Oil

An Introduction for New Zealanders

by Ralph D. Samuelson

Ministry of Economic Development
Manatū Ōhanga

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Comments

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Glossary

Note that words in *italics* are defined in the Glossary, Appendix B.

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Acknowledgements

The author owes a special debt to Barrie Wilkinson of East Harbour Management Services, whose initial draft of a 'New Zealand Oil Primer' in 2006 provided the starting point and inspiration for this book. The author is also grateful to the many individuals and organisations that provided information and gave generously of their time to assist with the work reported here. These include Roger Fairclough, Tony Fenwick, David Buckrell, Pene Burton Bell, Richard Cook, Mark Aliprantis, Joanne Canavan, Sarah Price, David Wilkinson, Simon Lawrence, and my colleagues in the Energy Information & Modelling Group at MED, Craig Wadsworth and Trevor Johnson at EECA, Stuart Badger at MoT, Ian Twomey at Hale & Twomey and Linda Guinness of Wordset Enterprises. However, the responsibility for the material in this book, including any errors of fact, interpretation or analysis, remains with the author.

The author is also grateful for the support of MED in the development and publication of this book. However, the views and interpretations presented are those of the author alone and not necessarily those of MED or the New Zealand Government.

Introduction

Oil is New Zealand's largest and arguably most problematic energy source. Policies related to oil have wide impacts, including those on the economy, the environment, consumers, foreign relations, and transport planning. Because of their wide impact, issues related to oil frequently attract great public interest and, sometimes, contentious debate. Yet oil is also a sophisticated business, and to usefully contribute to the dialogue requires a certain level of technological, economic, and institutional knowledge that can appear daunting to the newcomer.

The original concept for this book was to provide a background briefing for policy analysts at *MED* and other New Zealand government agencies who were going to be dealing with oil-related policy issues. However, we at MED quickly realised that the material would also be useful to elected officials, industry leaders, non-governmental organisation leaders, researchers, students, and concerned citizens. Although the potential audience has broadened, the goal remains the same: to provide the needed background, for those who want to better understand the oil-related policy issues facing New Zealand. This book does not attempt to analyse any policy issues, but rather to provide basic information that will be useful to anyone who does.

We at MED believe this publication is unique in providing an introduction to the oil industry from a policy perspective. While most of the material here should be common knowledge to those who have been exposed to oil policy issues for some time, it has not been very accessible to newcomers. By drawing the material together in one place, we hope to make it possible for newcomers to build their knowledge more quickly and with greater confidence.

Although this publication is designed to be read as a freestanding document, it complements the introduction to New Zealand energy provided in the Ministry of Economic Development's *New Zealand's Energy Outlook to 2030*.[1] The author has sought to minimise the overlap between the two publications. As the title implies, *Energy Outlook* focuses on the future outlook for all forms of energy, and the choices that New Zealand faces. *Energy Outlook* Chapter 4 on Climate Change, Chapter 5 on Transport Demand, and Chapter 6 on Oil and Transport Fuel Supply are especially recommended for those interested in oil, and are not duplicated here.

1 Available for download at http://www.med.govt.nz/energy/eo/2006/

Although oil and natural gas are often found together, this publication is limited in scope to oil, and discusses gas only to the extent that it impacts on the oil industry.

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1 The Fundamentals of Oil

Today, practically everyone is aware of the challenges that oil presents to the industrialised world, including rising prices, environmental impacts such as climate change and toxic emissions, risks of supply disruptions, and questions about long-term resource sustainability. Each of these challenges is ultimately framed by the natural characteristics of oil resources and the technology that has helped us to overcome some of oil's natural limitations. This chapter looks at oil's natural characteristics and at oil-related technology, since together they form the basic backdrop against which policies related to oil must be formulated.

Discussions of the oil industry often distinguish between the *upstream* and *downstream* segments, where 'upstream' refers to exploration, drilling, and production and 'downstream' refers to transportation, refining, and marketing. One also sometimes sees references to 'midstream', referring to transportation and processing. These terms make sense if one thinks of the oil industry as a river of oil flowing from oilfields to consumers. This chapter discusses the oil industry in a generally upstream to downstream sequence.

1.1 The Chemistry of Oil

Like coal and natural gas, oil is a *hydrocarbon*; that is, it is made of molecules primarily composed of hydrogen and carbon. In fact, crude oil is a mixture of hydrocarbon molecules of various sizes and shapes. The composition of the mixture varies widely from field to field, and will affect the cost and difficulty of both the production technology that must be used to extract the oil and the refining technology that must be used to turn it into products.

