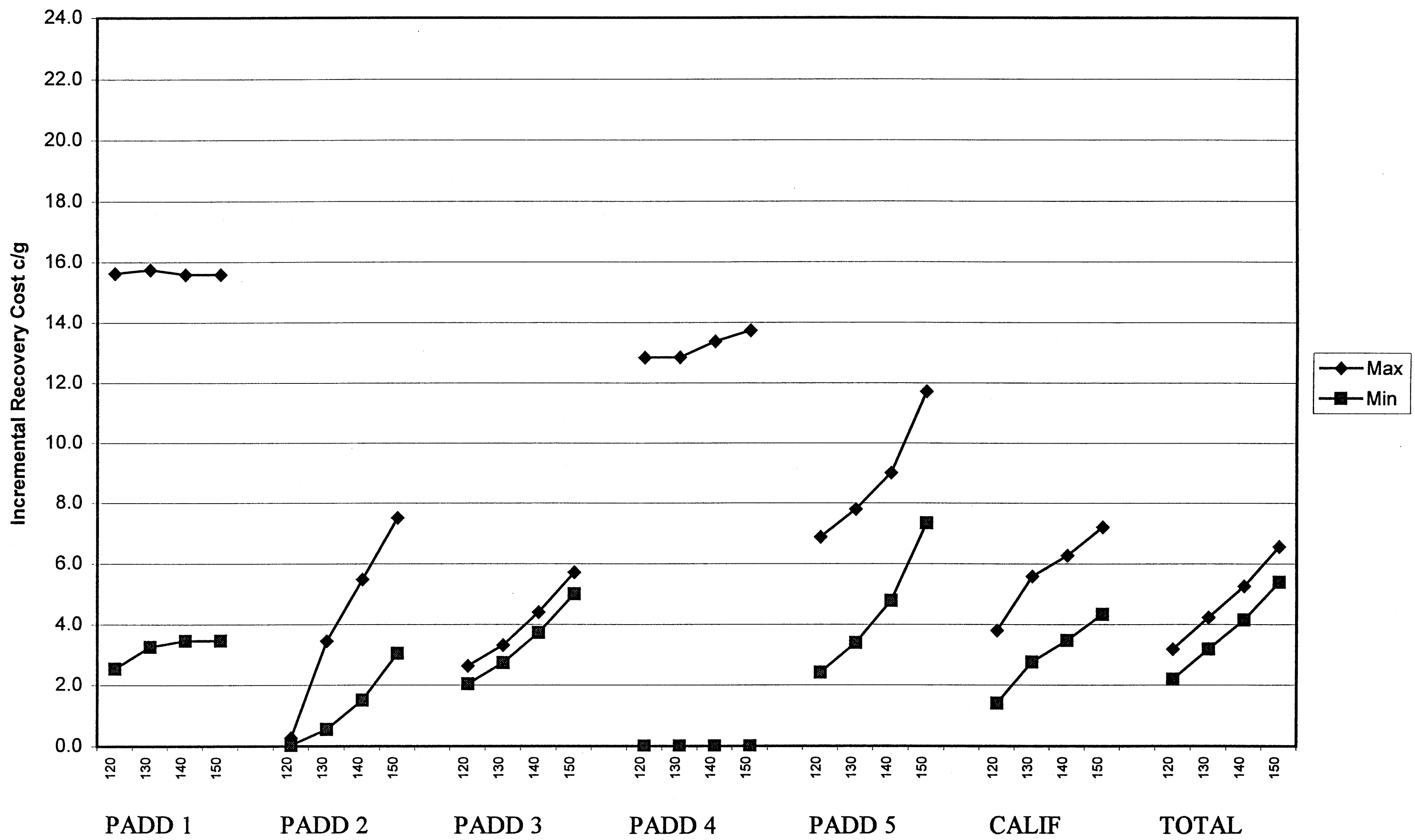
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 2d Comparison by PADD



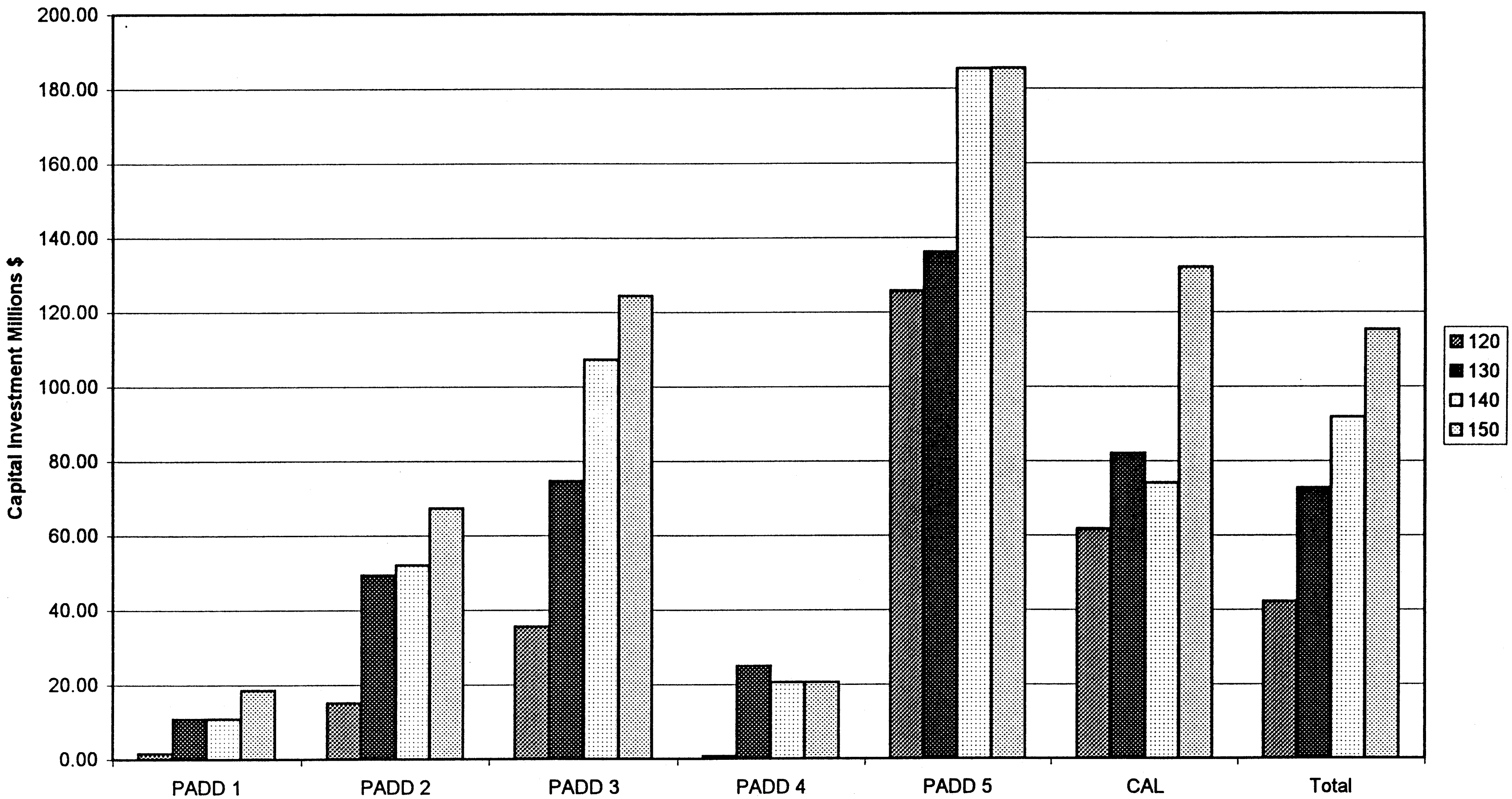
2d. If you indicated a reduction in jet fuel production in question 2a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.

Question 2e Comparison by PADD



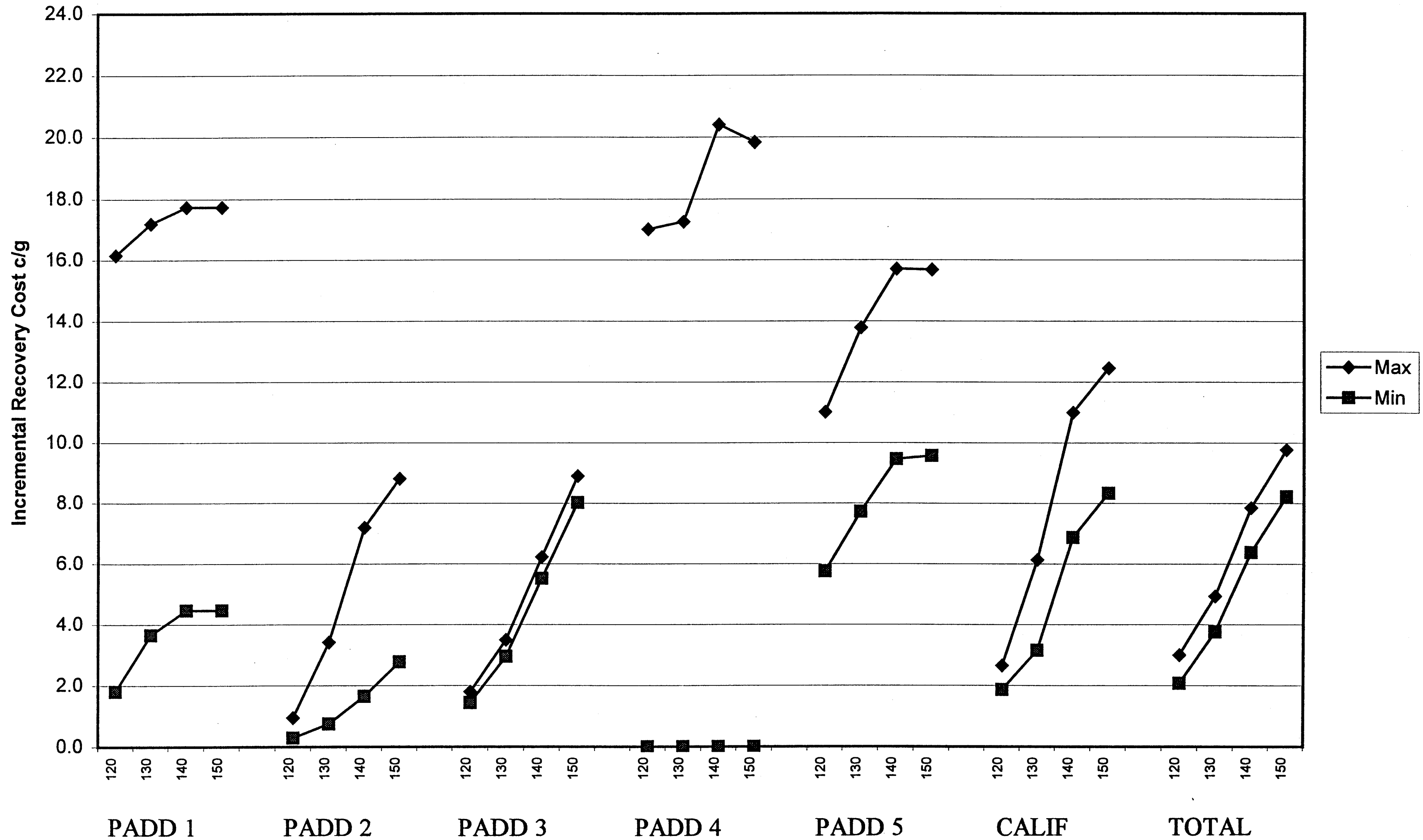
2e. What would be the total cost in the short term of these changes in jet fuel production resulting from **flash point specification changes,** including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point

Question 2f Comparison by PADD



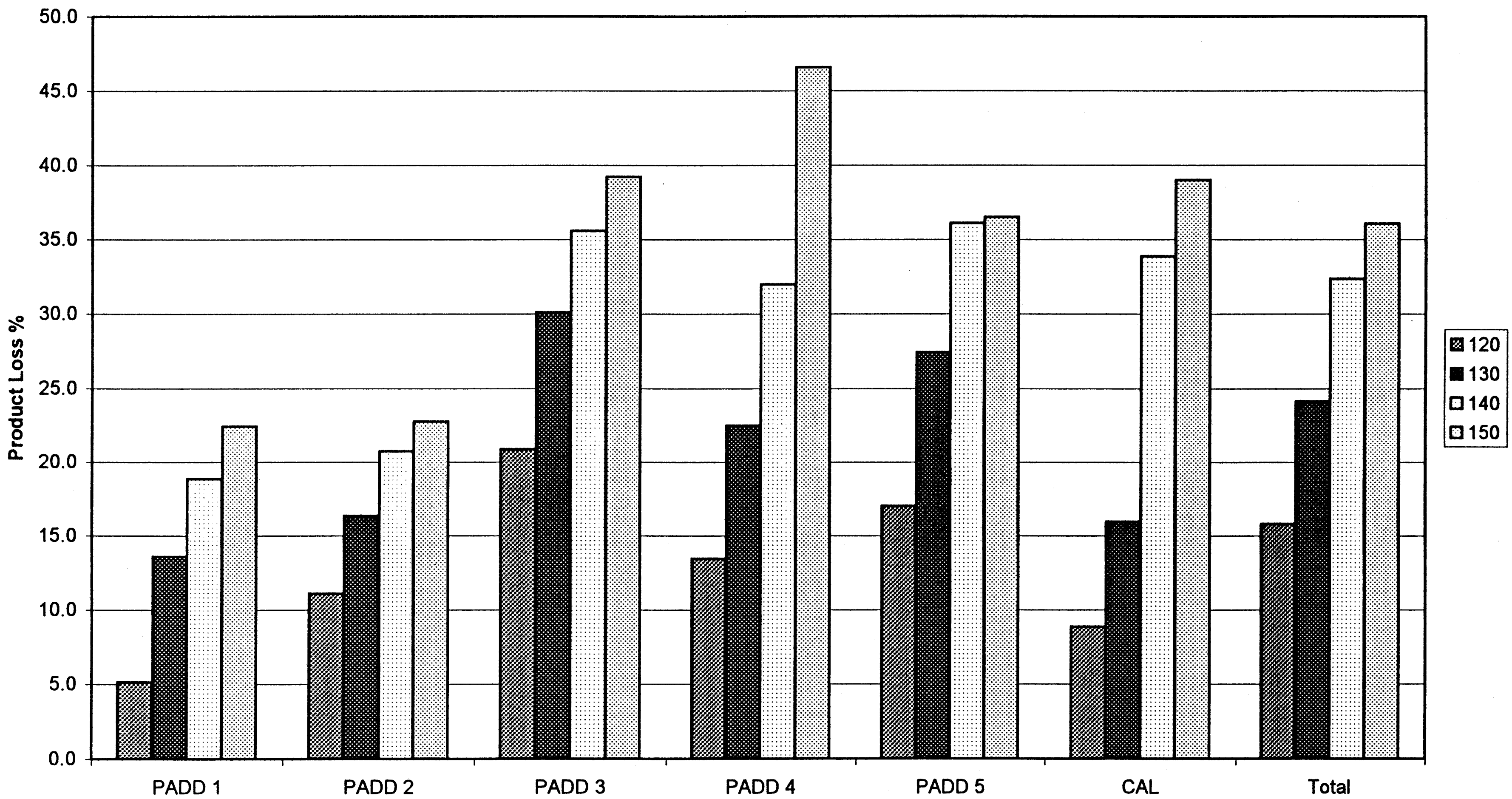
2f. If adequate time for capital investments were allowed, what would be the estimated capital investment required in millions of dollars to make up 100% of the lost production. Check one box for each flash point.

Question 2g Comparison by PADD



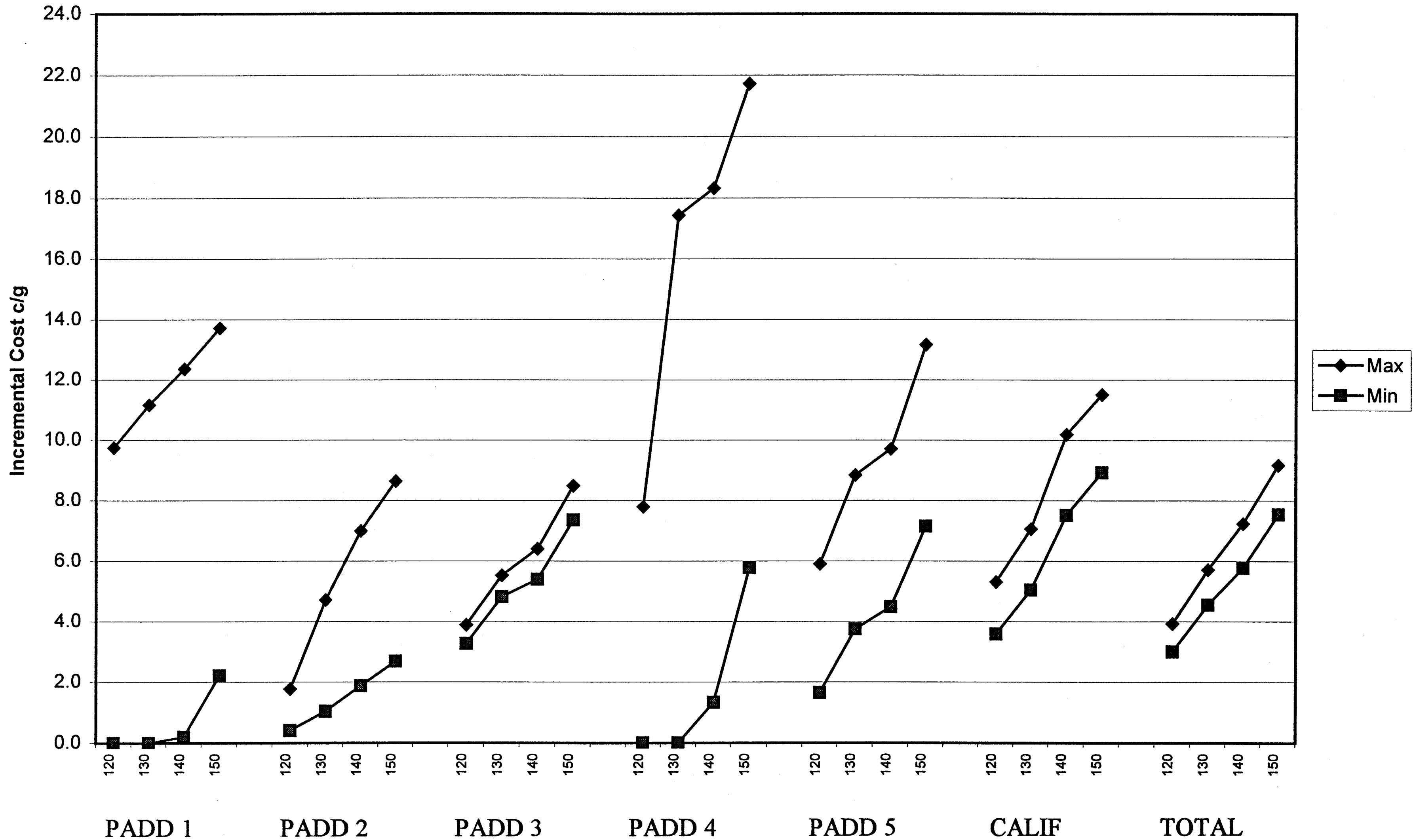
2g. What would be the estimated total cost of these long term changes to recover jet fuel production resulting from **flash point changes,** including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 15% ROI for capital investment decisions and 10% return on capital for deetermining per gal capital charges. Check one box for each flash point

Question 3a Comparison by PADD



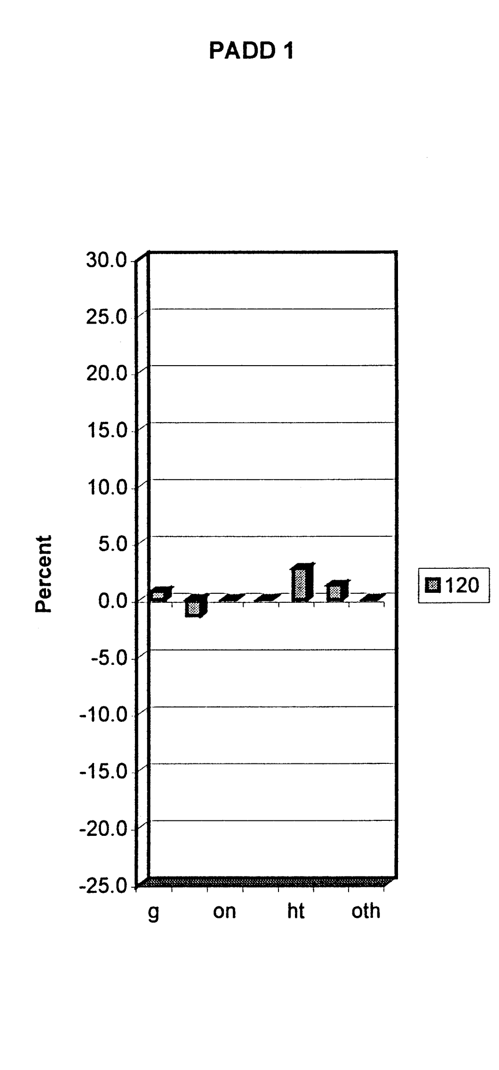
3a. If the **freeze point specification minimum was reduced to –53 deg F, in addition to the flash point changes projected above,** what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.