There is a natural order to hydrocarbon molecules from small to large, which as we shall see, also corresponds to *light* to *heavy*. The smallest hydrocarbon molecule is that of methane, CH_4, which is the principle component of natural gas. It has one carbon atom, and looks like this:

```
    H
    |
H – C – H
    |
    H
```

The next smallest hydrocarbon is ethane, C_2H_6 with two carbon atoms. It looks like this:

```
   H   H
   |   |
H–C– C–H
   |   |
   H– H
```

Make it a chain of three carbons and we get propane, C_3H_8:

```
   H   H   H
   |   |   |
H–C– C– C–H
   |   |   |
   H   H   H
```

In fact, we can keep adding carbons to get a variety of compounds, as shown in Table 1 opposite. Motor petrol is a mixture primarily of molecules with five to 12 carbons.[2] As the number of carbons increases, the molecular structure can get more complicated. Possible arrangements other than straight chains arise in these larger molecules, including side branches and rings. In fact, there are around 300,000 natural hydrocarbon compounds.[3] But we won't be discussing them here.

There are several interesting patterns in Table 1 worth noting. First, as the number of carbon atoms increases, the state of the compound goes from gas to liquid to semi-solid or solid. At the same time, the boiling points and melting points tend to rise. And perhaps most obviously, the molecules get bigger, resulting in the product getting denser. This brings us to the most basic method of classification of hydrocarbons, by what is casually called their 'weight', or, more accurately, their density. The smaller molecules are known as 'light' hydrocarbons, while the larger molecules are known as 'heavy' hydrocarbons.

Engineers in the oil industry could measure the density of hydrocarbons using specific gravity, which is simply the weight of some volume of the compound divided by the weight of an equal volume of water (or, equivalently, number of kilograms per litre). Indeed, in New Zealand and other metric countries, this is how the densities

2 See Charles E. Ophardt, *Elmhurst College Virtual Chembook,* 2003, "What Is Gasoline?" page, , http://www.elmhurst.edu/~chm/vchembook/514gasoline.html.

3 See the 'hydrocarbons" page of the Oppenheimer Technology website http://www.obio.com/hydrocarbon%20chains.htm

TABLE 1 HYDROCARBONS[4]

Compound	Carbons	Formula	Boiling Point °C	Melting Point °C	Normal State	Specific Gravity (Density)	API Gravity
Methane	C1	CH_4	-161	-182.5	Gas		
Ethane	C2	C_2H_6	-88	-183.3	Gas		
Propane	C3	C_3H_8	-46	-189.7	Gas	0.51	146°
Butane	C4	C_4H_{10}	-1	-138.4	Gas	0.58	112°
Pentane	C5	C_5H_{12}	36.1	-129.7	Liquid	0.626	95°
Hexane	C6	C_6H_{14}	68.7	-95.3	Liquid	0.658	84°
Heptane	C7	C_7H_{16}	98.4	-90.6	Liquid	0.682	76°
Octane	C8	C_8H_{18}	125.7	-56.8	Liquid	0.702	70°
Nonane	C9	C_9H_{20}	150.8	-53.5	Liquid	0.717	66°
Decane	C10	$C_{10}H_{22}$	174.1	-29.7	Liquid	0.728	63°
Kerosene	C12–C16		200–300		Liquid	0.79	47°
Distillate Fuel	C15–C18		Up to 360		Liquid	0.82	41°
Lubricating Oils	C16–C20		350 up		Liquid	0.89	27°
Residual Fuel Oil and Grease	C20 & up				Semisolid	0.93	21°
Pitch and Tar	C26 & up				Residue	1.2	-14°
Petroleum Coke	C26 & up				Residue	1.35	-27°

4 Except as noted, all data is from the table "Hydrocarbon Chains" on the iSOC© Technology website http://www.isocinfo.com/DocumentRoot/10/Hydrocarbon_Chains.pdf. Upper cut point for kerosene changed from 315 to 300 degrees based on statement in Roy J. Irwin et al, *Environmental Contaminants Encyclopedia; Kerosene Entry*, National Park Service, Washington, DC, July 1997, http://www.nature.nps.gov/hazardssafety/toxic/kerosene.pdf, p. 25 (of PDF file) that "The final boiling point specification [for straight-run kerosene] was raised to 300 degrees C in the early 1980s". Upper cut point for distillate fuel changed from 375 to 360 degrees based on Ministry of Economic Development, *Petroleum Products Specifications Regulations 2002*, July 2002, http://www.med.govt.nz/templates/MultipageDocumentPage____10182.aspx#P560_21331, which shows the 'Distillation – 95% volume recovered at (°C) (T95) point' for diesel fuel in New Zealand as 360°C. Density figures for propane, butane, pitch and tar, and petroleum coke are from Nathaniel B. Guyol, *Energy Interrelationships; a Handbook of Tables and Conversion Factors for Combining and Comparing International Energy Data*, Federal Energy Administration, Washington, DC, 1977, Table 15. Figures are 'norm' values. Density figures for hexane, heptane, octane, and nonane are from the Engineers Edge website, 'fluid characteristics' page, http://www.engineersedge.com/fluid_flow/fluid_data.htm, based on a temperature of 20° C. Density figure for decane is from the SImetric.co.nz website, 'Specific Gravity of Liquids' page, http://www.simetric.co.uk/si_liquids.htm, based on a temperature of 25°C. Density figures for kerosene, distillate fuel, lubricating oil, and residual fuel oil and grease are from Mieke Reece, *Special Issue Paper 9*; *Densities of Oil Products*, Energy Statistics Working Group Meeting, IEA, Paris, November 2004, http://www.iea.org/Textbase/work/2004/eswg/SIP9.pdf, table of 'Country Specific Information', column for New Zealand. Distillate fuel figure shown is for 'Gas/diesel oil', residual figure fuel shown is for 'Fuel Oil (Incl. Bunker fuel)'. API gravity figures are calculated from the corresponding density figures using the formula given in this section.