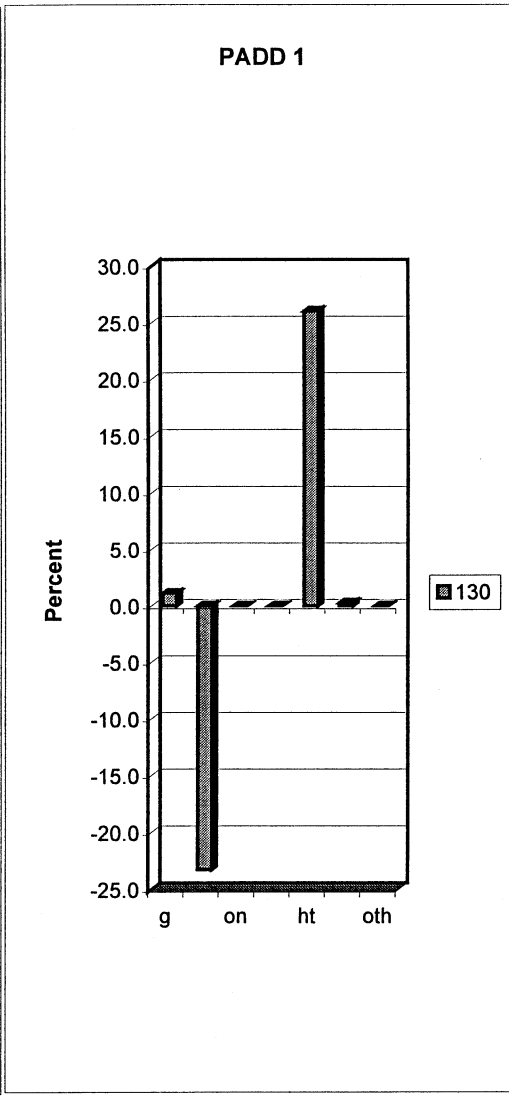
Question 3b Comparison by PADD

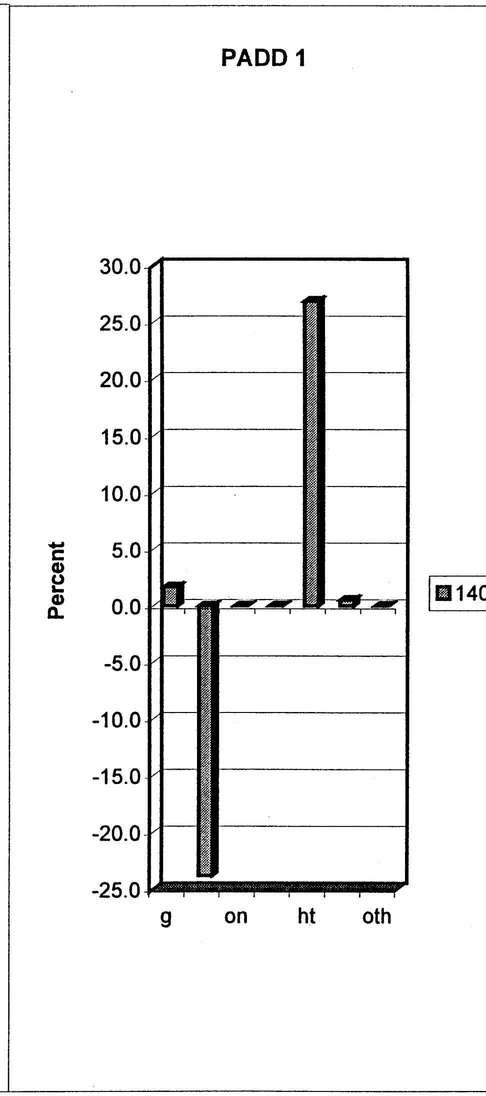


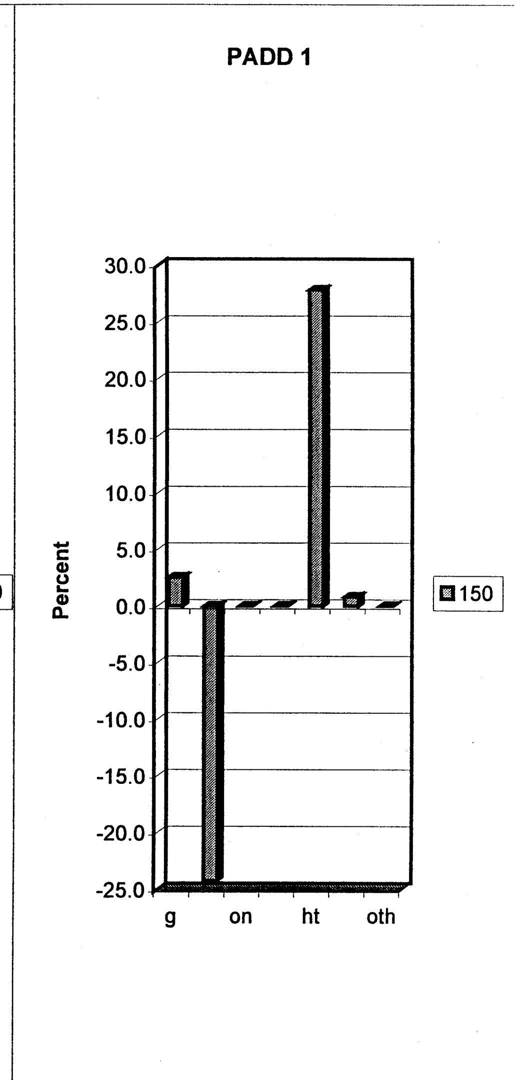
3b. What would be the total cost in the short term of these changes in jet fuel production resulting from **flash point and freeze specification changes,** including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point

Question 3C Comparisons for PADD 1





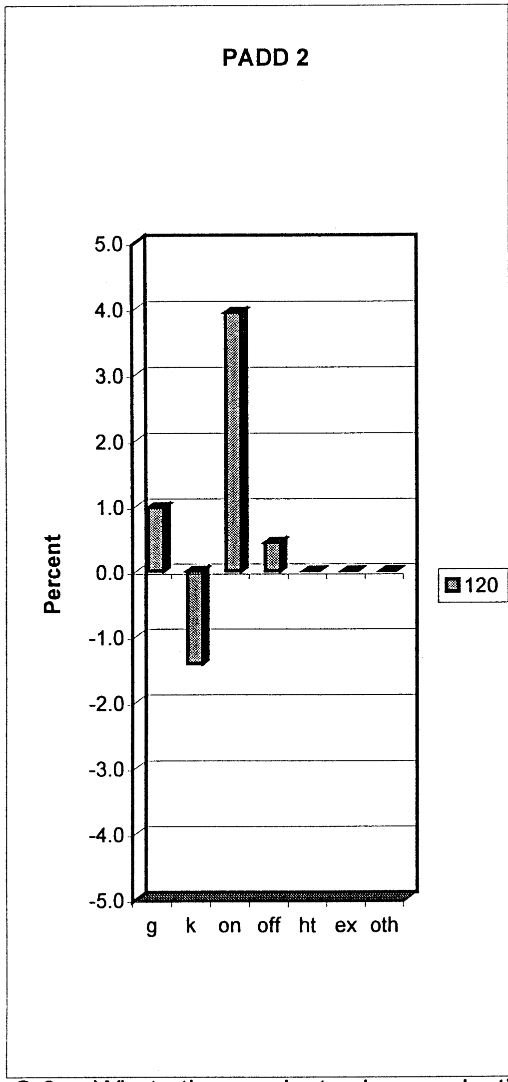


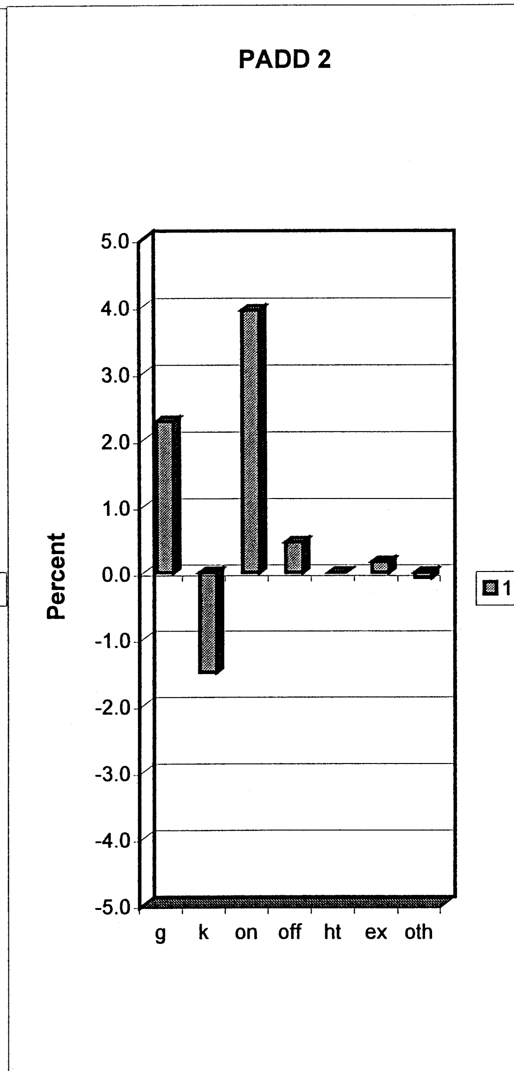


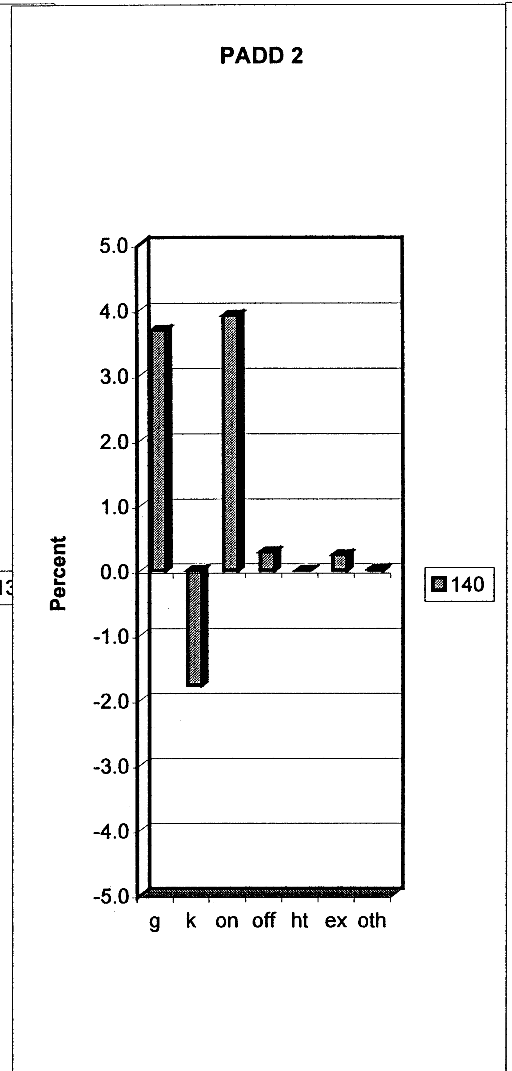
Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

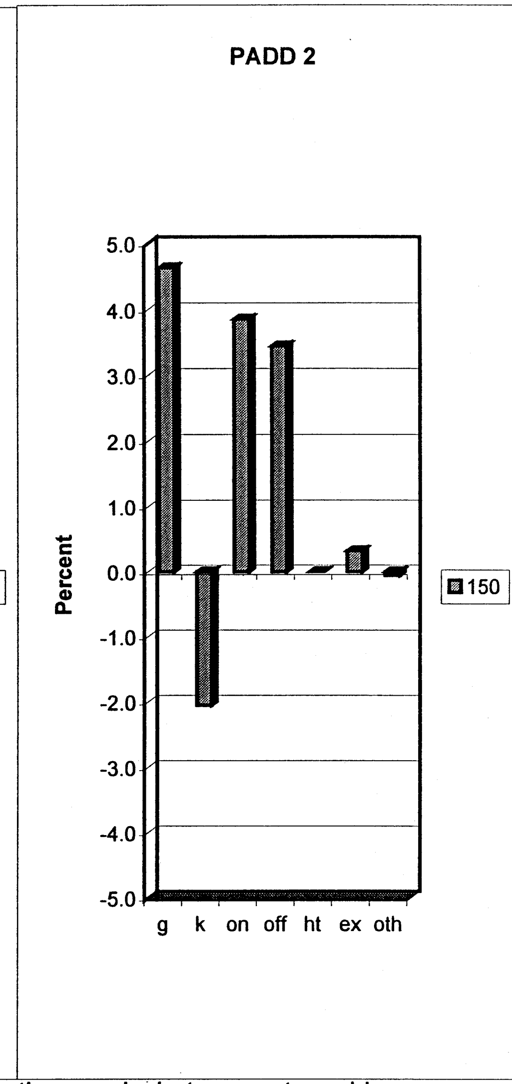
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3C Comparisons for PADD 2





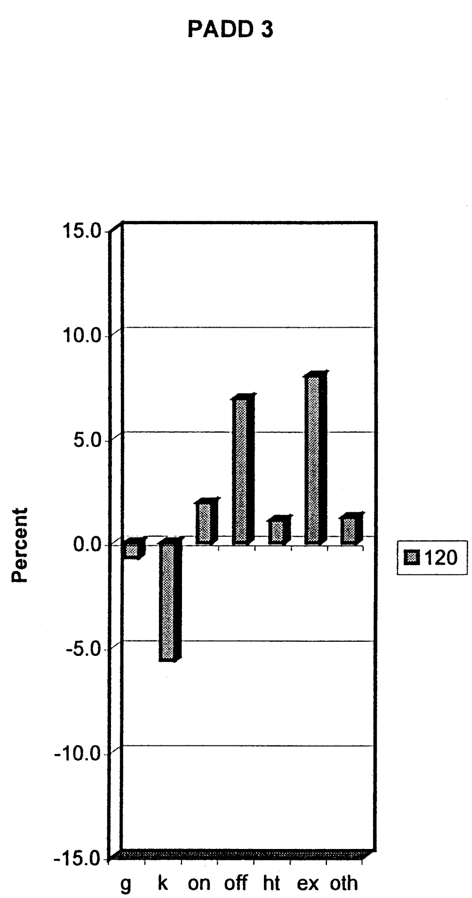


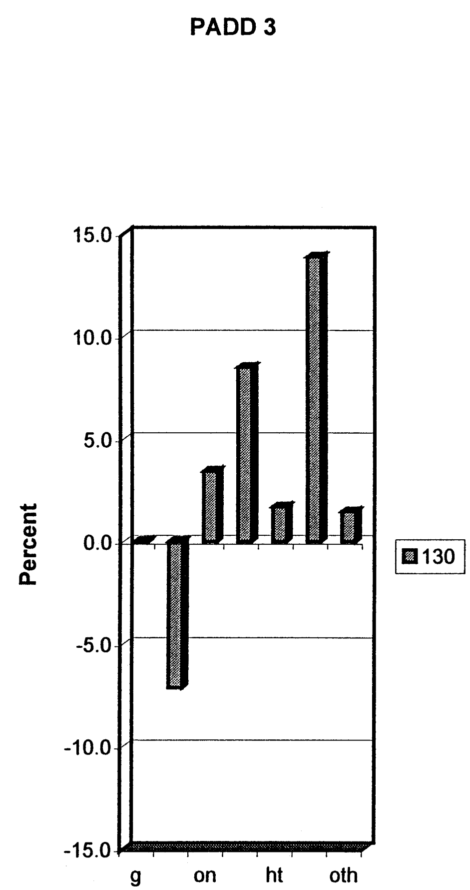


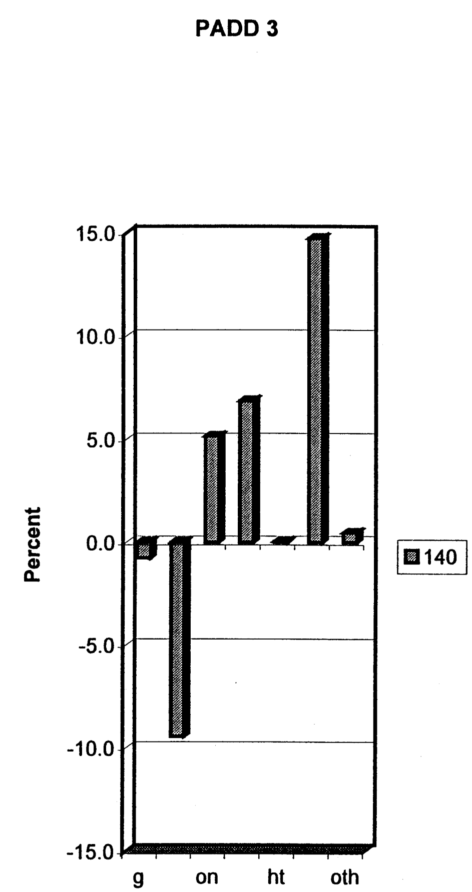
Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

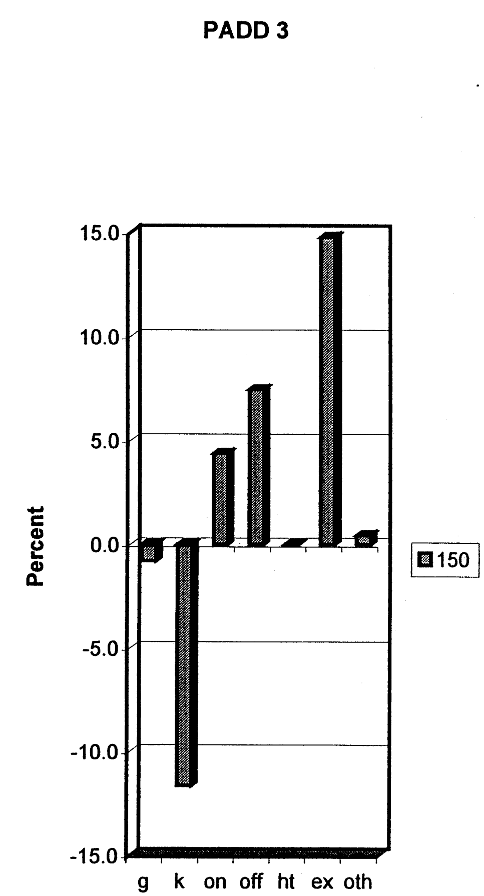
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3C Comparisons for PADD 3



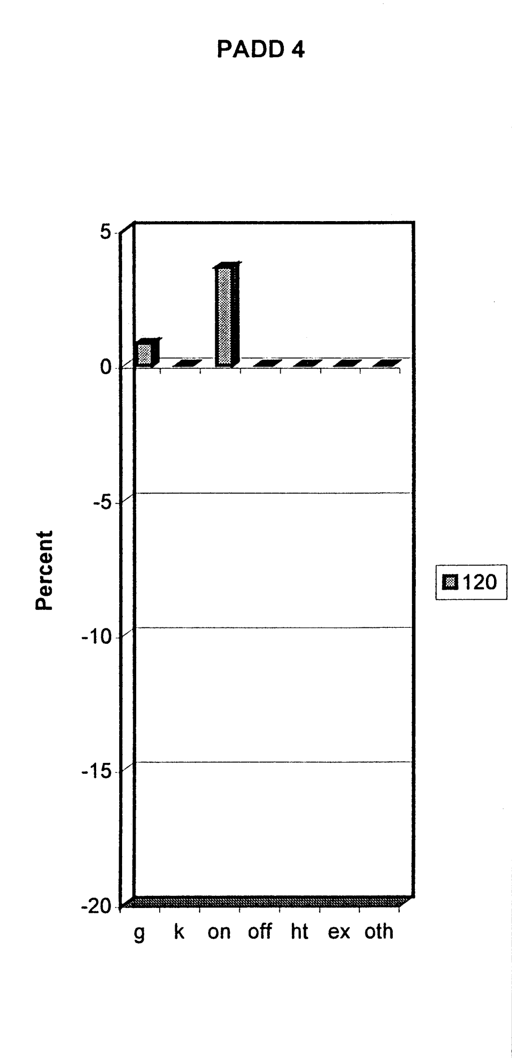


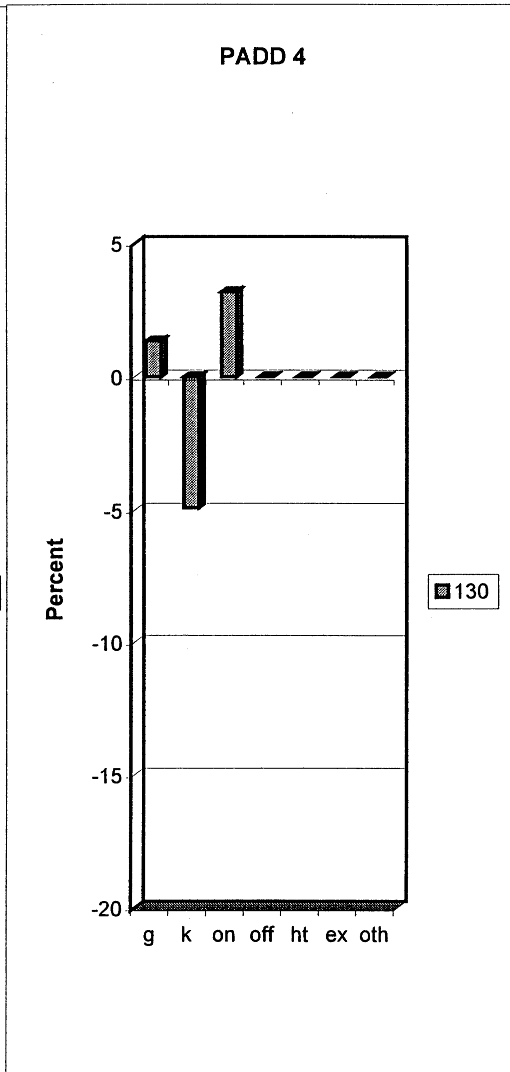


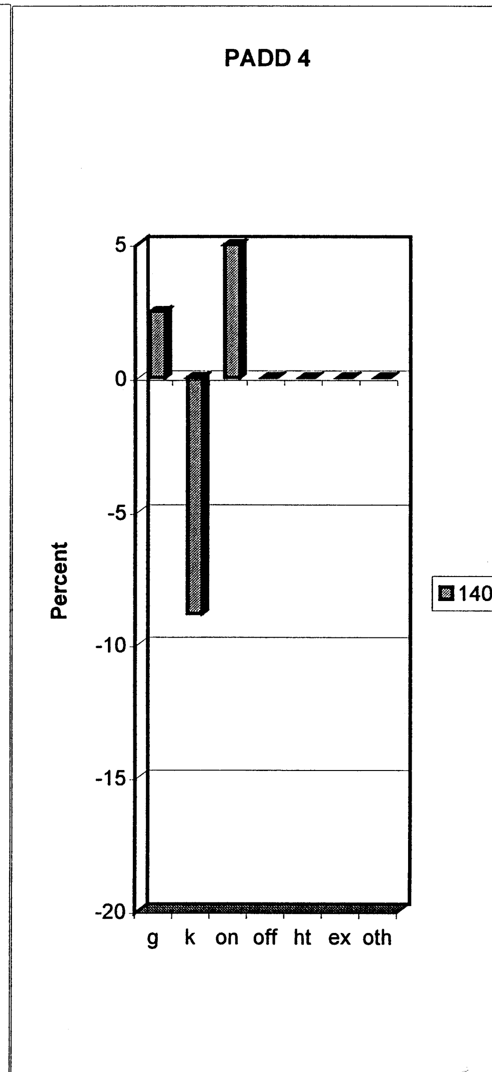


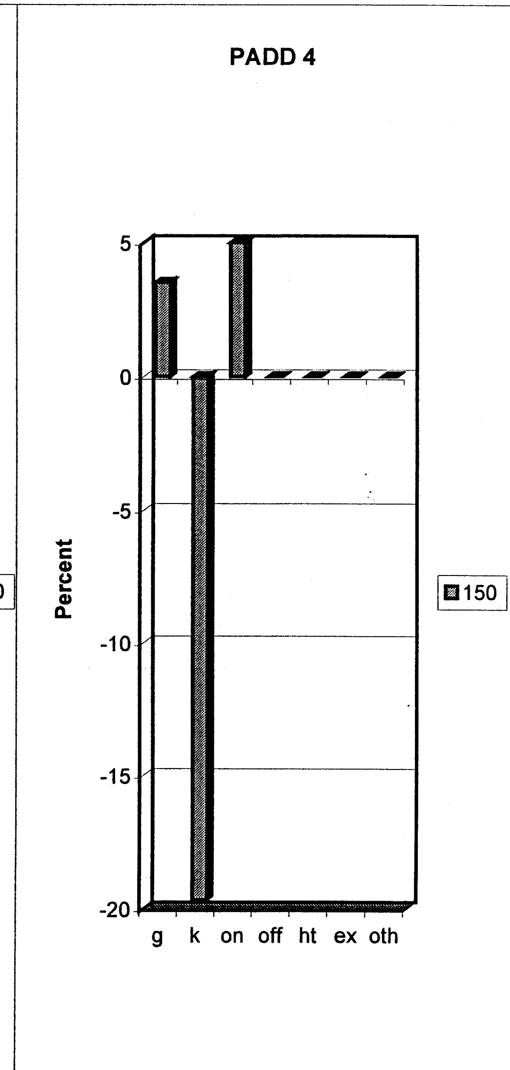
Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3C Comparisons for PADD 4



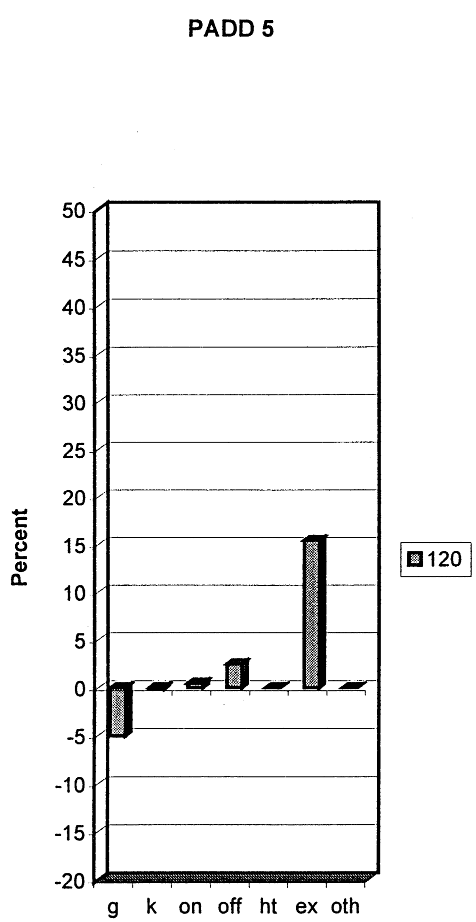


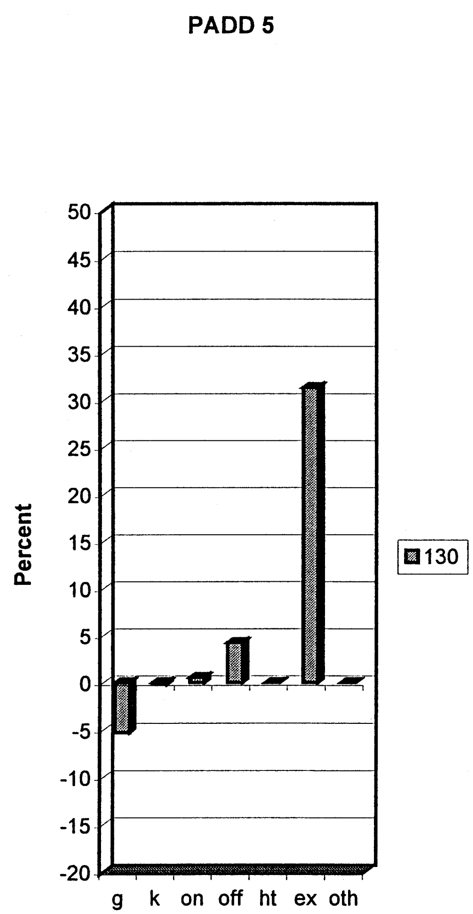


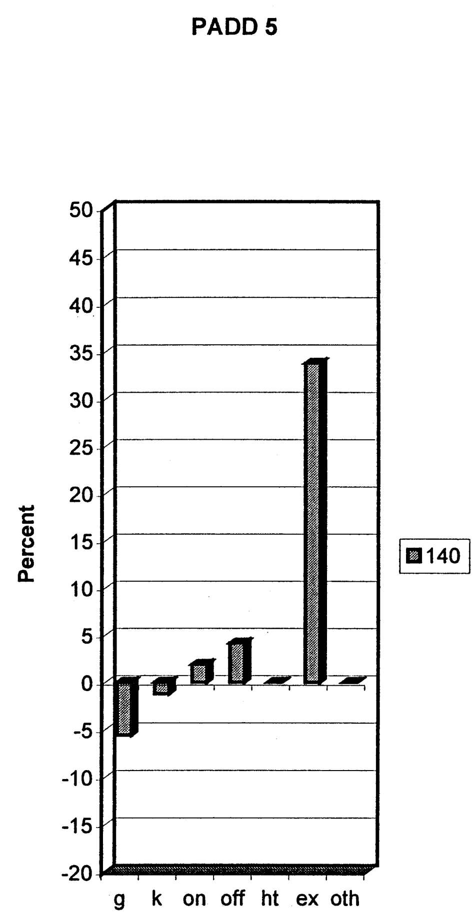


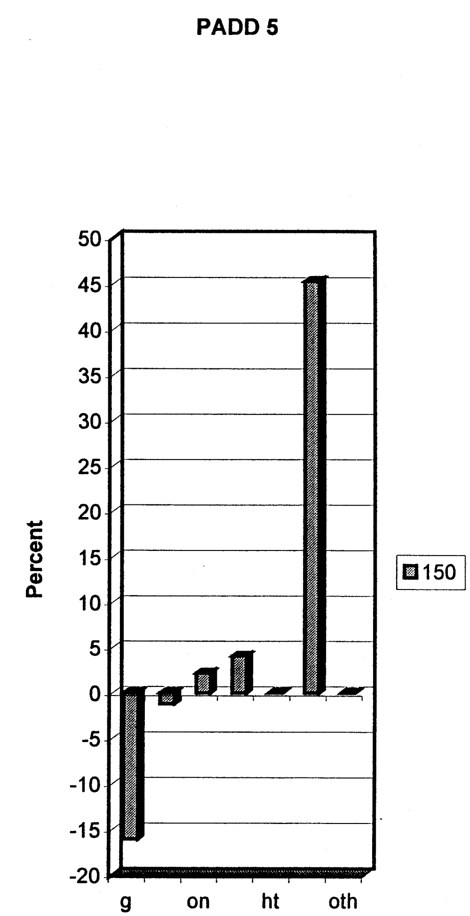
Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3C Comparisons for PADD 5





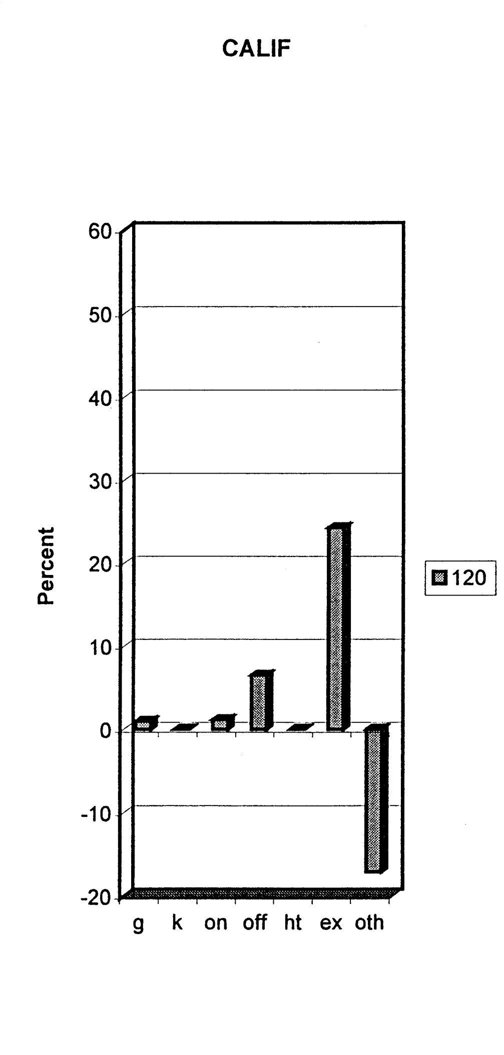


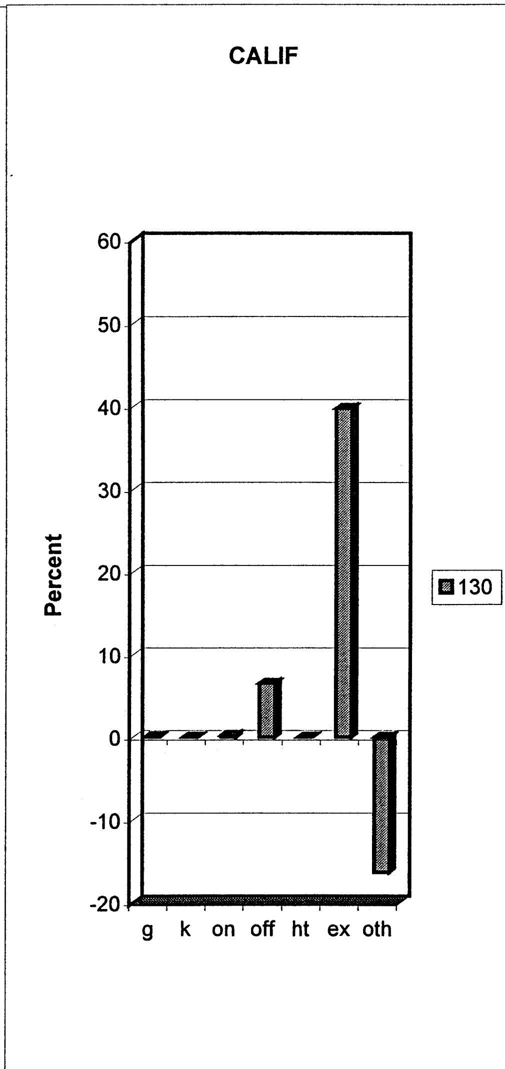


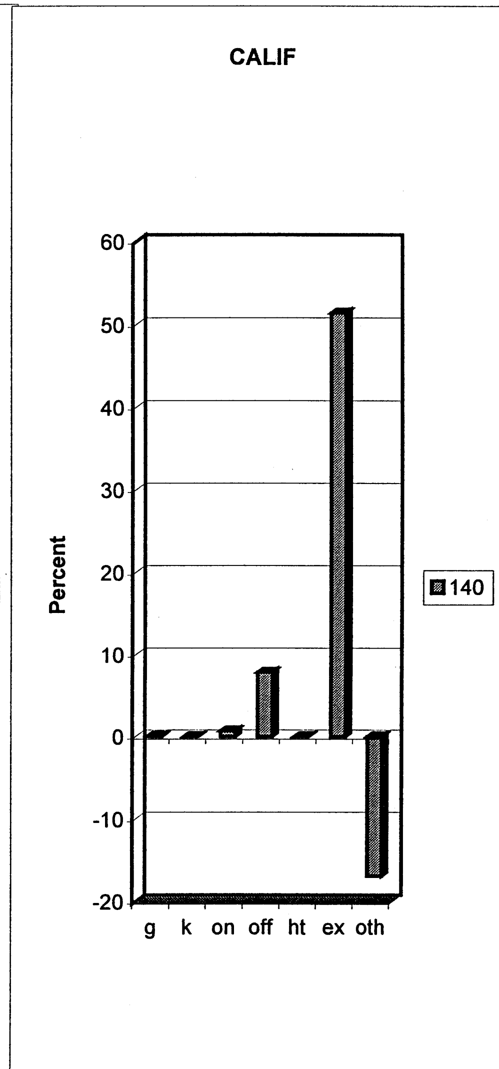
Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

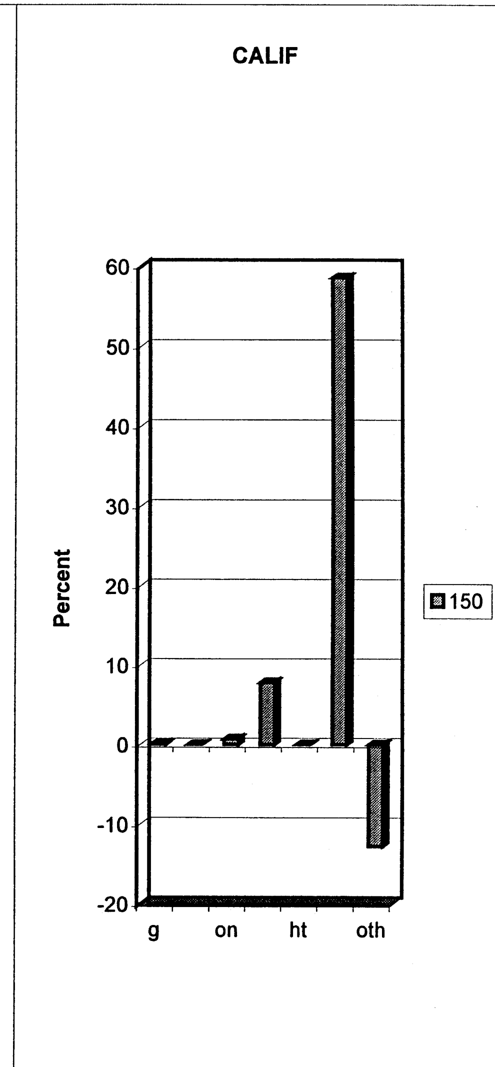
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3C Comparisons for CALIF



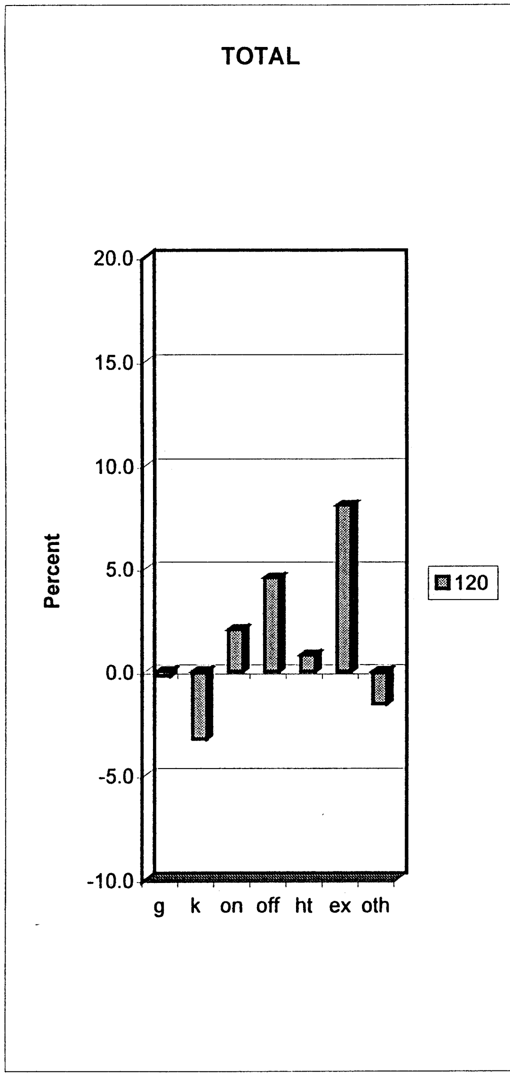


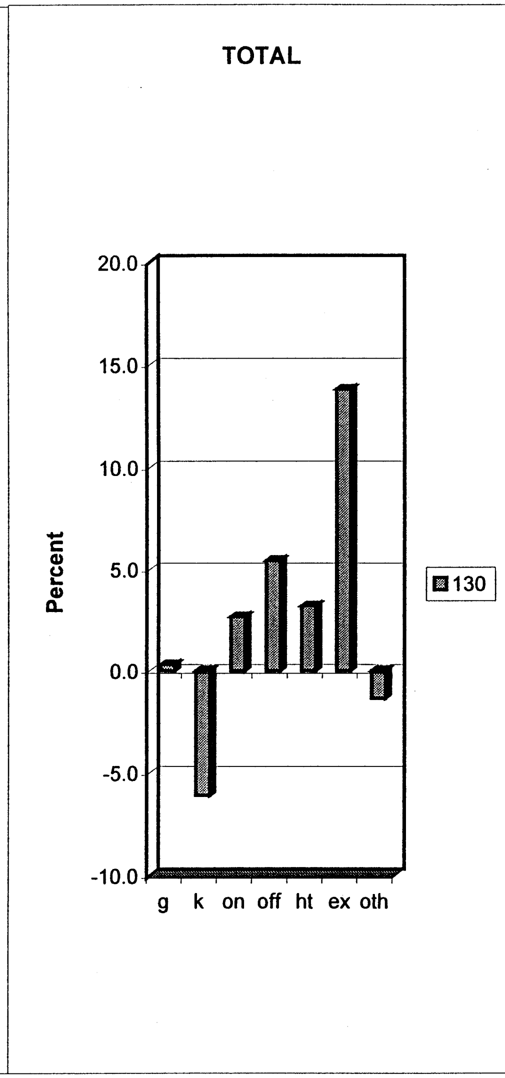


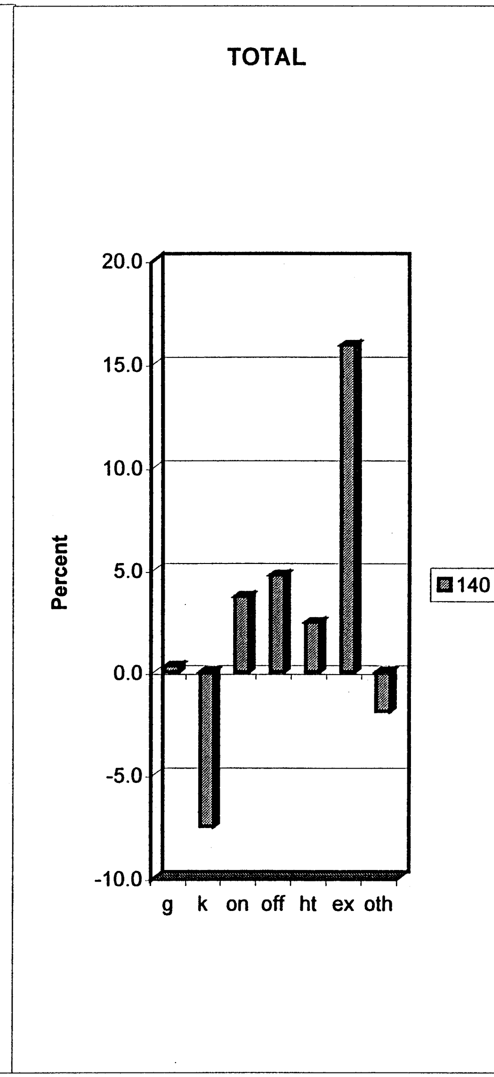


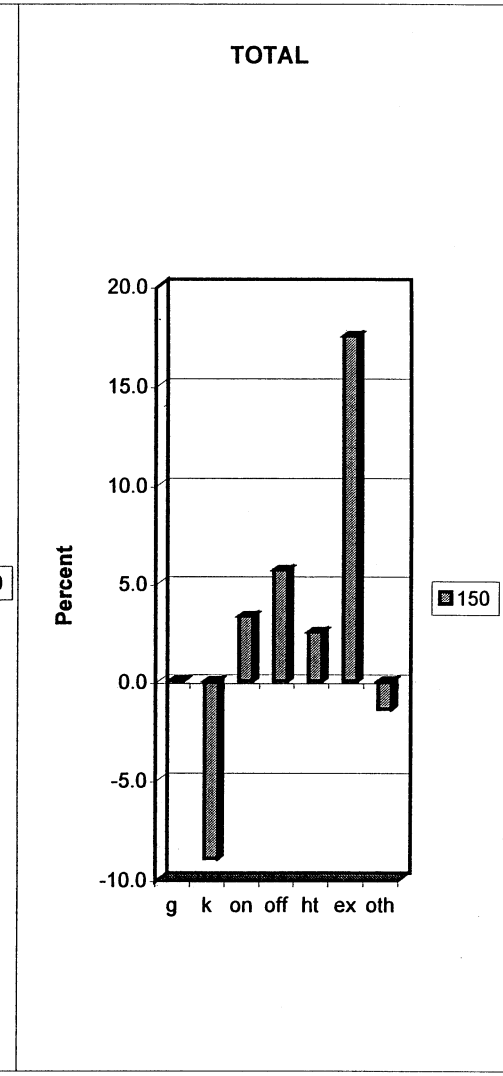
Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3C Comparisons for TOTAL