of oil products are generally measured.[5] But in the United States, and for crude oil worldwide, that would be too easy. In these cases, engineers generally use the American Petroleum Institute (API) Gravity scale, which for some obscure reason uses a unit of degrees, and is defined to be:

$$°API = \frac{141.5}{\text{specific gravity}} - 131.5.^{6}$$

API Gravity is the first of several odd American measurements we will be encountering in this book. The formula implies that water has an API gravity of 10° and that as the product gets lighter, the API gravity increases. Since most oil and oil products are lighter than water, they have an API gravity greater than 10°.

There is one more important trend to note in Table 1. The third column shows that as the number of carbon atoms increase, the ratio of hydrogen atoms to carbon atoms tends to decrease from 4:1 to around 2:1. Since the carbon atoms oxidise into carbon dioxide when they burn, while the hydrogen atoms oxidise into water vapour, this explains why heavier fuels tend to have higher emissions of carbon dioxide per unit of energy than lighter fuels. The third column stops after C_{10} because there are many alternative molecular structures for these larger molecules, but the trend to lower hydrogen to carbon ratios continues. The heavier hydrocarbons tend to contain ring structures, with hydrogen to carbon ratios closer to 1:1. Coal, the heaviest of the hydrocarbons, contains lots of these rings, and may have a ratio of hydrogen to carbon in the 1.2 to 1.0 range.[7]

Since the composition of crude oil varies greatly from field to field, the price of crude oil also varies from field to field and thus (contrary to the impression one would get from reading most newspapers) there is no single 'price of oil'. 'Light' crude oil (API gravity greater than 33°[8]) is the most valuable, since it contains more of the light hydrocarbons. These light hydrocarbons can be blended directly into liquid fuels. 'Heavy' crude oil (API gravity less than 28°) is less valuable, since it contains more heavy hydrocarbons that must be further processed to produce compounds useful as liquid fuels (see Section 1.5).

5 Thanks to Ian Twomey for pointing this out to the author.

6 See William L. Leffler, *Petroleum Refining in Nontechnical Language, Third Edition*, PennWell Books, Tulsa, Oklahoma, 2000, p. 15.

7 Many thanks to Stephen Goldthorpe, Energy Consultant, for helping me with this hydrocarbon chemistry.

8 There appears to be no uniformly accepted definition of 'light' and 'heavy' crude. These definitions are from Platts, a leading provider of energy market information. See http://www.emis.platts.com/thezone/guides/platts/oil/glossary.html#l.

Crude oil also can contain various impurities, which must be removed. Clearly, the less pure the oil is, the lower the value of the oil. The most common impurity is sulphur, which is often chemically bonded to the hydrocarbons so it is not easily removed. *Sweet crude* is low in sulphur (generally less than 1% by weight)[9], while *sour crude* is high in sulphur. These terms developed in the early days of the oil industry, when people used to actually taste the oil to determine if it had too much sulphur.[10]

1.2 Oil Products

Oil is important to us because there are so many useful products that can be made from it. Each product has properties which make it useful for certain applications, and which determine how it must be processed, distributed, and consumed.

Due to its high energy density, convenient liquid form, and historically low cost, oil has a special role as a transport fuel. In New Zealand, 86% of oil is used in the transport sector and oil products provide 99% of transport energy.[11]

Natural Gas – Natural gas is not an oil product. However, since it is the lightest of the hydrocarbon fuels and often found in association with oil, it is a good place to begin a discussion of oil products. The natural gas used by consumers is generally well over 90% methane (C1, see Table 1), with smaller amounts of ethane (C2) and other hydrocarbon and non-hydrocarbon gases.[12]

Natural gas is commonly used in New Zealand as an electricity generation fuel, in home and commercial heating appliances, and as a heat source in various industrial processes. It is also used to make methanol (a feedstock to the chemical industry) and urea (primarily used for fertiliser).[13] Compressed natural gas (CNG) was a significant transport fuel in New Zealand in the 1980s, but this use has declined to negligible levels since government subsidies were removed in 1987.[14]

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9 See definition of sweet crude in http://www.businessdictionary.com/definition/sweet-crude.html.