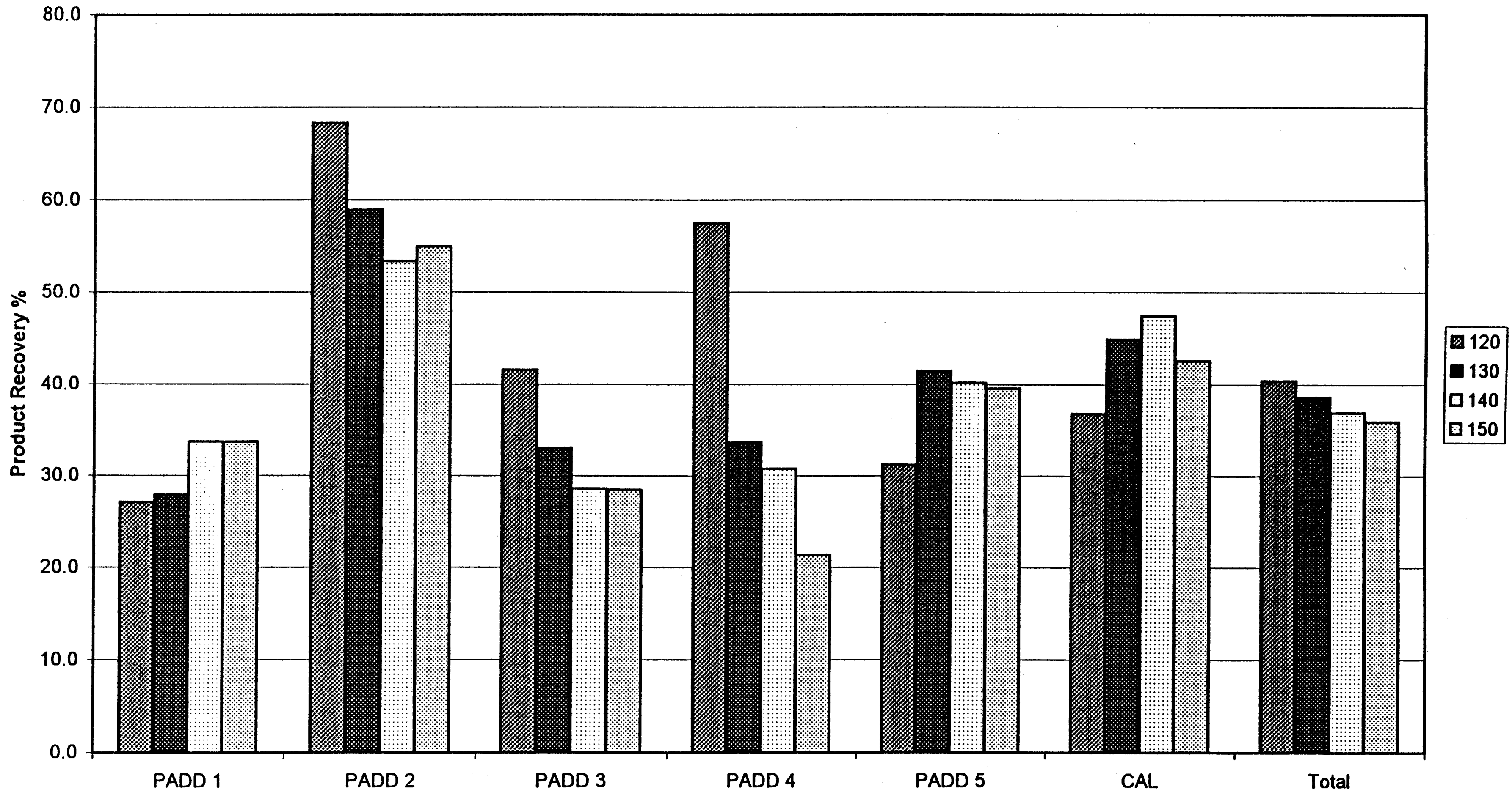




Q 3c. What other product volume reduction/increase (-/+) would result by the changes to the flash and freeze point specifications and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

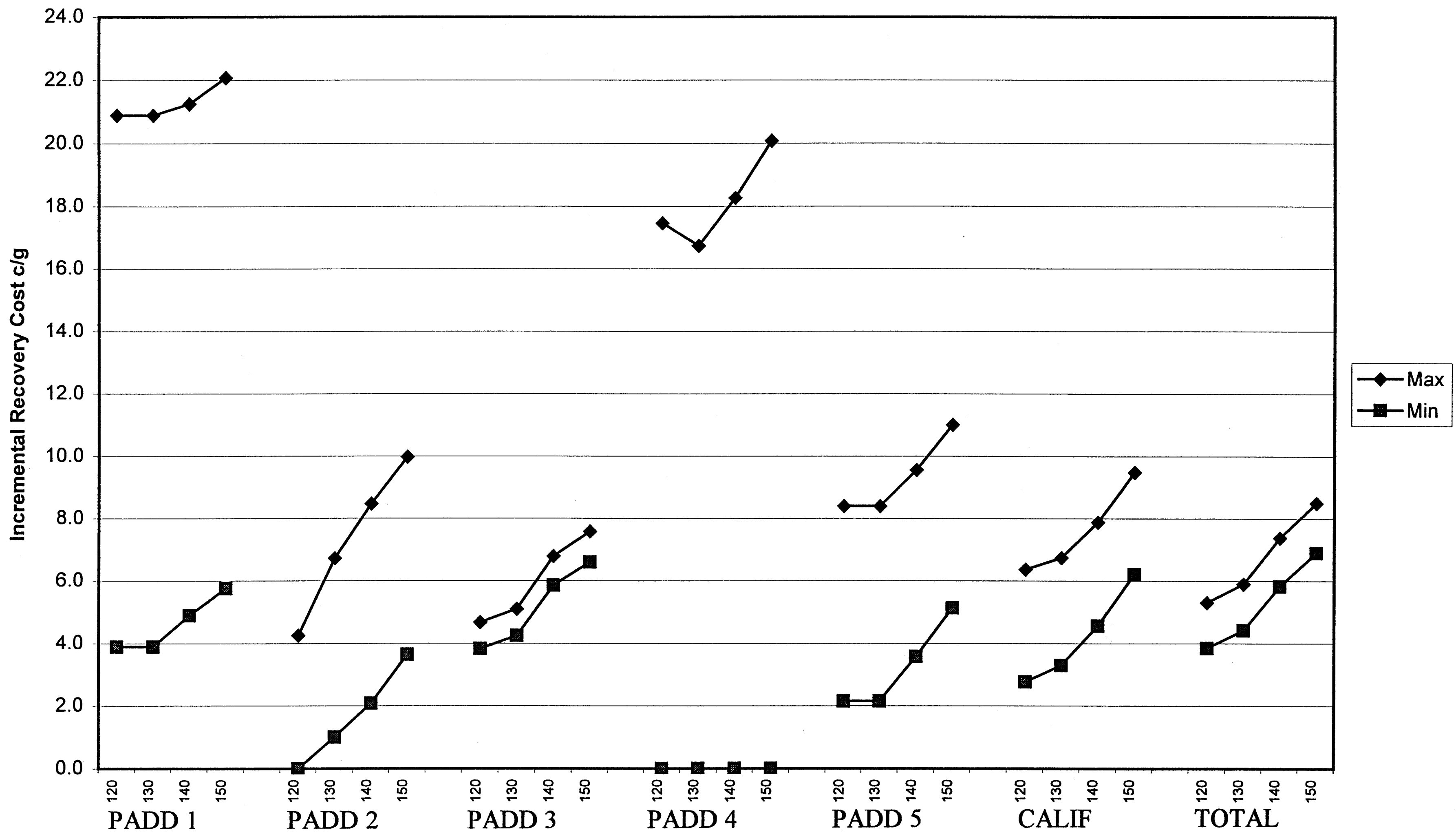
g=gasoline, k=kerosene, on=on road diesel, off=off-road diesel, ht=heating oil, ex=exports (naptha or gasoline), oth=other

Question 3d Comparison by PADD



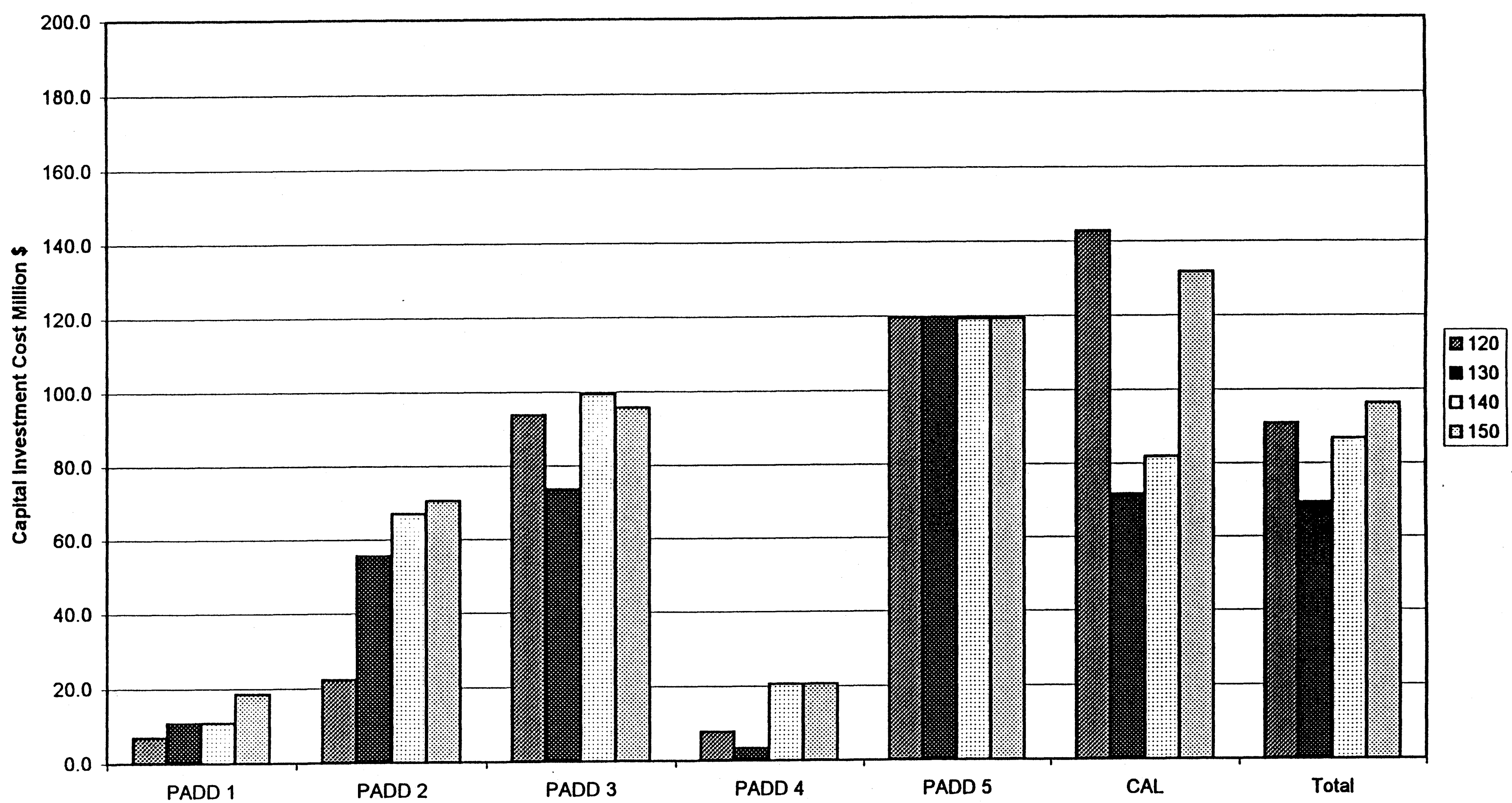
3d. If you indicated a reduction in jet fuel production in question 3a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.

Question 3e Comparison by PADD



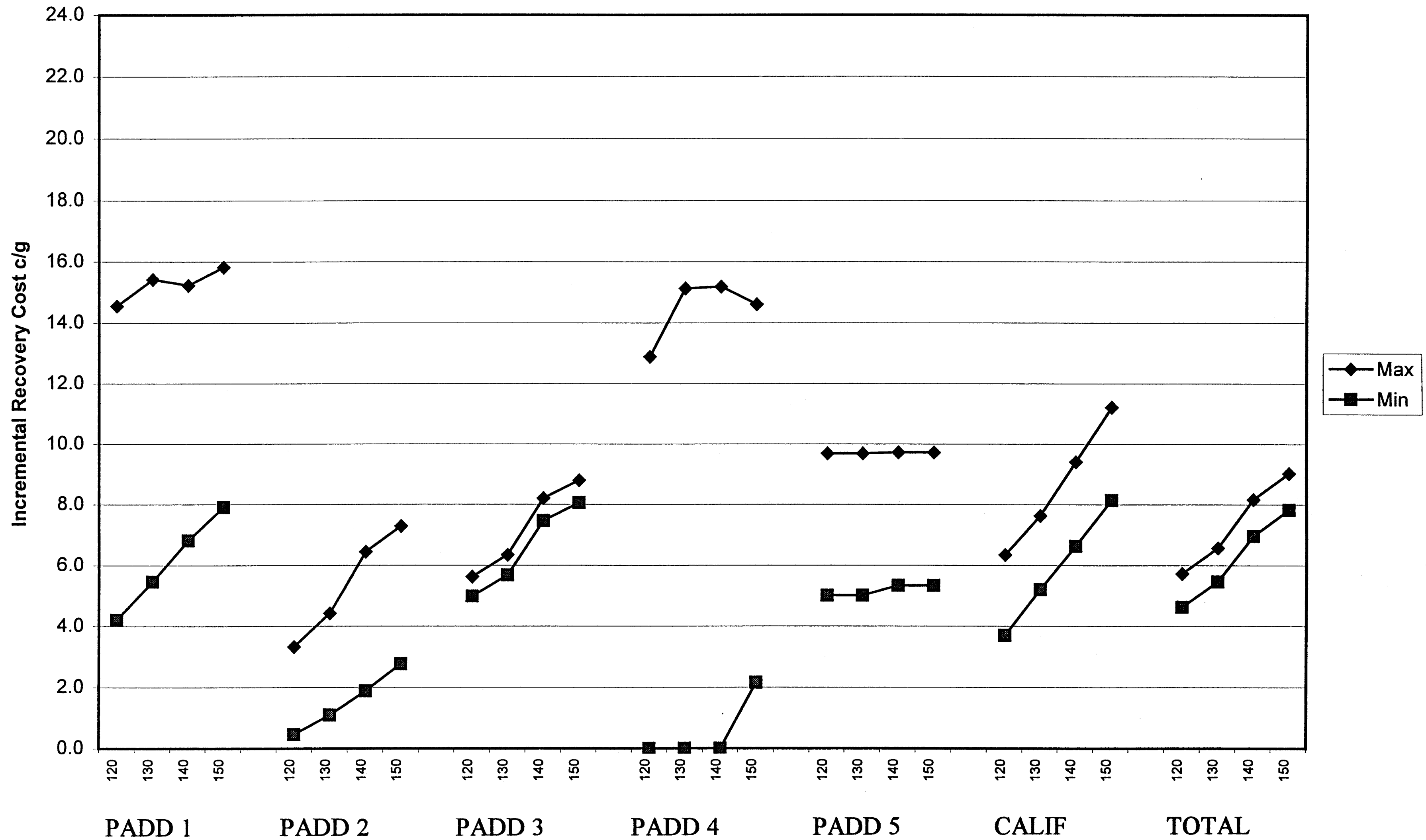
3e. What would be the total cost in the short term of these changes to recover losses in jet fuel production resulting from **flash and freeze point specification changes,** including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point

Question 3f Comparison by PADD



3f. If adequate time for capital investments were allowed, what would be the estimated capital investment required in milllions of dollars to make up 100% of the lost production? Check one box for each flash point.

Question 3g Comparison by PADD



3g. What would be the estimated total cost of these long term changes to recover jet fuel production resulting from **flash and freeze point changes,** including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 10% ROI for capital investment decisions and 10% return on capital for determining per gal capital charges. Check one box for each flash point

Summary of Question 4

PADD 1	**FLASH 120**	**FLASH 120**	**FLASH 130**	**FLASH 130**	**FLASH 140**	**FLASH 140**	**FLASH 150**	**FLASH 150**
	YES	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**
4 Benzene	0%	100%	20%	80%	20%	80%	20%	80%
4 Aromatics	40%	60%	60%	40%	60%	40%	60%	40%
4 Distillates E300/T90	40%	60%	40%	60%	40%	60%	40%	60%
4 Distillates E200/T50	0%	100%	20%	80%	0%	100%	20%	80%
Sulfur	0%	100%	0%	100%	0%	100%	0%	100%
Other	0%	100%	0%	100%	0%	100%	0%	100%
PADD 2	**FLASH 120**	**FLASH 120**	**FLASH 130**	**FLASH 130**	**FLASH 140**	**FLASH 140**	**FLASH 150**	**FLASH 150**
	YES	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**
4 Benzene	0%	100%	6%	94%	6%	94%	6%	94%
4 Aromatics	0%	100%	12.5%	87.5%	12.5%	87.5%	12.5%	87.5%
4 Distillates E300/T90	6%	94%	31%	69%	38%	63%	44%	56%
4 Distillates E200/T50	6%	94%	12.5%	87.5%	19%	81%	25%	75%
Sulfur	6%	94%	12.5%	87.5%	12.5%	87.5%	12.5%	87.5%
Other	0%	100%	0%	100%	6%	94%	6%	94%
PADD 3	**FLASH 120**	**FLASH 120**	**FLASH 130**	**FLASH 130**	**FLASH 140**	**FLASH 140**	**FLASH 150**	**FLASH 150**
	YES	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**
4 Benzene	3%	97%	6%	94%	9%	91%	12%	88%
4 Aromatics	6%	94%	12%	88%	26%	74%	32%	68%
4 Distillates E300/T90	6%	94%	18%	82%	32%	68%	41%	59%
4 Distillates E200/T50	0%	100%	9%	91%	15%	85%	18%	82%
Sulfur	6%	94%	12%	88%	12%	88%	15%	85%
Other	0%	100%	9%	91%	9%	91%	9%	91%
PADD 4	**FLASH 120**	**FLASH 120**	**FLASH 130**	**FLASH 130**	**FLASH 140**	**FLASH 140**	**FLASH 150**	**FLASH 150**
	YES	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**
4 Benzene	0%	100%	0%	100%	0%	100%	0%	100%
4 Aromatics	25%	75%	25%	75%	25%	75%	25%	75%
4 Distillates E300/T90	25%	75%	25%	75%	0%	100%	25%	75%
4 Distillates E200/T50	25%	75%	25%	75%	25%	75%	50%	50%
Sulfur	0%	100%	0%	100%	0%	100%	0%	100%
Other	0%	100%	0%	100%	0%	100%	0%	100%
PADD 5	**FLASH 120**	**FLASH 120**	**FLASH 130**	**FLASH 130**	**FLASH 140**	**FLASH 140**	**FLASH 150**	**FLASH 150**
	YES	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**
4 Benzene	12.5%	87.5%	12.5%	87.5%	12.5%	87.5%	12.5%	87.5%
4 Aromatics	25.0%	75.0%	37.5%	62.5%	50%	50%	50%	50%
4 Distillates E300/T90	12.5%	87.5%	25.0%	75.0%	37.5%	62.5%	37.5%	62.5%
4 Distillates E200/T50	12.5%	87.5%	25%	75%	25%	75%	25%	75%
Sulfur	25%	75%	25%	75%	25%	75%	25%	75%
Other	0%	100%	0%	100%	0%	100%	0%	100%
CALIF	**FLASH 120**	**FLASH 120**	**FLASH 130**	**FLASH 130**	**FLASH 140**	**FLASH 140**	**FLASH 150**	**FLASH 150**
	YES	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**
4 Benzene	0%	100%	0%	100%	0%	100%	0%	100%
4 Aromatics	30%	70%	30%	70%	50%	50%	50%	50%
4 Distillates E300/T90	40%	60%	50%	50%	70%	30%	70%	30%
4 Distillates E200/T50	40%	60%	50%	50%	60%	40%	60%	40%
Sulfur	20%	80%	20%	80%	20%	80%	20%	80%
Other	10%	90%	0%	100%	10%	90%	10%	90%
TOTAL	**FLASH 120**	**FLASH 120**	**FLASH 130**	**FLASH 130**	**FLASH 140**	**FLASH 140**	**FLASH 150**	**FLASH 150**
	YES	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**
4 Benzene	3%	97%	6%	94%	8%	92%	9%	91%
4 Aromatics	13%	87%	21%	79%	31%	69%	34%	66%
4 Distillates E300/T90	14%	86%	27%	73%	38%	62%	44%	56%
4 Distillates E200/T50	9%	91%	18%	82%	22%	78%	27%	73%
Sulfur	9%	91%	13%	87%	13%	87%	14%	86%
Other	1%	99%	4%	96%	6%	94%	6%	94%