10 See William L. Leffler, *Petroleum Refining in Non-Technical Language, Third Edition*, PennWell Books, Tulsa, Oklahoma, 2000, p. 17.

11 See Ministry of Economic Development, *New Zealand's Energy Outlook to 2030; Final Publication,* September 2006, http://www.med.govt.nz/energy/eo/2006/, p. 48.

12 See the statistics on average U.S. natural gas composition in slide 6 of William E. Liss and David M. Rue, Natural Gas Composition and Quality, Gas Technology Institute, 2005 at http://www.energy.ca.gov/2005_energypolicy/documents/2005-02-17+18_workshop/presentations/GTI_rue_liss_pan_1_2005.ppt#1. There appear to be no comparable statistics available on average composition of consumer natural gas in New Zealand.

13 See Ministry of Economic Development, *New Zealand's Energy Outlook to 2030; Final Publication,* September 2006, http://www.med.govt.nz/energy/eo/2006/, Section 10.3.

14 See Ministry of Economic Development, *New Zealand Energy Data File*, June 2007, http://www.med.govt.nz/energy/edf/2007/, p. 71 and Table E.6.

Methane and ethane are gases, and like to stay that way. In fact, no amount of pressure can liquefy them at ordinary temperatures.[15] Consequently, natural gas must typically be transported and distributed in gaseous form by pipeline. However, methane may be liquefied by super cooling it to around –161°C to produce *liquefied natural gas (LNG)*. LNG occupies about one six-hundredth the volume of the gas, allowing it to be conveniently transported in special insulated tanker ships.[16] LNG has thus allowed an intercontinental trade in natural gas to develop. New Zealand currently has no LNG facilities.

Liquefied Petroleum Gas (LPG) – LPG is typically a mixture of propane (C3), butane (C4), and isobutane (which has the same chemical formula as butane, but has one of its carbon atoms on a side branch), but may sometimes consist of pure propane.[17] In New Zealand, LPG is generally extracted from raw natural gas,[18] but it may also be produced from oil in a refinery.[19] LPG is a gas, but will readily liquefy under pressure at ordinary temperatures. It can therefore be transported and marketed in liquid form in simple pressurised containers. LPG should not be confused with LNG, discussed above.

LPG in New Zealand is commonly used in home and commercial heating appliances, as a heat source in various industrial processes, and as a fuel for forklift trucks.[20] As with CNG, LPG went through something of a boom and bust as a vehicle fuel in the 1980s, but still powers about 10,000 vehicles.[21] Because it can be delivered in pressurised containers, LPG is a convenient alternative to natural gas in rural areas and cities not served by the natural gas distribution network. LPG is also reticulated by pipeline to some areas of the South Island.[22]

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15 See the discussion of "Chemistry of Natural Gas" in George A. Burrell, et al, *The Condensation of Gasoline from Natural Gas,* U.S. Department of the Interior, Bureau of Mines, Bulletin 88 Petroleum Technology 20, 1915, http://www.distillationgroup.com/distillation/H001/H001.htm, p. 26.

16 See the California Energy Commission "Frequently Asked Questions About LNG" web page, http://www.energy.ca.gov/lng/faq.html.

17 See the "How Liquefied Petroleum Gas Works" page on the "How Stuff Works" website http://auto.howstuffworks.com/lpg1.htm.

18 See the LPG Association of New Zealand "About LPG" web page, http://www.lpga.org.nz/info.php.

19 See the "How Liquefied Petroleum Gas Works" page on the "How Stuff Works" website http://auto.howstuffworks.com/lpg2.htm. Thanks to Ian Twomey for pointing out the propane is frequently sold as LPG in New Zealand.

20 See the Statistics New Zealand *Manufacturing Energy Use Survey* web page http://www.stats.govt.nz/products-and-services/hot-off-the-press/manufacturing-energy-use-survey/manufacturing-energy-use-survey-yemar06-hotp.htm?page=para003Master.

21 See the LPG Association of New Zealand home page http://www.lpga.org.nz/.

22 See Ministry for the Environment, *Warm Homes Technical Report; Detailed Study of Heating Options in New Zealand,* http://www.mfe.govt.nz/publications/energy/warm-homes-heating-options-phase1-nov05/html/page4a.html.

Petrol – Motor petrol is a mixture of hydrocarbons in the C5 to C12 range.[23] It is also known as gasoline, especially in North America, where the word is often confusingly shortened to 'gas' in casual usage. In fact, petrol is a liquid, but it does need to vaporise easily, since in a petrol engine the fuel is vaporised and mixed with air (either by a carburettor or fuel injector) before it is ignited.

Petrol generally comes in two grades: regular and premium. Contrary to popular belief, premium petrol does not contain significantly more energy than regular petrol. In fact, the major difference between the two is that premium petrol is harder to ignite. This is because in a petrol engine, the combustion of the air and petrol vapour mix is supposed to spread smoothly though the cylinder following ignition by the spark plug. However, as the mix gets compressed when the piston reaches the top of its cycle, it heats-up, much like the air in a bicycle pump. If the fuel ignites too easily, this *heat of compression* will cause the mix to ignite prematurely in some parts of the cylinder. The result will be pressure waves that reverberate through the cylinder, known as engine 'knock' or 'ping'. Engine knock causes an annoying noise, reduces the engine's power, and can cause damage to the engine.

Premium petrol is formulated to be less prone to knocking. *Octane* is a measure of how resistant a fuel is to knocking: the higher the octane the more resistant the fuel is to knocking. Since high-performance engines are designed to compress the air and petrol vapour mixture more (that is, they have a higher *compression ratio*), they have a greater tendency to knock and are more likely to need premium fuel.[24] However, many consumers waste money buying premium fuel: if their engine does not knock on regular petrol, premium petrol will not noticeably improve their engine's performance.[25]

Adding further to the confusion about grades of petrol is the fact that there are two accepted methods of measuring octane, the Research Octane Number (RON) and the Motor Octane Number (MON). MON is determined under a more stressful test, and tends to be 8 to 10 points lower than RON. In New Zealand, and most other countries, the posted octane is usually RON. However, in the United States, regulations require the posted octane to be an average of RON and MON. Hence, in the United States,

23 See Charles E. Ophardt, *Elmhurst College Virtual Chembook*, 2003, "What Is Gasoline?" page, http://www.elmhurst.edu/~chm/vchembook/514gasoline.html.

24 See the discussion of engine knocking and octane numbers in William L. Leffler, *Petroleum Refining in Non-Technical Language, Third Edition*, PennWell Books, Tulsa, Oklahoma, 2000, pp. 134-139.

25 See the U.S. Federal Trade Commission *The Low Down on High Octane Gasoline* web page http://www.ftc.gov/bcp/edu/pubs/consumer/autos/aut12.shtm.

posted octane ratings run 4 or 5 points lower than they would be for the same fuel elsewhere.[26]

Jet Fuel – Jet fuel is generally a kerosene-type fuel composed of hydrocarbons in the C8 to C16 range.[27] It is a liquid, and it needs to stay that way, even at the extremely low temperatures encountered at high altitudes. This requirement has been a major obstacle so far to powering jet aircraft with biofuels (see Section 2.5.2), since today's biofuels tend to solidify at low temperatures.[28]

Diesel Fuel – Diesel fuel is a middle distillate, generally a bit heavier than jet fuel (C14 to C20[29]). Diesel engines have no spark plugs, and rely on heat of compression (discussed under Petrol above) to ignite the fuel when it is injected after the air in the cylinder is compressed by the piston. That is what makes diesel engines different from petrol engines. They, therefore, need a fuel that self-ignites easily—the very opposite of what a petrol engine needs. One measure of the quality of diesel fuel is its cetane number. Cetane is very much the opposite of octane: the higher the number the more easily the fuel self-ignites.[30]

Furnace Oil – Also known as number 2 oil or heating oil, it is essentially the same thing as diesel fuel—in fact, it often is the same thing.[31] It is commonly used for heating homes and businesses in many parts of the world; however, its use is practically unknown in New Zealand.[32]

Residual Fuel Oil – Residual fuel oil comes in several grades, often identified as fuel oil numbers 4 through 6.[33] These products are blends containing a large amount

26 See Ministry of Economic Development, *Resource Document (a detailed discussion of the Petroleum Products Specifications Regulations 1998 and the context in which they exist)*, August 2001, Section 7.1 "Octane Number", http://www.med.govt.nz/templates/MultipageDocumentPage____10301.aspx#P1396_141578. See also the Wikipedia article, *Octane Rating*, http://en.wikipedia.org/wiki/Octane_rating.

27 See the Wikipedia article *Jet Fuel*, http://en.wikipedia.org/wiki/Jet_fuel.

28 For a discussion of these and other issues related to bio jet fuel, see the *Aviation Week* article "Alternative Fuels for Jet Engines", September 17, 2007, http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=bca&id=news/bca0907p3.xml.

29 See The Institute of Petroleum *Coryton Refinery – Refining Process* web page, Figure 14, http://www.energyinst.org.uk/education/coryton/images/column.gif.

30 See William L. Leffler, *Petroleum Refining in Nontechnical Language, Third Edition*, PennWell Books, Tulsa, Oklahoma, 2000, pp. 154-155.