Appendix Table 1

Questions	Units			120	130	140	150
2A	% Loss	PADD 1	Avg	6.50	18.11	21.32	27.84
			Max	9.44	34.73	36.96	44.13
			Min	3.56	1.49	5.68	11.55
		PADD 2	Avg	1.70	10.55	17.42	22.66
			Max	2.62	14.56	24.25	30.01
			Min	0.79	6.53	10.59	15.32
		PADD 3	Avg	8.17	16.26	24.02	31.38
			Max	8.76	17.31	25.45	32.82
			Min	7.57	15.21	22.59	29.94
		PADD 4	Avg	3.75	16.37	24.17	39.22
			Max	26.96	44.13	46.43	49.39
			Min	0.00	0.00	1.91	29.05
		PADD 5	Avg	16.85	33.58	45.09	47.20
			Max	20.78	40.49	51.88	53.42
			Min	12.93	26.66	38.31	40.99
		CALIF	Avg	9.65	15.88	25.30	35.50
			Max	11.21	18.94	29.15	39.06
			Min	8.08	12.82	21.45	31.95
		TOTAL	Avg	8.11	16.74	24.72	32.13
			Max	9.00	18.37	26.81	34.23
			Min	7.21	15.11	22.63	30.02
2B	Cents/gal	PADD 1	Max	2.46	11.42	11.32	12.16
			Min	0.29	0.00	0.00	0.00
		PADD 2	Max	0.43	2.46	5.81	8.71
			Min	0.15	0.71	1.51	2.87
		PADD 3	Max	1.00	2.33	4.42	6.68
			Min	0.82	1.94	3.81	5.93
		PADD 4	Max	5.72	16.62	16.31	18.32
			Min	0.00	0.00	0.00	1.33
		PADD 5	Max	4.38	8.40	10.39	15.29
			Min	2.22	5.33	5.86	10.08
		CALIF	Max	1.67	5.14	8.58	10.54
			Min	1.13	3.82	6.20	7.88
		TOTAL	Max	1.30	3.46	5.62	7.96
			Min	0.94	2.63	4.48	6.61
2D	%	PADD 1	Avg	31.45	27.96	33.87	33.87
			Max	47.06	33.16	49.48	49.48
			Min	15.85	22.76	18.27	18.27
		PADD 2	Avg	63.20	54.74	48.48	51.52
			Max	77.76	66.12	61.66	65.71
			Min	48.64	43.35	35.31	37.32
		PADD 3	Avg	43.51	42.55	32.67	30.92
			Max	45.46	44.49	34.34	32.47
			Min	41.55	40.61	31.00	29.36
		PADD 4	Avg	46.48	36.15	31.99	29.90
			Max	119.14	78.63	58.95	52.52
			Min	0.00	0.00	5.02	7.28
		PADD 5	Avg	28.30	40.96	39.94	41.26
			Max	38.98	52.73	50.23	53.13
			Min	17.62	29.19	29.65	29.39
		CALIF	Avg	41.54	51.30	50.30	48.53
			Max	50.26	60.83	58.92	56.58
			Min	32.82	41.77	41.68	40.48
		TOTAL	Avg	42.03	44.19	38.98	38.23
			Max	45.25	47.27	41.91	41.26
			Min	38.81	41.10	36.05	35.19

Appendix Table 1

Questions	Units			120	130	140	150
2E	Cents/gal	PADD 1	Max	15.63	15.75	15.59	15.59
			Min	2.54	3.26	3.46	3.46
		PADD 2	Max	0.28	3.46	5.48	7.52
			Min	0.03	0.55	1.51	3.04
		PADD 3	Max	2.64	3.32	4.40	5.72
			Min	2.04	2.73	3.73	5.01
		PADD 4	Max	12.84	12.85	13.38	13.74
			Min	0.00	0.00	0.00	0.00
		PADD 5	Max	6.88	7.80	9.02	11.73
			Min	2.42	3.39	4.78	7.34
		CALIF	Max	3.81	5.58	6.27	7.21
			Min	1.41	2.76	3.47	4.34
		TOTAL	Max	3.18	4.23	5.26	6.57
			Min	2.19	3.19	4.15	5.40
2F	Millions of Dollars	PADD 1	Avg	1.63	10.95	10.95	18.53
			Max	4.03	24.27	24.27	47.06
			Min	0.00	0.00	0.00	0.00
		PADD 2	Avg	15.19	49.43	51.96	67.25
			Max	22.13	76.09	78.59	116.90
			Min	8.25	22.77	25.33	17.60
		PADD 3	Avg	35.57	74.72	107.28	124.47
			Max	38.80	80.01	115.45	133.46
			Min	32.34	69.43	99.12	115.47
		PADD 4	Avg	0.74	25.00	20.59	20.59
			Max	5.82	25.00	51.10	51.10
			Min	0.00	25.00	0.00	0.00
		PADD 5	Avg	125.76	136.17	185.26	185.45
			Max	172.35	181.67	238.25	238.17
			Min	79.16	90.67	132.28	132.73
		CALIF	Avg	61.66	81.96	74.09	132.10
			Max	84.87	111.79	104.26	168.96
			Min	38.46	52.14	43.92	95.25
		TOTAL	Avg	42.12	72.75	91.64	115.38
			Max	48.87	81.86	103.36	129.24
			Min	35.38	63.63	79.93	101.51
2G	Cents/gal	PADD 1	Max	16.15	17.20	17.74	17.74
			Min	1.80	3.66	4.46	4.46
		PADD 2	Max	0.95	3.42	7.20	8.82
			Min	0.29	0.75	1.65	2.78
		PADD 3	Max	1.80	3.50	6.23	8.91
			Min	1.44	2.96	5.52	8.03
		PADD 4	Max	17.01	17.26	20.42	19.84
			Min	0.00	0.00	0.00	0.00
		PADD 5	Max	11.02	13.79	15.71	15.68
			Min	5.75	7.73	9.47	9.57
		CALIF	Max	2.66	6.14	11.01	12.46
			Min	1.87	3.15	6.88	8.34
		TOTAL	Max	3.00	4.94	7.86	9.77
			Min	2.07	3.75	6.38	8.23

Appendix Table 1

Questions	Units			120	130	140	150
3A	% Loss	PADD 1	Avg	5.13	13.58	18.84	22.42
			Max	16.49	31.03	34.06	36.66
			Min	0.00	0.00	3.62	8.19
		PADD 2	Avg	11.10	16.36	20.71	22.72
			Max	16.47	22.40	28.09	30.10
			Min	5.73	10.33	13.33	15.34
		PADD 3	Avg	20.87	30.13	35.59	39.25
			Max	21.90	31.34	37.02	40.62
			Min	19.83	28.93	34.15	37.88
		PADD 4	Avg	13.43	22.50	32.01	46.57
			Max	36.27	43.97	47.95	50.16
			Min	0.00	1.03	16.06	42.97
		PADD 5	Avg	17.02	27.44	36.12	36.51
			Max	23.45	34.10	42.98	43.07
			Min	10.60	20.79	29.26	29.95
		CALIF	Avg	8.85	15.93	33.89	39.02
			Max	10.95	19.77	38.02	42.68
			Min	6.75	12.08	29.76	35.36
		TOTAL	Avg	15.80	24.13	32.37	36.07
			Max	17.36	25.98	34.50	38.14
			Min	14.24	22.28	30.25	34.00
3B	Cents/gal	PADD 1	Max	9.75	11.17	12.37	13.72
			Min	0.00	0.00	0.20	2.21
		PADD 2	Max	1.77	4.72	7.00	8.64
			Min	0.41	1.04	1.87	2.68
		PADD 3	Max	3.89	5.53	6.40	8.49
			Min	3.27	4.82	5.39	7.36
		PADD 4	Max	7.80	17.44	18.32	21.72
			Min	0.00	0.00	1.33	5.78
		PADD 5	Max	5.91	8.85	9.71	13.17
			Min	1.65	3.75	4.48	7.15
		CALIF	Max	5.31	7.06	10.19	11.52
			Min	3.58	5.04	7.52	8.93
		TOTAL	Max	3.93	5.71	7.24	9.18
			Min	3.01	4.55	5.77	7.55
3D	%	PADD 1	Avg	27.11	27.89	33.68	33.68
			Max	31.76	32.55	47.64	47.64
			Min	22.45	23.24	19.73	19.73
		PADD 2	Avg	68.31	58.94	53.38	54.98
			Max	81.24	71.34	67.12	68.93
			Min	55.39	46.54	39.64	41.03
		PADD 3	Avg	41.55	33.06	28.55	28.43
			Max	43.20	34.70	29.97	29.85
			Min	39.90	31.43	27.13	27.00
		PADD 4	Avg	57.48	33.70	30.76	21.32
			Max	116.87	70.76	56.18	39.30
			Min	0.00	0.00	5.34	3.35
		PADD 5	Avg	31.20	41.47	40.15	39.49
			Max	39.92	50.89	48.87	48.39
			Min	22.48	32.05	31.43	30.59
		CALIF	Avg	36.81	44.89	47.46	42.58
			Max	43.50	53.85	55.87	50.21
			Min	30.12	35.93	39.06	34.95
		TOTAL	Avg	40.36	38.64	36.93	35.94
			Max	43.38	41.52	39.84	38.83
			Min	37.34	35.76	34.01	33.06

Appendix Table 1

Questions	Units			120	130	140	150
3E	Cents/gal	PADD 1	Max	20.90	20.90	21.26	22.08
			Min	3.90	3.90	4.89	5.75
		PADD 2	Max	4.25	6.72	8.48	9.98
			Min	0.00	1.01	2.08	3.65
		PADD 3	Max	4.68	5.10	6.79	7.58
			Min	3.83	4.25	5.85	6.60
		PADD 4	Max	17.46	16.74	18.28	20.09
			Min	0.00	0.00	0.00	0.00
		PADD 5	Max	8.41	8.41	9.57	11.01
			Min	2.14	2.14	3.58	5.13
		CALIF	Max	6.36	6.74	7.88	9.49
			Min	2.76	3.30	4.56	6.21
		TOTAL	Max	5.31	5.89	7.38	8.51
			Min	3.85	4.41	5.82	6.90
3F	Millions of Dollars	PADD 1	Avg	7.00	10.95	10.95	18.53
			Max	18.27	24.27	24.27	47.06
			Min	0.00	0.00	0.00	0.00
		PADD 2	Avg	22.38	55.51	67.02	70.50
			Max	29.66	82.55	117.13	120.53
			Min	15.11	28.47	16.91	20.47
		PADD 3	Avg	93.82	73.64	99.41	95.61
			Max	100.57	80.49	108.47	104.68
			Min	87.07	66.79	90.35	86.55
		PADD 4	Avg	7.84	3.43	20.59	20.59
			Max	33.27	8.52	51.10	51.10
			Min	0.00	0.00	0.00	0.00
		PADD 5	Avg	119.68	119.68	119.33	119.33
			Max	168.73	168.73	170.73	170.73
			Min	70.64	70.64	67.92	67.92
		CALIF	Avg	142.90	71.75	81.90	131.75
			Max	188.03	104.09	112.38	168.60
			Min	97.76	39.41	51.42	94.90
		TOTAL	Avg	90.88	69.38	86.66	96.19
			Max	101.78	79.79	100.05	110.05
			Min	79.97	58.97	73.26	82.33
3G	Cents/gal	PADD 1	Max	14.55	15.42	15.23	15.82
			Min	4.20	5.46	6.81	7.91
		PADD 2	Max	3.33	4.42	6.45	7.30
			Min	0.46	1.09	1.88	2.77
		PADD 3	Max	5.63	6.34	8.21	8.81
			Min	4.99	5.68	7.47	8.06
		PADD 4	Max	12.89	15.13	15.19	14.61
			Min	0.00	0.00	0.00	2.15
		PADD 5	Max	9.69	9.69	9.73	9.73
			Min	5.01	5.01	5.33	5.33
		CALIF	Max	6.34	7.64	9.42	11.22
			Min	3.69	5.20	6.63	8.15
		TOTAL	Max	5.73	6.58	8.17	9.03
			Min	4.62	5.46	6.97	7.82

Product: Jet "A" Turbine Fuel

Spec Sheet:

SPECIFICATION POINTS	ASTM METHOD	SPECIFICATION LIMIT
Gravity, API	D1298/D4052	37-51
Total Acidity, mgKOH/gr, Max	D3242	0.1
Freezing Point, F(C), Max	D2386	-40 (-40)
Existent Gum, mg/100 ml, Max	D381	7.0
Sulfur, Total Wt%, Max	D1226/D1552/ D2622/D4294	0.3
Mercaptan Sulfur, Wt% (1), Max	D3227	0.003
Corrosion, Copper Strip, 2 Hrs. @ 212F(100C), Max	D130	1
Water Separation Rating, Min	D3948	85
Water Tolerance, M1, Vol Interface Rating, Max	D1094	1b
Aromatics, Vol%, Max (3)	D1319	22
Net Heat of Combustion BTU/Pound, Min	D3338/D4529/D4809	18,400
Flash, TCC F(C), Min (2)	D56	100
Viscosity, CST @ -4F(-20C), Max	D445	8
Thermal Stability: Filter Pressure Drop, (4) mm. Hg, Max	D3241	25
Tube Deposit		Less Than Code 3
Distillation, F(C) 10% Recovered, Max 50% Recovered 90% Recovered End Point, Max Residue, Vol%, Max Loss, Vol%, Max	D86	 401 (205) Report Report 572 (300) 1.5 1.5

EUROPIA Input to Discussions of ARAC FTHWG
Task Group No 6/7: »Fuel Properties«

Effect of Jet A-1 Flash Point on Product Availability and Properties

Introduction

Following the investigations into the cause of the TWA Flight 800 accident in 1996, the US Federal Aviation Administration (FAA) has set up a working group to reduce the likelihood of aeroplane fuel tank ignition. API is participating in the ARAC FTHWG task groups (Aviation Rulemaking Advisory Committee's Fuel Tank Harmonisation Working Groups) together with representatives of the US government, airlines and aircraft builders. API have invited EUROPIA as well as other oil industry groups around the world to contribute to the discussions. One options under consideration is raising the flash point of Jet A from min. 100°F / 38°C to the limit presently applied for JP-5 military jet fuel (min. 140°F / 60°C). This change would have a serious impact on manufacturing yields of jet fuel.

Terms of reference for the committees have been issued in January 1998 and a report is due in six months time with a deadline of July 23. The ARAC-FTHWG recommendations for rule-making advice to FAA will impact not only domestic US but also world-wide regulations.

Other means to be investigated to further reduce the risk of aeroplane tank explosions are auditing and improving, if necessary, the hardware installation, enhancing maintenance practices of fuel systems, exploring better ways to rule-out ignition sources in aeroplane tanks, and reducing flammability of jet fuel by reliable, safe means. This includes technologies like fuel-tank cooling, inerting the atmosphere in the fuel tank, using articulated foam in the fuel tanks, ullage sweeping or active explosion suppression. For all these options the feasibility and cost/benefits will be investigated.

Current Flash Point Levels for Jet A-1 in Europe

Current flash points of Jet A-1 production in Europe are close to the specification of min. 100°F (min. 38°C). The MOD survey for the U.K. reports an average of 108°F (42°C), and individual refineries report averages of 103°F (39.5°C) to 113°F (45°C). Based on these data and an additional evaluation carried out by P. Brook (DERA, Pyestock) the following distributions for Jet A-1 flash points were estimated at levels from the 5%tile up to the 95%tile (Table 1). As requested by ARAC FTHWG TG 5 and 8 also estimates were made for flash point specifications of 120°F, 130°F, 140°F and 150°F in addition to the current specification of 100°F. All these distributions are skewed with most data points close to the specification limit. For the higher flash point specification cases it was assumed that the distribution would become more narrow as refineries are getting more limited to produce aviation kerosene.

Table 1
Flash Point Distributions for Jet A-1 Production in the U.K. at Present Specification of 100°F and Estimates for Higher Specification Limits

	Flash Points [°F] for Different Percentiles of the Distribution				
	5%	**25%**	**50%**	**75%**	**95%**
Current Distribution for Flash Point Specification of min. 100°F:					
Summer	101.1	104.2	106.5	109.7	116.5
Winter	100.6	102.4	104.6	106.9	112.3
Whole Year	100.8	103.5	106.2	109.4	114.6
Estimated Distribution for Flash Point Specification Limits of:					
120°F	121.0	124.0	126.0	129.5	134.0
130°F	131.0	133.5	135.0	137.5	141.0
140°F	141.0	143.0	144.0	146.0	148.5
150°F	151.0	152.5	153.5	154.5	156.0

API/NPRA Aviation Fuels Survey
Regarding the refinery impacts of raising flash point of Jet A / A-1 above the current specification of 100°F (38°C) API/NPRA (American Petroleum Institute / National Petrochemical & Refiners Association) have prepared a questionnaire which has been sent to US refining companies. It investigates the effects of raising flash point to specifications of 120°F (49°C), 130°F (54°C), 140°F (60°C) and 150°F (66°C) on

- Jet A / A-1 yield,
- incremental production costs,
- potential for short term recovery of lost yield,
- short and long term operating costs and capital requirements to recover the lost yield,
- impact on yields and properties of other products

at two freeze point levels, viz. -40°C (-40°F, Jet A) and -47°C (-53°F, Jet A-1). EUROPIA member companies have also used this questionnaire but only covered the -47°C freeze point case as this is the current specification outside the US. A copy of the questionnaire is given in Appendix 1.

All information obtained in Europe from individual refining companies is based on the assumption that present specification for other fuels products remain unchanged, and, therefore, represent a short-term view. However, ongoing discussions within the 15 countries of the European Union (EU) will impact severely on specifications of unleaded gasolines and automotive diesel fuel with subsequent effects on product availability and processing requirements.

In addition to obtaining information form individual refinery companies, the effects were also investigated by using the CONCAWE refinery LP model which simulates the effects for the overall European refinery industry. With this model also the implications of future automotive fuels specifications have been investigated.

Responses from Individual European Refinery Companies

Responses representing 33 refineries in Europe were obtained at EUROPIA and were included in the analysis. These are representing more than two thirds of the present jet fuel production in Europe but less than 50% of the crude distillation capacity. Some of the refineries presently not producing jet fuel use all their kerosene stocks to manufacture a special diesel fuel (City Diesel).

For an easy interpretation of the results it is important to show not only the distribution of the responses but also the weighted averages of the effect of increasing jet fuel flash point on product yields and manufacturing costs. However, the questionnaire yielded ranges rather than exact numbers. For the purpose of estimating weighted averages, it is assumed that for each response the mean of the range allowed as response would represent the exact value. In cases where responses were given as "greater than" the exact value was assumed to be the limiting value plus the last defined step change. Weighted averaged were always based on total Jet A-1 production and not on total crude processing capacity.

Due to the time constraints in a number of cases individual refineries responded only to part of the questions. Where not all refineries responded to a question, we have worked with the data from those that did respond. This assumes that a similar distribution of responses would apply. Also in some cases the reply "not feasible" was obtained, and this was added to the list of possible answers.

Detailed Survey Analysis by Question

The first question was related to general information on the refinery processing capacity related to jet fuel. The consolidated response is given in Table 2 below.

Question 1:
Please indicate the following information regarding your refinery
Crude thruput, b/cd
Hydrocracking capacity, for jet fuel b/cd
RFG and CARB production as a % of total gasoline
Current Jet A/A1 Production, b/cd
Current JP-5 Production, b/cd
Current JP-8 Production, b/cd

Table 2
General Information on European Refineries Responding to API/NPRA Survey

Number of Refineries Covered	36
Crude thruput, b/cd	5,372,500
Hydrocracking capacity, for jet fuel b/cd	160,700
RFG and CARB production as a % of total gasoline	0
Current Jet A/A1 Production, b/cd	472,450
Current JP-5 Production, b/cd	1,500
Current JP-8 Production, b/cd	414

This represents a crude throughput capacity of 5,372,500 b/cd (Total EU crude distillation capacity 12,300,000 b/cd). Hydrocracking capacity for jet fuel production is 160,700 b/cd. Current Jet A-1 production of these 36 refineries is 472,450 b/cd (total EU production 640,000 b/cd in 1995) ranging from 2% to 22% of the refinery crude throughput. Production of reformulated gasoline as well as JP-5 and JP-8 production are not important in Europe: none of the refineries surveyed produced reformulated or CARB gasolines; only one refinery reported JP-5 production (1,500 b/cd), and two refineries manufactured JP-8 at a total of 414 b/cd. In Europe, military jet fuel grade JP-8 and the civil aviation Jet A-1 differ only in the military requiring extra additives.