31 See William L. Leffler, *Petroleum Refining in Nontechnical Language, Third Edition*, PennWell Books, Tulsa, Oklahoma, 2000, pp. 153.

32 See *Statistics New Zealand Census of Population and Dwellings 2002* data table on home heating type at http://www2.stats.govt.nz/domino/external/web/prod_serv.nsf/092edeb76ed5aa6bcc256afe0081d84e/5605ab881ace7506cc256bc5007c97eb?OpenDocument.

33 See the chart of fuel oils in William L. Leffler, *Petroleum Refining in Nontechnical Language, Third Edition*, PennWell Books, Tulsa, Oklahoma, 2000, pp. 157.

of residue, the stuff that is left at the bottom of the distillation tower (see Figure 2). Often shortened to 'resid', residual fuel oil is really heavy stuff, in the C20 and up range. Residue and some residual fuel oils are so thick they have to be heated before they can be pumped through a pipeline. Although it can be difficult to handle, residual fuel oil is generally the cheapest of the oil-based fuels because residue is the least desirable component of crude oil.[34] Residual fuel oil was, and still is in some parts of the world, popular as an industrial boiler fuel. However, the market for residual fuel oil went through a sharp decline worldwide after the oil price shocks of the 1970s, since it is generally easy to switch to coal or gas for boiler fuel.[35] In New Zealand its use has also declined, and today it probably accounts for less than 3% of New Zealand's domestic oil product consumption.[36]

Residual fuel oil is also used in special heavy duty diesel engines that power large ships and, in some countries, electricity generators.[37] However, New Zealand's only remaining oil-fired power station, Whirinaki, has gas turbine engines and runs on diesel fuel.[38]

That covers the major oil-based fuels. To these we must add some significant non-fuel products derived from oil, including tar and bitumen used for roads and buildings, lubricating oils, plastics, waxes, and a wide variety of chemicals.

1.3 The Geology of Oil[39]

New Zealand's oil and gas generally has a different geological origin from oil and gas in other parts of the world. To start with, most of the world's oil and gas is derived

34 See William L. Leffler, *Petroleum Refining in Nontechnical Language, Third Edition*, PennWell Books, Tulsa, Oklahoma, 2000, pp. 157 and 165.

35 See Francisco Parra, *Oil Politics; A Modern History of Petroleum*, I.B. Tauris, London, 2004, pp. 243.

36 See Ministry of Economic Development, *New Zealand Energy Data File, January 2007*, http://www.med.govt.nz/energy/edf/2007/, Table D.12 shows 8.69 PJs of consumer energy from fuel oil (light and heavy combined) in 2006, while Table D.5 shows 259.37 PJs of consumer energy from all oil products total.

37 See William L. Leffler, *Petroleum Refining in Nontechnical Language, Third Edition*, PennWell Books, Tulsa, Oklahoma, 2000, pp. 166-167,

38 See the Whirinaki electricity generation plant case study brochure on the website of Power Measurement Ltd. http://www.pwrm.com/library/literature/case_studies_and_articles/Contact_Energy_Case_Study.pdf.

39 The discussion of the usual story in this section is drawn from Charles F. Conway, *The Petroleum Industry; A Nontechnical Guide*, PennWell Publishing, Tulsa, Oklahoma, 1999, chapters 1-3 and Norman J. Hyne, *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production*, Penn Well Publishing, Tulsa, Oklahoma, 2001, chapters 11,12, and 14. The discussion of the New Zealand story is based on discussions with Dr. Richard Cook, Chief Petroleum Geologist, Ministry of Economic Development and the Ministry of Economic Development publication *New Zealand's Petroleum Basins*, 2004, http://www.crownminerals.govt.nz/cms/petroleum/publications/#nz-petroleum-basins, pp. 4-5.

from microscopic plants in the ocean, such as plankton and algae. In New Zealand, however, most oil and gas is derived from the remains of lowland forests. The conversion processes that produced the oil and gas are quite different as well. This section starts by looking at the more usual story, then looks at how the situation in New Zealand differs.

In the usual story, oil and gas begins with microscopic ocean plant material that settles to the bottom of the ocean, and gets buried in sediment there. The plant material has to be buried quickly in sediment to prevent bacterial decay, the fate of most dead organic matter.

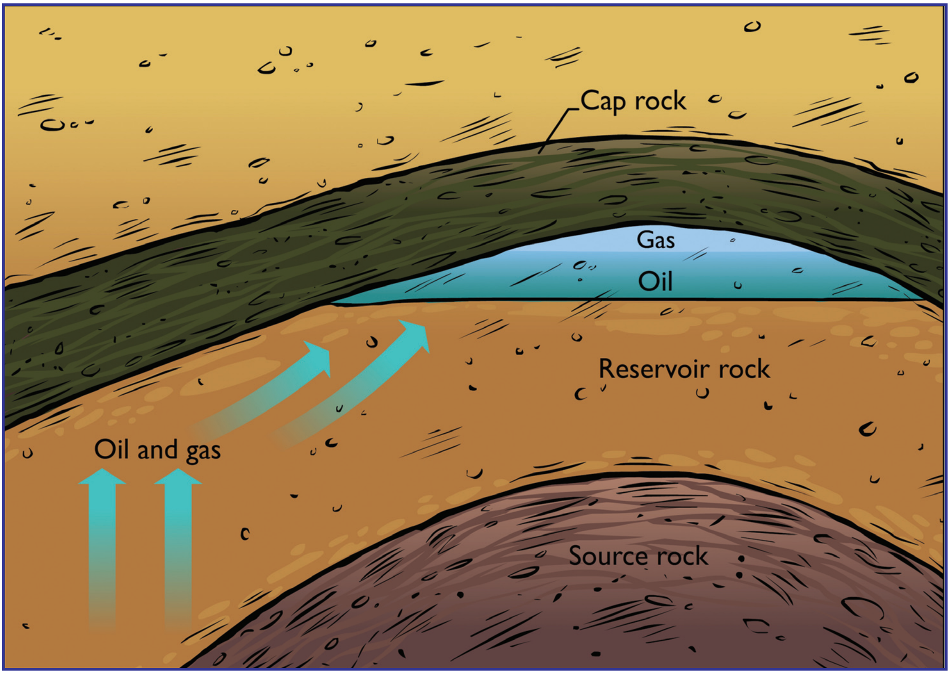
Over many millions of years, more layers of sediment settle on top of the organic material and the sediment in which it is buried, increasing the pressure on it, and causing it to harden into rock, typically shale. As the rock is buried deeper, temperatures rise, causing the organic matter in the rock to be converted to oil or gas. This rock in which oil or gas is formed is known to petroleum geologists as *source rock*. The deeper the organic material is buried, the higher the temperature, and the lighter the oil. This is because the heat tends to 'crack' the oil molecules, as in a refinery (see Section 1.5 below). If source rock that is buried too deeply, all the oil will be converted to gas.

Source rock is normally impermeable. However, the creation of the oil and gas causes a large increase in volume. This volume increase stresses the source rock, causing it to fracture, allowing the oil or gas to escape. The oil or gas is thus released (see Figure 1).

What happens next depends on the nature of the rock above the source rock. Assuming it is *porous* and *permeable*, the oil and gas will *migrate*. Porous rock is composed of granular material with lots of microscopic spaces between the grains that can hold oil. But for the oil to flow, it is not enough for the rock to be porous. The spaces must be linked together, making the rock permeable for the oil. Petroleum geologists devote a great deal of effort to analysing the permeability and porosity of *reservoir rocks*, that is, rocks through which oil and gas could potentially flow.

Since the reservoir rock was originally formed under the ocean, the pores in it will initially be filled with seawater. Since oil and gas is lighter than sea water (oil floats on water), it tends to rise through the reservoir rock. As the oil and gas rises, it eventually either leaks out onto the surface as a gas or oil seep (and is soon lost) or hits a layer of some *impermeable* rock that stops it, known to petroleum geologists as *cap rock*. If the cap rock has any slope to it, the oil will continue to rise along the underside of the slope. Over millions of years, the oil and gas can migrate some distance. Instances

FIGURE 1 MIGRATION OF OIL FROM SOURCE ROCK TO TRAP



where oil has migrated as much as 80 km have been recorded, and gas can move hundreds of kilometres.

If there are places where the cap rock stops rising and starts falling, the oil and gas will tend to accumulate at the highest point in the structure, known as a *trap*. Basically, a trap is like an upside down bowl that prevents the oil and gas from rising any further. There are a number of kinds of traps; they are what petroleum geologists look for.

In New Zealand, the oil and gas story more commonly begins in lowland forests on coastal plains adjacent to the ocean. These were areas that might be casually referred to as 'bogs' or 'swamps', since the land under them is saturated with water. Dead plant material in these forests falls into the water-logged soil. Because the soil is low in oxygen, the plant material does not decay. Over an extended period of time, this vegetable matter may build up into a layer tens of metres thick.

However, over geological time, things change. Movements of the earth's crust (*tectonics*) may or may not cause the land to sink under the ocean. In any case, the land somehow ceases to be a forest, and other types of sediment can now accumulate on top of the layer of vegetable matter. As the sediment accumulates, the resulting pressure and heat on the vegetable matter cause it to be converted to coal.