> *Question 2.a:*
> *If the flash point specification minimum was raised, **with no other specification changes**, what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.*

Listed below in Table 3 is a summary of the production volumes affected.

Table 3
Jet Fuel Production Affected by Raising the Flash Point Specification from min. 100°F to Levels Between 120 and 150°F

	Jet Fuel Production Affected, b/cd			
Revised minimum flash point specification, °F:	**120**	**130**	**140**	**150**
a. increase of greater than 5%	0	0	0	0
b. increase of 0-5%	0	0	0	0
c. no change	42,300	15,800	15,800	15,800
d. reduction of 0 - 4.9%	2,000	0	0	0
e. reduction of 5 - 9.9%	146,000	2,000	0	0
f. reduction of 10 - 19.9%	40,400	11,000	2,000	0
g. reduction of 20 - 29.9%	111,300	168,400	0	0
h. reduction of 30 - 39.9%	97,550	95,600	24,400	0
i. reduction of 40 - 49.9%	0	24,950	207,600	24,400
j. reduction of greater than 50%	30,900	132,600	162,950	363,150
k. not feasible	0	13,300	39,900	49,300
Total Production Covered:	**470,450**	**463,650**	**452,650**	**452,650**
% Production Loss	**21%**	**39%**	**53%**	**61%**

The data clearly indicates that with increasing flash point specification an increasing portion of today's jet fuel production volume can no longer be produced as production losses are 30% and higher.

This information also allows to estimate the weighted average production loss, and the complementing remaining production when increasing Jet A-1 flash point from the current specification of min. 100°F (See Table 3, last line, and Figure 1). When increasing the flash point specification to 120°F 21% are lost, and this effect increase to a loss of 61% at a flash point specification of 150°F.

> *Question 2.b:*
> *What would be the total cost in the short term of these changes in jet fuel production resulting from* ***flash point specification changes****, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.*

Listed in Table 3 below are the jet fuel production volumes affected. Except for a few refineries production cost increases are in the moderate to high range for the higher flash points discussed.

The data also allow to estimate the weighted average cost increases when increasing Jet A-1 flash point from the current specification of min. 100°F (See Table 3, last line, and Figure 2). When increasing the flash point specification to 120°F the average cost increase is estimated at 11.2 cpg, and it is greater than 20 cpg at a flash point specification of 150°F.

Table 4
Short Term Jet Fuel Production Costs Resulting from Raising the Flash Point Specification from min. 100°F to Levels Between 120 and 150°F

	Jet Fuel Production Affected, b/cd			
Revised minimum flash point specification, °F:	**120**	**130**	**140**	**150**
a. zero	33,600	0	0	0
b. 0.1 - 1.9 cpg	4,000	33,600	15,800	15,800
c. 2 - 4.9 cpg	150,30	48,000	2,000	0
d. 5 - 9.9 cpg	29,400	85,900	83,300	48,000
e. 10 - 14.9 cpg	8,900	7,400	24,000	59,300
f. 15 - 19.9 cpg	166,00	0	0	0
g. greater than 20 cpg	47,550	213,550	220,950	213,550
h. not feasible	0	51,300	77,900	87,300
Total Capacity Covered:	**441,750**	**441,750**	**423,950**	**423,950**
Weighted Average cpg	**11.2**	**17.1**	**19.9**	**> 20**

Question 2.c:
*What other product volume reduction/increase (-/+)would result by the changes to the **flash point specification** and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.*

Gasoline
Kerosene
On-road diesel
Off-road diesel
Heating oil
Exports (naphtha or gasoline)
Other

Short terms production cost changes are mainly arising from the requirement use a narrower kerosene cut to blend Jet A-1 at increased flash point levels while keeping freeze point at the -47°C/-53°F level. These fractions have to be down-graded as gasoline or diesel or — in more cases — exported as naphtha. Although most refineries responding to the questionnaire gave a qualitative indication little information exists on the quantitative effects.

The next question (2.d.) asked how much of the "lost" jet fuel production could be made up in the short term:

> *Question 2.d:*
> *If you indicated a reduction in jet fuel production in question 2a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.*

Listed in Table 5 below are the jet fuel production volumes affected. Except for a few refineries only a small fraction of the lost volumes can be recovered in the short term when raising flash point specification above the present limit of 100°F.

Table 5
Short Term Jet Fuel Production Recovery

	Jet Fuel Production Affected, b/cd			
Revised minimum flash point specification, °F:	**120**	**130**	**140**	**150**
a. 100% of the reduction	68,700	22,400	17,800	15,800
b. 75 - 99%	24,000	35,300	0	0
c. 50 - 74%	30,000	24,000	59,300	35,300
d. 25 - 49%	144,00	30,000	30,000	24,000
e. less than 25%	151,80	268,850	235,850	265,850
f. not feasible	7,400	45,400	45,400	45,400
Total:	**425,950**	**425,950**	**388,350**	**386,350**
Weighted Average Recoverable on Short Term Basis, %	**42%**	**26%**	**24%**	**20%**
Percent Production Compared to 100°F Flash Point Spec.	**88%**	**71%**	**60%**	**51%**

This information also allows to estimate the weighted average production recovery, and how this would affect the remaining jet fuel production when increasing Jet A-1 flash point from the current specification of min. 100°F (See Table 4, last two lines and Figure 3). When adjusting refinery processing in the short term to make up for the production losses from increasing the flash point specification to 120°F some of the 20% "loss" are recovered leading to a 88% production compared to the present specification of 100°F. At a flash point specification of 150°F the production capacity recovers from the 37% obtained under question 2.a. to a 51% production compared to the present situation at a flash point specification of 100°F.

Question 2.e.
What would be the total cost in the short term of these changes to recover losses in jet fuel production resulting from ***flash point specification changes,*** *including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.*

Listed in Table 6 below are the jet fuel production volumes affected. Expect for a few refineries production costs to recover the losses in jet fuel production are in the moderate to high range for the higher flash points discussed.

Table 6
Costs for Short Term Recovery of Lost Jet Fuel Production Resulting from Raising the Flash Point Specification from min. 100°F

	Jet Fuel Production Affected, b/cd			
Revised minimum flash point specification, °F:	**120**	**130**	**140**	**150**
a. zero	15,800	15,800	15,800	15,800
b. 0.1 - 1.9 cpg	2,000	0	0	0
c. 2 - 4.9 cpg	194,600	32,000	30,000	0
d. 5 - 9.9 cpg	22,000	148,600	2,000	30,000
e. 10 - 14.9 cpg	59,300	0	144,000	0
f. greater than 15 cpg	85,550	182,850	182,850	326,850
Total	**379,250**	**379,250**	**374,650**	**372,650**
Weighted Average, cpg	**8.7**	**12.9**	**14.9**	**> 15**

This information also allows to estimate the weighted average cost for recovering the lost production volumes when increasing Jet A-1 flash point from the current specification of min. 100°F (See Table 6, last line, and Figure 4). When increasing the flash point specification to 120°F the average cost for the recovery of the lost volume is estimated at 8.7 cpg, and greater than 15 cpg at a flash point specification of 150°F.

Question 2.f:
If adequate time for capital investments were allowed, what would be the estimated capital investment required in millions of dollars to make up 100% of the lost production. Check one box for each flash point.

Listed in Table 7 below are the jet fuel production volumes affected and the cost ranges involved. Heavy investment will be required to make up the lost production. For a flash point specification of 140°F and above this will be for most existing refineries in the range of 100 to 500 MM$ indicating installation of hydrocracking units. The weighted average investment required to make up 100% of the lost jet fuel production is also shown in Figure 5.

Table 7
Capital Investment Required to Make up 100% of Lost Jet Fuel Production Resulting from Raising the Flash Point Specification from min. 100°F

	Jet Fuel Production Affected, b/cd			
Revised minimum flash point specification, °F:	**120**	**130**	**140**	**150**
a. 0 - 9.9 $million	85,900	35,600	17,800	17,800
b. 10 - 49.9 $million	202,600	4,600	0	0
c. 50 - 99.9 $million	22,000	270,300	30,000	0
d. 100 - 499.9 $million	9,400	9,400	249,700	202,300
e. not feasible	48,450	48,450	48,450	125,850
Total Production Covered:	**368,350**	**368,350**	**345,950**	**345,950**
Weighted Average Investment, $million	**148**	**182**	**349**	**> 500**

Question 2.g.
*What would be the estimated total cost of these long term changes to recover jet fuel production resulting from **flash point changes**, including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 15% ROI for capital investment decisions and 10% return on capital for determining per gal capital charges. Check one box for each flash point.*

Listed in Table 8 below are the jet fuel production capacities affected. They indicate that heavy investment will be required to make up the lost production. For a flash point specification of 140°F and above the costs will be for most existing refineries in Europe higher than 20 cpg. The effect of increased flash point on additional costs is also shown in Figure 6.

Table 8
Costs for Long Term Recovery of Lost Jet Fuel Production Resulting from Raising the Flash Point Specification from min. 100°F

	Jet Fuel Production Affected, b/cd			
Revised minimum flash point specification, °F:	**120**	**130**	**140**	**150**
a. zero	0	0	0	0
b. 0.1 - 1.9 cpg	57,000	11,000	0	0
c. 2 - 4.9 cpg	144,000	46,000	0	0
d. 5 - 9.9 cpg	22,000	0	46,000	0
e. 10 - 14.9 cpg	0	166,000	0	0
f. 15 - 19.9 cpg	0	0	0	0
g. greater than 20 cpg	54,950	54,950	220,950	259,550
h. not feasible	0	0	0	7,400
Total Production Covered:	**277,950**	**277,950**	**266,950**	**266,950**
Weighted Average Costs, cpg	**7.6**	**13.0**	**22.0**	**> 20**

LP Modelling for the European Refinery Industry
In addition to the responses from individual refineries the CONCAWE LP model has been used to estimate the expected effects on available volumes of jet fuel in relation to increasing the flash point specification.

The range of flash points from the current level of 100°F (38°C) to a potential of 140°F (60°C) has been investigated in order to assess

- jet fuel availability,
- effects on products other than jet fuel.

<u>Distillation</u>
In order to meet an increased flash point of 140°F (60°C), it is expected that the effective cut point between naphtha and kerosene needs to be raised to 170 to 180°C depending on crude and distillation column performance; an increase of the IBP of the jet fuel also requires a reduction of FBP to around 250°C to meet the freeze point specification of -47°C. Based on available crude yield data this may entail a loss of potential kerosene fraction (mainly used for jet fuel and automotive diesel blending) of some 30 to 40% compared to the current maximum yield on crude.

A further complication would be a potential gap developing between naphtha feed to the reformer (when end point is limited due to gasoline specifications) and such a high flash point kerosene fraction when used in jet fuel. The current hardware does not allow for producing this 'gap'-product, and new distillation hardware would be required. In addition, there will be a serious loss of flexibility for optimisation of summer/winter demand slates.

Overall EU Supply

Jet fuel volume is expected to grow substantially to a level of around 50 MTPA (1,000,000 b/cd) by the year 2010. Using the CONCAWE model for the EU-15, we have investigated the potential effects of an increase in jet fuel flash point up to 140°F (60°C). As a basis we have used the year 2000 qualities of other transportation fuels as defined in the EU Council Common Position of October 1997.

In order to maintain the future production volume of 50 MTPA, substantial investments would be required in creating new molecules suitable for aviation kerosene blending. The model predicts a requirement for some 25 MTPA additional hydrocracking capacity.

The EU-wide optimal LP based solution for transport fuel reformulation (2000 specifications) for a high flash point jet fuel is very different from that for the current flash point jet fuel. This reflects the higher availability of naphtha (due to the increase in average cutpoint) and the need for more hydrocracking capacity at the expense of FCC processing.

Conclusions from LP Modelling

- An increase in kerosene flash point leads to a substantially reduced flexibility in product slate adjustments (selection of naphtha/kerosene cutpoint).
- The restrictions in cutpoint flexibility may lead to additional separation requirements (separation sharpness and/or production of 'gap' product (heavy naphtha 150 - 180°C fraction).
- Substantial investments in additional hydrocracking to replace the losses in kerosene yield from crude distillation.
- The selection of a high flash point Jet-A1 specification impacts severely on the preferred solution for changes in specifications for ground transportation fuels (gasoline and automotive diesel fuel).

Summary

The data from the survey of European refineries and the CONCAWE LP modelling demonstrate the following impact of increasing jet fuel flash point:

- **Even at a 120°F flash point specification, Jet A-1 availability will be severely limited. Due to the cut point changes required Jet A-1 availability will be reduced by 21%, and the effect increases to 61% at 150°F flash point. Clearly, this indicates the effects a short term rule on aviation fuel flash point would impose on civil aviation.**

- **The API/NPRA survey does not take into account the future growth expected for jet fuel demand.**

- **The impact in Europe in greater than in the US. This is due to:**
  - **a) the manufacture of the lower freeze point Jet A-1 grade in Europe which additionally reduces the potential jet fuel yield on crude;**
  - **b) the demand barrel shape in Europe differs with less motor gasoline and more middle distillates required from a barrel of crude oil. This tends to produce higher front end cut points and flash points for US jet fuel;**
  - **c) Europe has a stronger demand for diesel fuel for which kerosene is also required. Environmental pressures in Europe are likely to require a lighter diesel fuel containing more kerosene in the near future.**

- **Short term cost increases are estimated at 11.2 cpg for 120°F flash point and more than 20 cpg for 150°F.**

- **In order to make up for the lost volumes in Europe heavy investment would be required including additional hydrocracking capacity.**

Figure 1

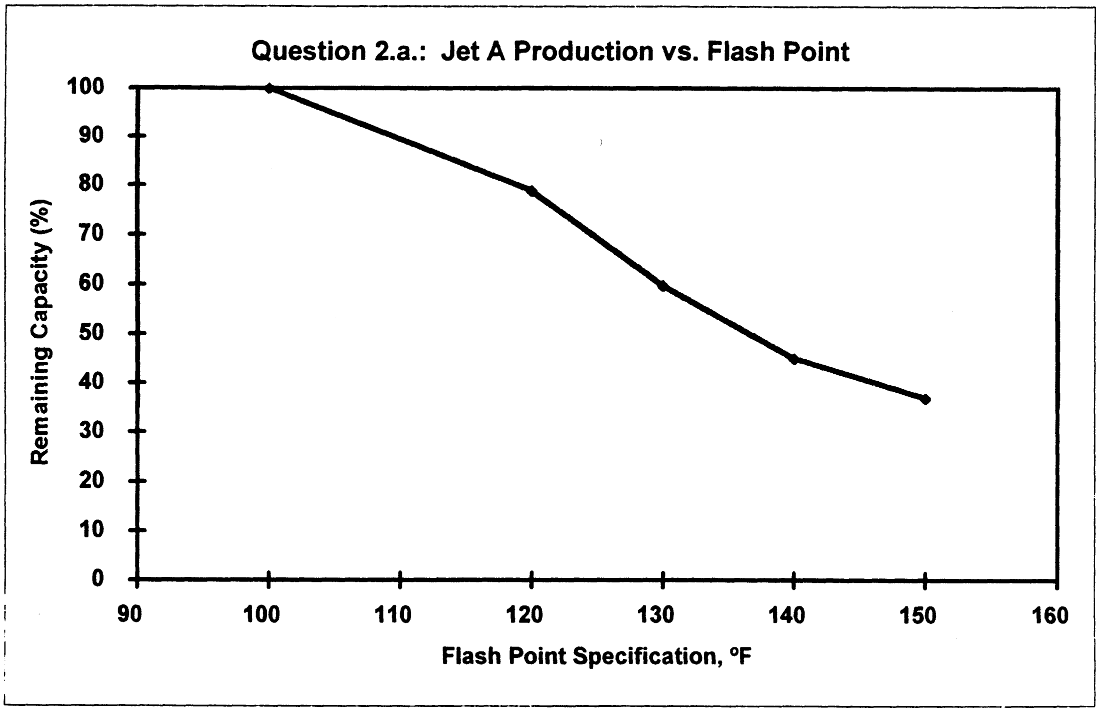


Figure 2

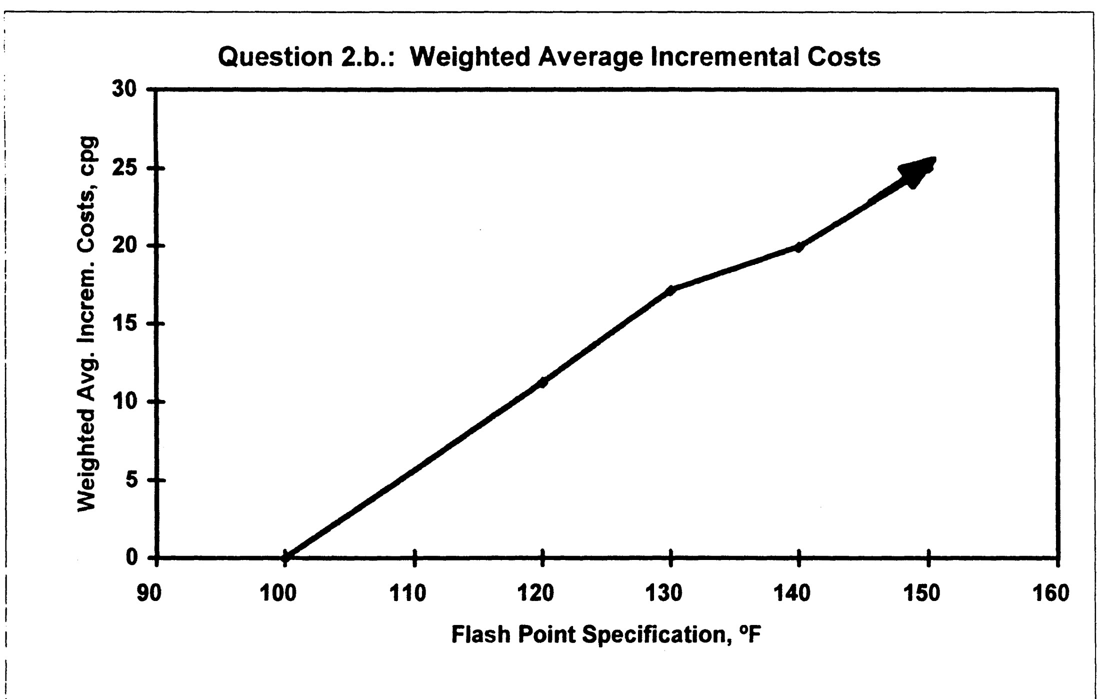


Figure 3

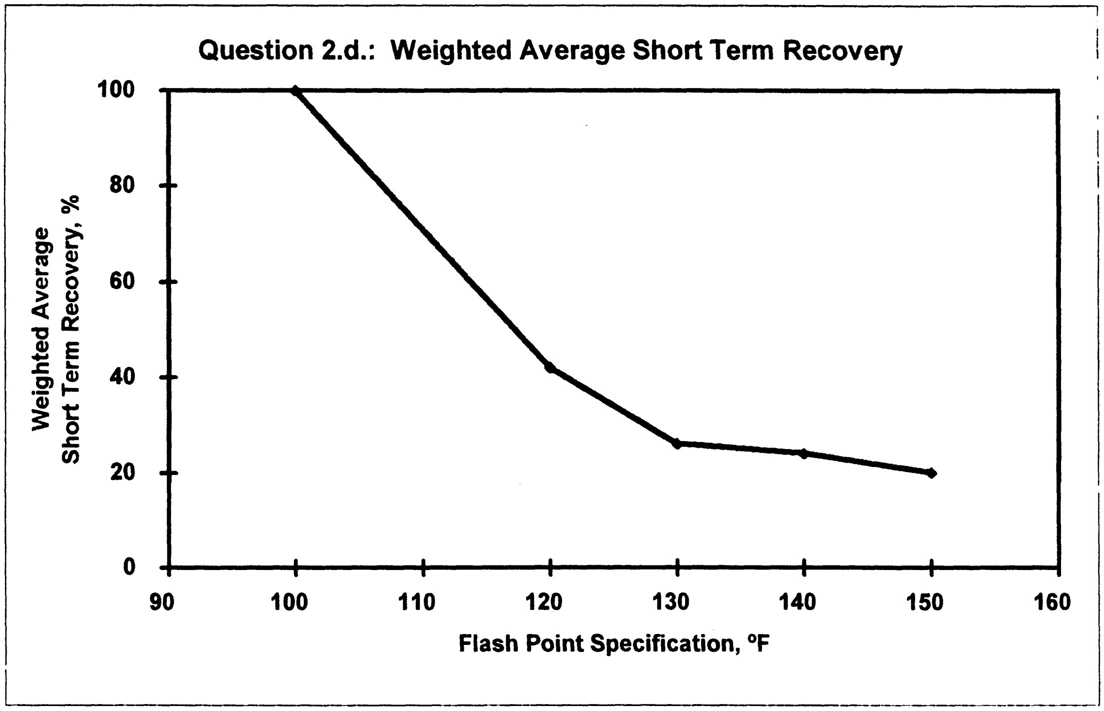


Figure 4

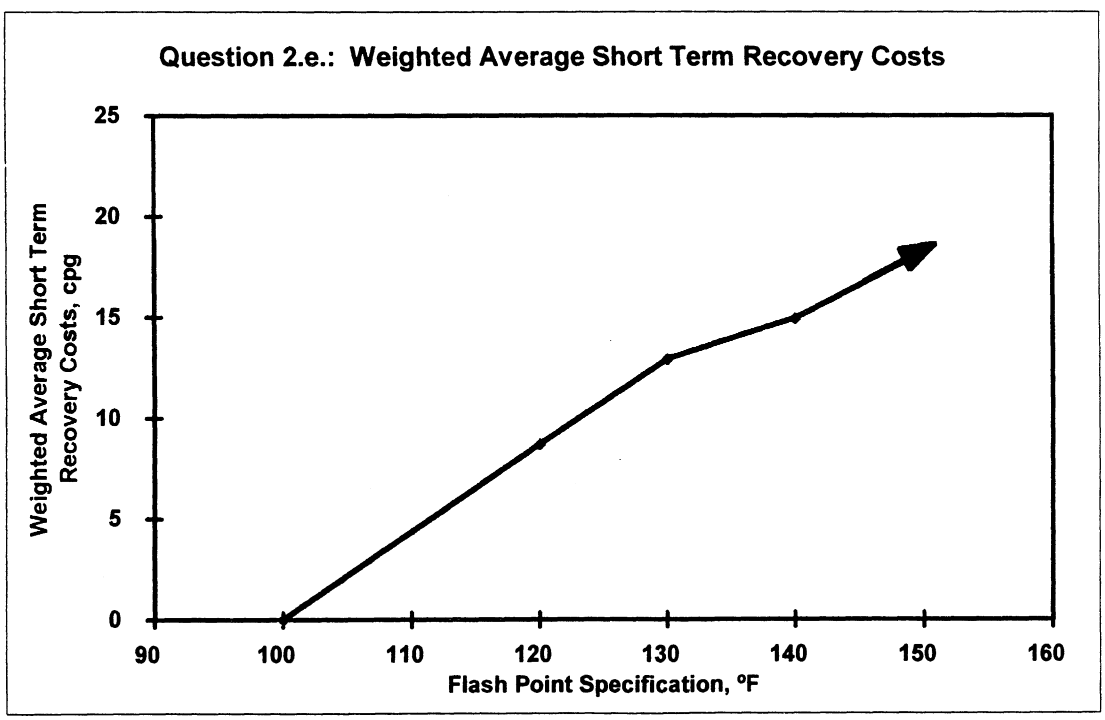


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Figure 5

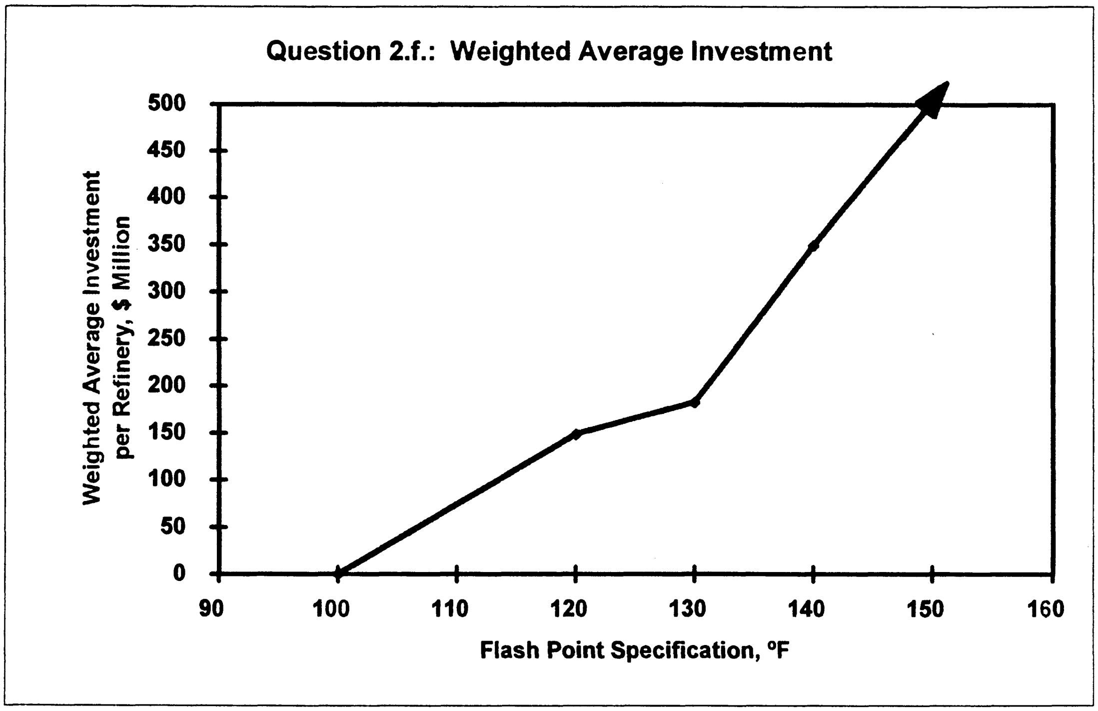
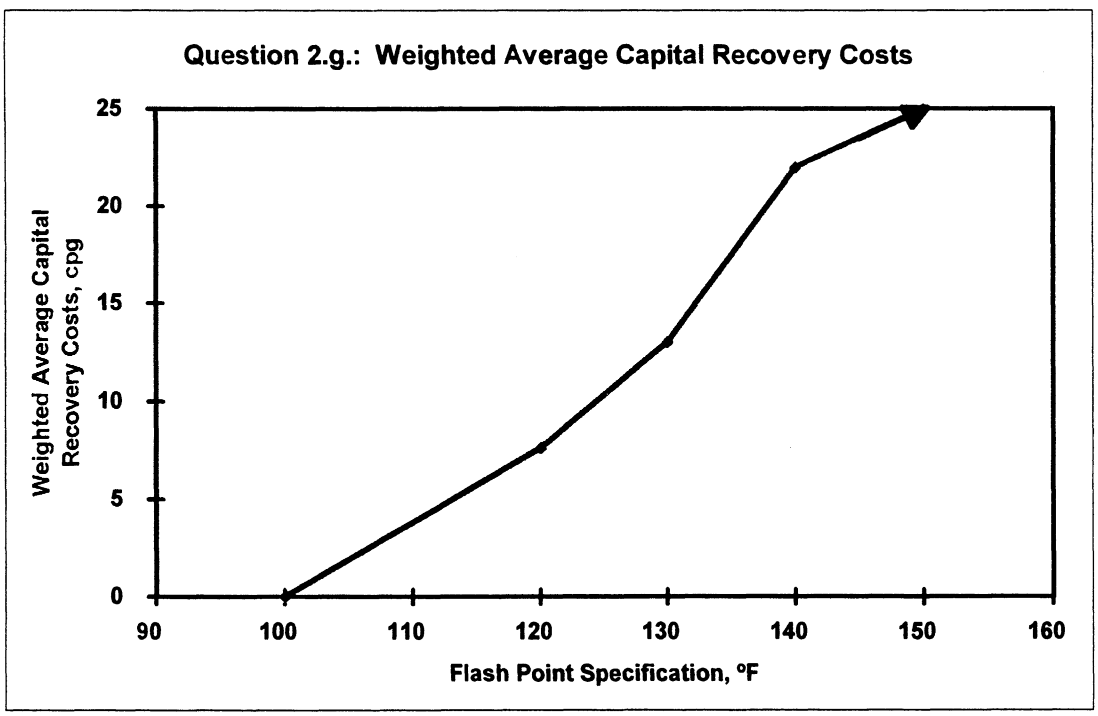


Figure 6



API/NPRA Aviation Fuel Properties Survey

Please fill out this Questionnaire for each refinery in which you produce Commercial Aviation Jet A. Use 1997 calendar year data. If seasonality is a significant factor in your refineries, fill out a copy of your questionnaire for each season.

If applicable, indicate:
Months in winter season________ Months in summer season ________

PADD_________________

1. Please indicate the following information regarding your refinery

Crude thruput, b/cd	____________
Hydrocracking capacity, for jet fuel b/cd	____________
RFG and CARB production as a % of total gasoline	____________
Current JetA/A1 Production, b/cd	____________
Current JP-5 Production, b/cd	____________
Current JP-8 Production, b/cd	____________

THE FOLLOWING SERIES OF QUESTIONS REFER ONLY TO RAISING THE FLASH POINT MINIMUM SPECIFICATION FROM 100 DEGREES F.

2a. **If the flash point specification minimum was raised, with no other specification changes,** what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. increase of greater than 5%	☐	☐	☐	☐
b. increase of 0-5%	☐	☐	☐	☐
c. no change	☐	☐	☐	☐
d. reduction of 0-4.9%	☐	☐	☐	☐
e. reduction of 5-9.9%	☐	☐	☐	☐
f. reduction of 10-19.9%	☐	☐	☐	☐
g. reduction of 20-29.9%	☐	☐	☐	☐
h. reduction of 30-39.9%	☐	☐	☐	☐
i. reduction of 40-49.9%	☐	☐	☐	☐
j. reduction of greater than 50%	☐	☐	☐	☐

API/NPRA Aviation Fuel Properties Survey

2b. What would be the total cost in the short term of these changes in jet fuel production resulting from **flash point specification changes**, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

	Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a.	zero	☐	☐	☐	☐
b.	.1-1.9 cpg	☐	☐	☐	☐
c.	2-4.9 cpg	☐	☐	☐	☐
d.	5-9.9 cpg	☐	☐	☐	☐
e.	10-14.9 cpg	☐	☐	☐	☐
f.	15-19.9 cpg	☐	☐	☐	☐
g.	greater than 20 cpg	☐	☐	☐	☐

2c. What other product volume reduction/increase (-/+)would result by the changes to the **flash point specification** and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
gasoline	____	____	____	____
kerosene	____	____	____	____
on-road diesel	____	____	____	____
off-road diesel	____	____	____	____
heating oil	____	____	____	____
exports (naptha or gasoline)	____	____	____	____
other________________________	____	____	____	____

API/NPRA Aviation Fuel Properties Survey

2d. If you indicated a reduction in jet fuel production in question 2a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. 100% of the reduction	☐	☐	☐	☐
b. 75-99%	☐	☐	☐	☐
c. 50-74%	☐	☐	☐	☐
d. 25-49%	☐	☐	☐	☐
e. less than 25%	☐	☐	☐	☐

2e. What would be the total cost in the short term of these changes to recover losses in jet fuel production resulting from **flash point specification changes,** including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. zero	☐	☐	☐	☐
b. .1-1.9 cpg	☐	☐	☐	☐
c. 2-4.9 cpg	☐	☐	☐	☐
d. 5-9.9 cpg	☐	☐	☐	☐
e. 10-14.9 cpg	☐	☐	☐	☐
f. greater than 15 cpg	☐	☐	☐	☐

2f. If adequate time for capital investments were allowed, what would be the estimated capital investment required in millions of dollars to make up 100% of the lost production. Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. 0-9.9 $million	☐	☐	☐	☐
b. 10-49.9 $million	☐	☐	☐	☐
c. 50-99.9 $million	☐	☐	☐	☐
d. 100-499.9 $million	☐	☐	☐	☐
e. not feasible	☐	☐	☐	☐

API/NPRA Aviation Fuel Properties Survey

2g. What would be the estimated total cost of these long term changes to recover jet fuel production resulting from **flash point changes**, including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 15% ROI for capital investment decisions and 10% return on capital for determining per gal capital charges. Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. zero	☐	☐	☐	☐
b. .1-1.9 cpg	☐	☐	☐	☐
c. 2-4.9 cpg	☐	☐	☐	☐
d. 5-9.9 cpg	☐	☐	☐	☐
e. 10-14.9 cpg	☐	☐	☐	☐
f. 15-19.9 cpg	☐	☐	☐	☐
g. greater than 20 cpg	☐	☐	☐	☐

THE FOLLOWING SERIES OF QUESTION REFER TO RAISING THE FLASH POINT MINIMUM SPECIFICATION FROM 100 DEGREES F AND REDUCING THE FREEZE POINT MINIMUM SPECIFICATION TO -53 DEGREES F.

3a. If the **freeze point specification minimum was reduced to -53 deg F, in addition to the flash point changes projected above**, what would be the volume impact on your ability to meet this specification, relative to your production? Assume no changes in relative values of distillate products and no capital investment. Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. increase of greater than 5%	☐	☐	☐	☐
b. increase of 0-5%	☐	☐	☐	☐
c. no change	☐	☐	☐	☐
d. reduction of 0-4.9%	☐	☐	☐	☐
e. reduction of 5-9.9%	☐	☐	☐	☐
f. reduction of 10-19.9%	☐	☐	☐	☐
g. reduction of 20-29.9%	☐	☐	☐	☐
h. reduction of 30-39.9%	☐	☐	☐	☐
i. reduction of 40-49.9%	☐	☐	☐	☐
j. reduction of greater than 50%	☐	☐	☐	☐

API/NPRA Aviation Fuel Properties Survey

3b. What would be the total cost in the short term of these changes in jet fuel production resulting from **flash point and freeze point specification changes**, including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

	Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a.	zero	☐	☐	☐	☐
b.	.1-1.9 cpg	☐	☐	☐	☐
c.	2-4.9 cpg	☐	☐	☐	☐
d.	5-9.9 cpg	☐	☐	☐	☐
e.	10-14.9 cpg	☐	☐	☐	☐
f.	15-19.9 cpg	☐	☐	☐	☐
g.	greater than 20 cpg	☐	☐	☐	☐

3c. What other product volume reduction/increase (-/+)would result by the changes to the **flash and freeze point specifications** and what percent would you expect? Assume no changes in relative values of distillate products and no capital investment. Indicate with either -/+ numeric percentages.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
gasoline	____	____	____	____
kerosene	____	____	____	____
on-road diesel	____	____	____	____
off-road diesel	____	____	____	____
heating oil	____	____	____	____
exports (naptha or gasoline)	____	____	____	____
other________________________	____	____	____	____

API/NPRA Aviation Fuel Properties Survey

3d. If you indicated a reduction in jet fuel production in question 3a, approximately how much of the reduction could be made up in the short term (up to 24 months)? Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. 100% of the reduction	☐	☐	☐	☐
b. 75-99%	☐	☐	☐	☐
c. 50-74%	☐	☐	☐	☐
d. 25-49%	☐	☐	☐	☐
e. less than 25%	☐	☐	☐	☐

3e. What would be the total cost in the short term of these changes to recover losses in jet fuel production resulting from **flash and freeze point specification changes,** including incremental operating costs, and economic losses through downgrades or changed product slate in cpg over the full volume of jet fuel produced? Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. zero	☐	☐	☐	☐
b. .1-1.9 cpg	☐	☐	☐	☐
c. 2-4.9 cpg	☐	☐	☐	☐
d. 5-9.9 cpg	☐	☐	☐	☐
e. 10-14.9 cpg	☐	☐	☐	☐
f. 15-19.9 cpg	☐	☐	☐	☐
g. greater than 20 cpg	☐	☐	☐	☐

3f. If adequate time for capital investments were allowed, what would be the estimated capital investment required in millions of dollars to make up 100% of the lost production? Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. 0-9.9 $million	☐	☐	☐	☐
b. 10-49.9 $million	☐	☐	☐	☐
c. 50-99.9 $million	☐	☐	☐	☐
d. 100-499.9 $million	☐	☐	☐	☐
e. not feasible	☐	☐	☐	☐

API/NPRA Aviation Fuel Properties Survey

3g. What would be the estimated total cost of these long term changes to recover jet fuel production resulting from **flash and freeze point changes**, including incremental operating costs, capital charges and any/or economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced? Assume 1998 dollars, 15% ROI for capital investment decisions and 10% return on capital for determining per gal capital charges. Check one box for each flash point.

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
a. zero				
b. .1-1.9 cpg				
c. 2-4.9 cpg				
d. 5-9.9 cpg				
e. 10-14.9 cpg				
f. greater than 15 cpg				

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4. Would any of the changes to flash point specifications create difficulty with gasoline compliance parameters

Revised minimum flash point spec:	*120*	*130*	*140*	*150*
yes				
no				
If yes, which ones, in particular				
benzene				
aromatics				
distillates E300/T90				
distillates E200/T50				
sulfur				
other______________				

Please return completed survey to:

Harold S. Haller & Company
24803 Detroit Road
Cleveland, Ohio 44145
Phone: 440.871.6597
Fax: 440.871.1182

[Report on API/NPRA Jet Fuel Survey]

May 1998

IMPACTS OF JET A-1 FLASH POINT CHANGES

Petroleum Association of Japan

Introduction

This is the report of Petroleum Association of Japan(PAJ) on member refiners' state of manufacturing jet fuel and simulation of suggested Jet A-1 specification changes which was requested by American Petroleum Institute(API) requiring on the letter of March 13, 1998.

As a commercial aviation fuel, in Japan, there is not Jet A but Jet A-1, which is produced in accordance with "PAJ Joint Fueling System Checklist Issue12", referred to "Aviation Fuel Quality Requirements for Jointly Operated Systems Joint Fueling System Checklist Issue 16 for Jet A-1".

Supply and Demand

Balance of supply and demand of Jet fuel including bond stock during FY1997 (from April 1997 to March 1998) in Japan are showed in Table 1.

Table 1 : Supply and Demand of Jet Fuel in Japan (FY 1997)

-Supply		
Production	9,557,000kl	(165,000bcd)
Import	3,162,000kl	(54,000bcd)
-Demand		
Domestic Sales	4,779,000kl	(82,000bcd)
Export	8,190,000kl	(135,000bcd)

Ref.:Production of Household Heating Kerosene 28,230,000kl(486,000bcd)

(Source: Ministry of International Trade and Industry)

Coverage of the Survey

PAJ asked for refining companies of "Refining Technology Working Group" member to respond to the questionnaires formatted by API, and obtained responses from 24 refineries (12 companies), out of 26 refineries manufacturing Jet fuel. Then those responded data were compiled by the working group.

These are representing 85% of jet fuel production and 72% of the crude distillation capacity in Japan.

-Coverage rate of jet fuel production:

140,000bcd / 165,000bcd = 85%

-Coverage rate of crude distillation capacity:

3,809,000BPSD / 5,323,000BPSD = 72%

Detailed Survey Analysis by Questions

1. General information on the refineries responded

Table 2: General Information on the Refineries Responded.

Crude thruput (FY1997)	3,078,040bcd
Hydrocracking capacity for jet fuel (Mar.'98)	21,000bcd
RFG and CARB production	0%
Current Jet A-1 production (FY1997)	138,084bcd
Current JP-5 production (FY1997)	2,002bcd
Current JP-8 production (FY1997)	0bcd

-Yield of Jet A-1:

138,000bcd / 3,078,000bcd = 4.5%

-Hydrocracking rate

(assumption of Jet fuel yield : 30%, 21,000bcd$\times$0.3 = 6,300bcd)

vs. crude thruput: 6,300bcd / 3,078,000bcd = 0.2%

vs. Jet A-1 production: 6,300bcd / 138,000bcd = 4.6%

Manufacturing Jet A-1 in Japan almost depends on straight run kerosene, so the rate of hydrocracking kerosene is low.

2. Production Affected by Specification Changes

Since the yield of household heating kerosene is extremely high in Japan(11%) compared to other OECD countries, raising the minimum flash point of Jet A-1, which shared the same yield with household heating kerosene, may affect serious impacts for jet fuel supply including aspects of manufacturing, storage, transportation and so on.

Table 3: Production Yield of Heating Kerosene (1996)

Japan	10.8 %
United State	0.38%
United Kingdom	3.63%
France	0.11%
Germany	0.03%
Holland	0.26%

(Source: OECD)

Table 4 : Production Affected by Raising Minimum Flash Point

	Jet Fuel Affected, bcd			
Revised min. flash point spec.°F	120	130	140	150
℃	49	54	60	66
a. increase of greater than 5%	0	0	0	0
b. increase of 0-5%	0	0	0	0
c. no change	6,882	0	0	0
d. reduction of 0-4.9%	12,220	4,120	4,120	0
e. reduction of 5-9.9%	3,800	0	0	4,120
f. reduction of 10-19.9%	42,782	8,100	0	0
g. reduction of 20-29.9%	34,560	16,830	11,500	0
h. reduction of 30-39.9%	37,900	41,862	9,630	3,400
i. reduction of 40-49.9%	0	67,172	28,162	8,100
j. reduction of greater than 50%	0	0	84,672	122,464
% Production Loss	26%	37%	51%	67%

When raising Jet A-1 minimum flash point, production volume shall lose with regardless of the level. Volume of its loss becomes bigger, according to the flash point level from 120°F(49℃) to 150°F(66℃).
The survey shows 10-30% production may loses when flash point change from current 100°F(38℃) to 120°F(49℃), 20-40% loss at 130°F(54℃), and majority of refiners loses greater than 60% of production at 150°F(66℃).
For reference, quantitative analysis estimated on this result indicates 26% production loss in the minimum case of 120 °F(49℃) and 67% in the maximum case of 150 °F(66 ℃). Those figures are very similar to EUROPIA's result (Table 4).

As to the reduction of freezing point, we have no serious impact, because we produce kerosene with less than 53°F(-47℃). Accordingly PAJ omits the survey of third set of questions (3a though 3g).

In order to manufacture new specification of jet fuel, most of Japanese refiners have to give up the current pattern of refining, which is same range cut of both household heating kerosene and Jet A-1 in crude distillation units, and to build new segregated lines and tanks for new jet fuel. Also we could consider to build new hydrocracking units.
However it is very difficult to install new units or facilities with reasons of limitation of refinery space and environmental/safety regulations at this moment in Japan. So that we conclude incremental costs are infeasible in case of requiring capital investment, for this time. (Question 2b., 2e.,2f. and 2g.)

3. Technical Feasibility to Recover Volume

Both household heating kerosene and Jet A-1 have been drawn in same cut range, and Jet A-1 has been adjusted specification just before loading in Japan.
If lifting the minimum flash point, almost Japanese refiners must change the current refining pattern to new one, drawing the yield of jet fuel including kerosene from narrow cut (short cut) and, then, producing household heating kerosene blended light kerosene and heavy kerosene which are cut separately.
In above case, refineries shall be required an option from following countermeasures technically;

a. To process in topper increased number of trays. (Figure 1)

b. To cut the same yield of current kerosene and jet fuel in topper, next, to fractionate in new re-run units, and then to process hydro-de-sulferization (HDS) units. (Figure 2)

c. To cut the same yield of current kerosene and jet fuel in topper, next, to process HDS units, and then to fractionate in re-run units.(Figure 3)

Further, refineries need to build new segregated off-site facilities(e.g. storage tanks, pipe laying) for Jet A-1 from current dual purpose facilities. As well as, responding this specification changes, we have to face additional problems of increasing energy utilization to increasing CO2 emission, or utilization of surplus heavy naphtha.
It is also infeasible to build new hydrocracking units as mentioned above.

Conclusion

Proposed specification changes of commercial aviation fuel flash point may introduce serious affection toward not only jet fuel supply but also household heating kerosene in Japan, and shall be too difficult to respond actually. PAJ will stand a pessimistic position at this moment.
Though we considered to respond with import jet fuel from Asian market, this changes might have world-wide impact. Accordingly it is necessary to judge based on comprehensive assessments of its impacts not only in Western market but also in Asian market.

Figure 1 : To process in crude distillate unit (topper) increasing of number of traies .

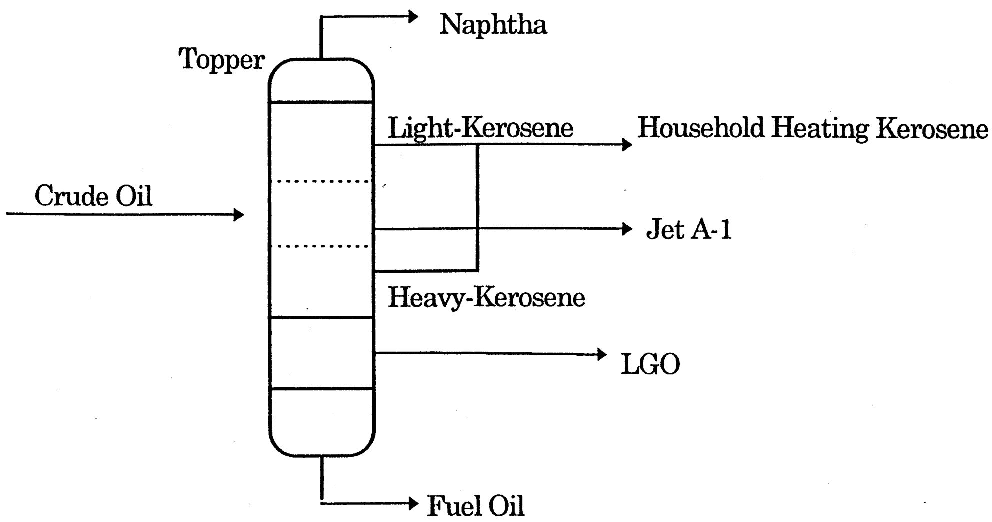


Figure 2 : To cut the same yield of current kerosene and jet fuel in topper, next, to fractionate in new re-run units, and then to process hydro-de-sulferization (HDS) units.

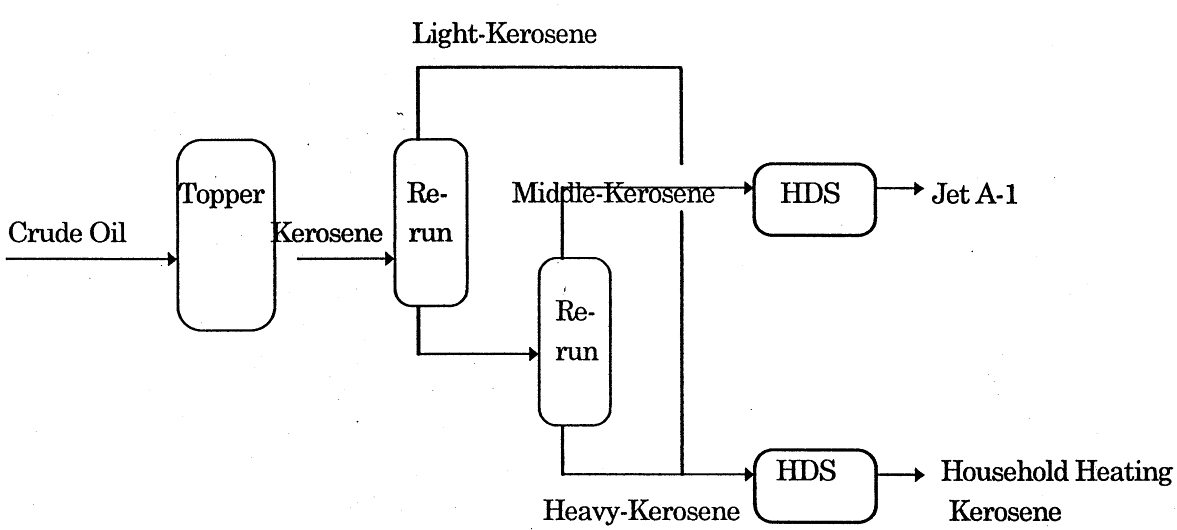
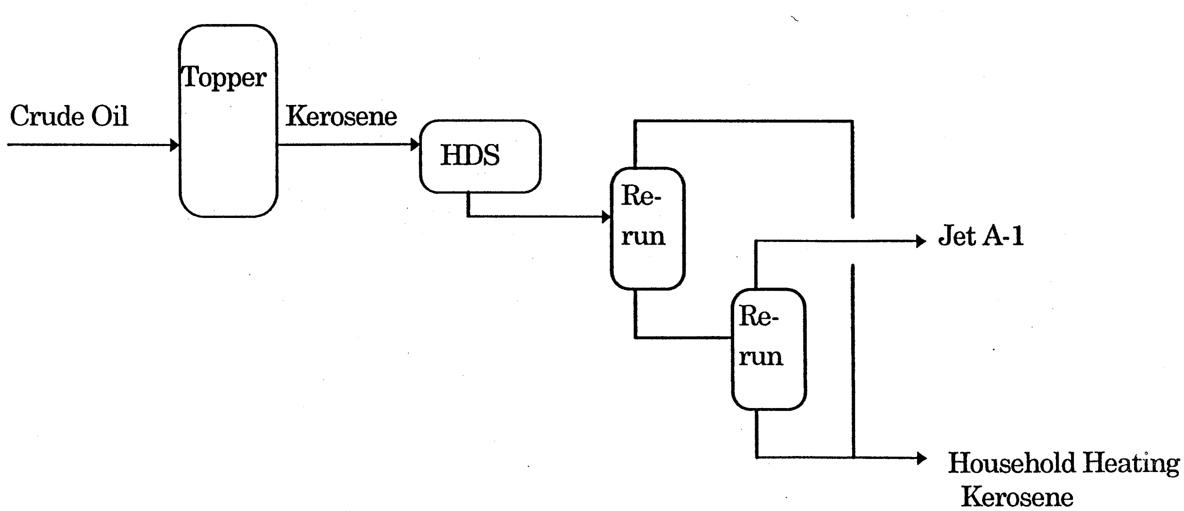


Figure 3 :To cut the same yield of current kerosene and jet fuel in topper, next, to process HDS units, and then to fractionate in re-run units.



OPERATIONAL ISSUES – ALL ENGINE MANUFACTURERS

See notes below						
			FUEL DELIVERY SYSTEM			
Section	**Fuel Property**	**Limiting***	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**
9.2.3.2	Inc. Flash Point	Yes			Suction lift performance improved	Reduced risk of vapor locking and lower TVP
9.2.3.2	Inc. IBP				Suction lift performance improved	Reduced risk of vapor locking and lower TVP
9.2.3.2	Inc. 10% Distilled				Suction lift performance improved	Reduced risk of vapor locking and lower TVP
9.2.3.2	Inc. 90% Distilled					
9.2.3.2	Inc. FBP					
9.2.3.3	Inc. Viscosity @ -20°	Poss.	Decreased	Loss of cold day operations	Red. cold start performance Dec. filter life Red. Heat exchange efficiency	Red. Control/pump perf. (dec. pumpability) + red. heat transfer effy
9.2.3.3	Change Visc. vs. T		Decreased	Loss of cold day operations	Cold start performance	Failure to control/pump fuel (dec. pumpability)
9.2.3.4	Inc. Aromatics		Inc. seal failures	Increase		Aromatics causing excessive swell
9.2.3.4	Change Arom. Types					
9.2.3.4	Dec. smoke point	Poss.				
9.2.3.5	Inc. total sulphur					
9.2.3.5	Dec. total sulphur					
9.2.3.6	Dec. thermal stab		Decreased	Increased maintenance	Inc. cleaning frequency	Fuel coking on critical parts
9.2.3.6	Inc. Thermal stab		Increased	Reduced maintenance	Dec. cleaning frequency	Improved due to reduced coking
9.2.3.7	Change Fz Pt. Characteristics**		Dec. reliability	Cold fuel operational limits***	Interruption of fuel supply	Blockage of pumps, filters and orifices etc.

*Denotes high proportion of population likely to be

**Denotes sharper transition to solid and larger xtals/filter blocking

OPERATIONAL ISSUES – ALL ENGINE MANUFACTURERS

			FUEL DELIVERY SYSTEM			
Section	**Fuel Property**	**Limiting***	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**
9.2.3.8	Improve lubricity		Increased	Reduced maintenance	Inc. fuel pump performance and life	Reduced pump wear
9.2.3.8	Reduce lubricity		Decreased	Increased maintenance	Dec. fuel pump performance and life	Inc. pump wear and failure rates
9.2.3.9	Inc. Density				Flow meter and control calibration & less accuarate fuel sched.	Change in density
9.2.3.9	Dec. Net. Ht. Comb.		Modified fuel control increased	Inadequate high power fuel supply	Insufficient heat at max. flow	

*Denotes high proportion of population likely to be
**Denotes sharper transition to solid and larger xtals/filter blocking

OPERATIONAL ISSUES – ALL ENGINE MANUFACTURERS

			COMBUSTION SYSTEM				HOT-END				EMMISIONS
Section	**Fuel Property**	**Limiting***	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**	
9.2.3.2	Inc. Flash Point	Yes	Decreased	Hard starting	More difficult ignition	Dec. atomization and evaporation efficiency					
9.2.3.2	Inc. IBP		?	?	Degrade cold starting and altitude relight performance	Dec. atomization and evaporation efficiency					Increased due to comb inefficiency
9.2.3.2	Inc. 10% Distilled				Degrade cold starting and altitude relight performance	Dec. atomization and evaporation efficiency					Increased due to comb inefficiency
9.2.3.2	Inc. 90% Distilled				Degrade cold starting and altitude relight performance	Dec. atomization and evaporation efficiency					Increased due to comb inefficiency
9.2.3.2	Inc. FBP		Inc. carbon deposition & red . liner life	Increased	Degrade cold starting and altitude relight performance	Dec. atomization and evaporation efficiency					Increased due to comb inefficiency
9.2.3.3	Inc. Viscosity @ - 20°	Poss.				Red. heat transfer effy.					Higher smoke
9.2.3.3	Change Visc. vs. T										Secondary effects due to inefficiency in combustor

*Denotes high proportion of population likely to be
**Denotes sharper transition to solid and larger xtals/filter blocking

OPERATIONAL ISSUES – ALL ENGINE MANUFACTURERS

		COMBUSTION SYSTEM					HOT-END				EMISSIONS
Section	**Fuel Property**	**Limiting***	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**	
9.2.3.4	Inc. Aromatics			Increased maintenance liner and injector life	Increased wall temps/carbon depostion + low power emissions	Inc. flame radiation and carbon production		increase	Blade and guide vane life	Carbon	Increased smoke/UHC/CO
9.2.3.4	Change Arom. Types			??	??	??					??
9.2.3.4	Dec. smoke point	Poss.		Increased maintenance	Excessive wall temps/carbon deposition	Inc. flame radiation and carbon production		Increase	Blade and guide vane life	Carbon	Higher smoke
9.2.3.5	Inc. total sulphur			Increased maintenance	Nozzle flow and spray pattern	Fuel nozzle coking	decrease	Increased maintenance	Hot and component	Increased	Increased SOx
9.2.3.5	Dec. total sulphur						Increased	Decreased maintenance	Hot and component	Decreased	Reduced Sox
9.2.3.6	Dec. thermal stab			Increased maintenance		Inc. fuel nozzle coking					
9.2.3.6	Inc. Thermal stab			Reduced maintenance		Dec. fuel nozzle coking					
9.2.3.7	Change Fz Pt. Characteristics**										
9.2.3.8	Improve lubricity			Less maintenance	Dec. sticking of fuel nozzle divider valves	Lubrication of moving parts					

*Denotes high proportion of population likely to be

**Denotes sharper transition to solid and larger xtals/filter blocking

OPERATIONAL ISSUES – ALL ENGINE MANUFACTURERS

			COMBUSTION SYSTEM				HOT-END				EMISSIONS
Section	**Fuel Property**	**Limiting***	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**	**Reliability**	**Cost of Ownership**	**Functionality**	**Mechanism**	
9.2.3.8	Reduce lubricity			More maintenance	Inc. sticking of fuel nozzle divider valves	Lubrication of moving parts					
9.2.3.9	Inc. Density			Increased range (same HV assumed)		Higher energy density fuel					Increased due to lower comb
9.2.3.9	Dec. Net. Ht. Comb.			May require component changes	Fuel nozzle max. flow – new nozzles	Insufficient heat at max. flow					Poss. Increase in all emissions

*Denotes high proportion of population likely to be
**Denotes sharper transition to solid and larger xtals/filter blocking

APPENDIX --- Section 14.5 --- Estimate of Ten-Year Cost of Flash Point Change for Jet Fuel

In drafting the Executive Summary of the FTHWG Report (see request at end of this note), the "Ten-Year" Cost of the various Technology Options was estimated. For Flash Point Changes, the attached spreadsheet was constructed to estimate the cost of a Flash Point Change.

The estimate is straightforward based on the annual-cost information in the API/NPRA and EUROPIA Surveys (Sections 14.1 and 14.2). These annual-cost information (basically the Answers to Survey Question 2g) include "incremental operating costs, capital charges and any economic losses through downgrades of changed product slate in cpg over the full volume of jet fuel produced." Therefore the spreadsheet displays the "Ten-Year" Cost for different "annual-cost" cpg numbers. Per the attached request, the "Ten-Year" Cost can be for Jet Fuel Volume with / without a growth rate (ex. is 3.5%).

If, in response to a Flash Point Change from 100F->120F, the Annual-Cost (for 7% ROI) was 2 cpg for U.S. Jet Fuel (with 1.6 Million Barrels/Day) and 8 cpg for Rest-of-World Jet Fuel (with 2.1 Million Barrels/Day) ::

…the no-growth "Ten-Year" Costs are $ 4.9 Billion + $25.8 Billion ➔ $30.7 Billion
(with 3.5% growth ➔ $38.0 Billion)

Different Volumes and cpg numbers can be estimated by simple interpolation/extrapolation of the values in the tables …or … by simple calculation using the selected cpg number and volume for gallons/ ten-years.

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==== Question from Ivor Thomas for "FTHWG Overview Report / Summary" ====
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From: Thomas, Ivor[SMTP:Ivor.Thomas@PSS.Boeing.com]
Sent: Thursday, July 02, 1998 10:21 AM
To: Lieder CA (Chuck) at MSXWHWTC
Subject: Question about "Deltas / Increases" in Cost of Jet Fuel

Chuck, thanks for the input. On another subject: In order to do a cost benefit analysis we are trying to estimate the US and World fleet cost to implement the various solutions over a ten year duration. This would include cost of design and installation and running costs for ten years. We haven't got enough to time worry implementation schedules. If I look at the 120 Flash Fuel, can you project out a ten year cost to the airlines. Oren did a quick look which assumed a straight $.02/gal (US) and $.08/gal (Rest of the World) and a 3.5% pa growth rate. This comes to $4.6B for US and $12.4B for Rest of the World. Is there any logic to assume the $.02/gal would come down over time as the refineries use the added capability to make more profit on other components and as the cost gets lost in the overall price Competition.

...from Ivor Thomas
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Some Cost Estimation of Jet Fuel SCENARIOs

….Assumptions….	MB/D	Gallons/D	Gallons/Yr
U.S. Jet Fuel Use	1.60E+06	6.72E+07	2.45E+10
Rest-of-World Use	2.10E+06	8.82E+07	3.22E+10

Quickie Results….	DELTA CO$T "Summary"	...with Vol Increase	...No Vol Increase
	if US => 2 cpg ; WorldWide => 8 cpg	$35,968,451,430	$30,660,000,000
	if US => 2 cpg ; WorldWide => 5 cpg	$24,638,389,230	$21,002,100,000
	if US => 3 cpg ; WorldWide => 8 cpg	$38,845,927,545	$33,112,800,000

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U.S. Jet Fuel Use	Volume Increase from ZERO Year	Delta CO$T =	1 cpg	2 cpg	3 cpg	4 cpg	6 cpg
Year ZERO	0		$245,280,000	$490,560,000	$735,840,000	$981,120,000	$1,471,680,000
ONE	3.5		$253,864,800	$507,729,600	$761,594,400	$1,015,459,200	$1,523,188,800
TWO	7.1		$262,750,068	$525,500,136	$788,250,204	$1,051,000,272	$1,576,500,408
THREE	10.9		$271,946,320	$543,892,641	$815,838,961	$1,087,785,282	$1,631,677,922
FOUR	14.8		$281,464,442	$562,928,883	$844,393,325	$1,125,857,766	$1,688,786,650
FIVE	18.8		$291,315,697	$582,631,394	$873,947,091	$1,165,262,788	$1,747,894,182
SIX	22.9		$301,511,746	$603,023,493	$904,535,239	$1,206,046,986	$1,809,070,479
SEVEN	27.2		$312,064,658	$624,129,315	$936,193,973	$1,248,258,630	$1,872,387,945
EIGHT	31.7		$322,986,921	$645,973,841	$968,960,762	$1,291,947,682	$1,937,921,524
NINE	36.3		$334,291,463	$668,582,926	$1,002,874,388	$1,337,165,851	$2,005,748,777
=TOTAL=		=TOTAL=	$2,877,476,114	$5,754,952,229	$8,632,428,343	$11,509,904,458	$17,264,856,687
	TOTAL...if no Growth --->		$2,452,800,000	$4,905,600,000	$7,358,400,000	$9,811,200,000	$14,716,800,000

Rest-of-World Use	Volume Increase from ZERO Year	Delta CO$T =	3cpg	5 cpg	8 cpg	10 cpg	15 cpg
Year ZERO	0		$965,790,000	$1,609,650,000	$2,575,440,000	$3,219,300,000	$4,828,950,000
ONE	3.5		$999,592,650	$1,665,987,750	$2,665,580,400	$3,331,975,500	$4,997,963,250
TWO	7.1		$1,034,578,393	$1,724,297,321	$2,758,875,714	$3,448,594,643	$5,172,891,964
THREE	10.9		$1,070,788,636	$1,784,647,727	$2,855,436,364	$3,569,295,455	$5,353,943,182
FOUR	14.8		$1,108,266,239	$1,847,110,398	$2,955,376,637	$3,694,220,796	$5,541,331,194
FIVE	18.8		$1,147,055,557	$1,911,759,262	$3,058,814,819	$3,823,518,524	$5,735,277,786
SIX	22.9		$1,187,202,502	$1,978,670,836	$3,165,873,338	$3,957,341,672	$5,936,012,508
SEVEN	27.2		$1,228,754,589	$2,047,924,315	$3,276,678,904	$4,095,848,631	$6,143,772,946
EIGHT	31.7		$1,271,761,000	$2,119,601,666	$3,391,362,666	$4,239,203,333	$6,358,804,999
NINE	36.3		$1,316,272,635	$2,193,787,725	$3,510,060,359	$4,387,575,449	$6,581,363,174
=TOTAL=		=TOTAL=	$11,330,062,201	$18,883,437,001	$30,213,499,202	$37,766,874,002	$56,650,311,003
	TOTAL...if no Growth --->		$9,657,900,000	$16,096,500,000	$25,754,400,000	$32,193,000,000	$48,289,500,000

	Scenarios for Estimates =>	U.S. +1 / W +3cpg	U.S. +2 / W +5cpg	U.S. +3 / W +8cpg	U.S. +4 / W +10cpg	U.S. +6 / W +15cpg
= WorldWide TOTAL =	**= WorldWide TOTAL =**	**$14,207,538,315**	**$24,638,389,230**	**$38,845,927,545**	**$49,276,778,460**	**$73,915,167,689**
	TOTAL...if no Growth --->	**$12,110,700,000**	**$21,002,100,000**	**$33,112,800,000**	**$42,004,200,000**	**$63,006,300,000**

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