This coal is, however, a bit different from most of the coal found in other parts of the world. The New Zealand coal is geologically much younger—'only' about 50–150 million years old compared to 280 to 360 million years old elsewhere—and thus originates from more highly-evolved plants. Because of the different chemical composition of these plants, the coal contains a waxy oil, as well as gas. So instead of marine rock, it is this coal that becomes the source rock for much of New Zealand's oil.

The coal is slightly permeable. The oil and gas therefore does not need to fracture the coal to escape from it; it can just very slowly (over geological time) soak through it and enter the reservoir rock above. Even if the reservoir rock was not originally formed under the ocean, its pores will still be filled with seawater since the rock is permeable and below sea level. The oil can thus rise through the reservoir rock. From here, the story is similar to the rest of the world: the oil and gas migrates through the reservoir rock and may eventually accumulate in a trap.

Petroleum geologists today most commonly seek out traps using *seismic surveys*. These involve generating some intense sound on the earth's surface, such as with a small explosion. By capturing the reflected sound waves from the rocks below and analysing them with computers, it is possible to plot out a quite accurate picture of the rock layers. There are even seismic techniques that can detect the presence of gas-filled porous rocks. But the only way to find out for sure just what is down there is to drill.

1.4 Oil Production

Let us suppose you have now drilled into a new structure. Where is the oil and gas? The odds are good you will not find any at all. Most *wildcat* (or *exploration*) wells, that is, wells drilled in hopes of finding a new oil or gas field, do not find marketable quantities of oil or gas.[40] That is a big risk for oil producers. But if you do find oil or gas, it will, of course, be in a trap under the cap rock. Free gas, if any, will tend accumulate above the oil, if any, since gas is lighter than oil. The old seawater that originally filled the pores in the reservoir rock will be on the bottom, since it is heavier than oil.[41]

40 See Charles F. Conway, *The Petroleum Industry; a Nontechnical Guide*, PennWell Publishing, Tulsa, Oklahoma, 1999, Chapter 3, p.41.

41 See Norman J. Hyne, *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production*, PennWell Publishing, Tulsa, Oklahoma, 2001, Chapter 11, p. 154-155.

The bad news here is that an oil and gas *reservoir* is not a big pool, like a water reservoir, that one can just pump out. Rather, the oil and gas is still in the reservoir rock.[42] Fortunately, the oil and gas is under considerable pressure, which will tend to push it through the rock toward the lower pressure of the well. How quickly it flows depends upon many factors. But it will always take time to produce the oil.[43]

As the oil and gas is produced, the pressure in the reservoir tends to dissipate. This causes the flow of oil to slow down, and may allow increasing amounts of water to mix with the oil (the *water cut*).[44] Inevitably, much of the oil is left trapped in the reservoir rock. Although oil production technology is continually improving, the industry typically leaves about two-thirds of the original oil in the ground.[45] Petroleum engineers develop production plans so as to maximise the production, which involves producing the oil in a way that preserves the natural pressure for as long as possible. They may then use *secondary recovery techniques* to help restore the pressure, typically by injecting water into the reservoir.[46] *Tertiary* or *enhanced recovery techniques* may also be used to loosen up the oil, typically with steam, chemicals, or carbon dioxide.[47]

The use of carbon dioxide for this purpose is of special interest, since it provides an inadvertent demonstration of the potential for *carbon capture and storage* to mitigate greenhouse gas emissions. The carbon dioxide used today for tertiary recovery is found in underground reservoirs, often mixed with natural gas, from which it must be separated before the gas can be sold.[48] However, in the future, it could be extracted from the flue gases of power plants and other fuel-burning facilities.[49]

42 See Charles F. Conway, *The Petroleum Industry; a Nontechnical Guide*, PennWell Publishing, Tulsa, Oklahoma, 1999, Chapter 2, p.24-25.

43 See Martin Raymond and William Leffler, *Oil and Gas Production in Nontechnical Language,* PennWell Publishing, Tulsa, Oklahoma, 2006, Chapter 8, pp. 163-165

44 See Martin Raymond and William Leffler, *Oil and Gas Production in Nontechnical Language,* PennWell Publishing, Tulsa, Oklahoma, 2006, Chapter 8, pp. 167-168.

45 For a discussion of this issue, see Institut Français de Pétrole 'Pushing back the boundaries in oil and gas production' web page, http://www.ifp.com/axes-de-recherche/reserves-prolongees/repousser-les-limites-de-l-exploration. See also Norman J. Hyne, *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production,* PennWell Publishing, Tulsa, Oklahoma, 2001, Table 26-1, p. 432.

46 See Martin Raymond and William Leffler, *Oil and Gas Production in Nontechnical Language,* PennWell Publishing, Tulsa, Oklahoma, 2006, Chapter 8, pp. 167-181.

47 See Martin Raymond and William Leffler, *Oil and Gas Production in Nontechnical Language,* PennWell Publishing, Tulsa, Oklahoma, 2006, Chapter 8, pp. 181-186.

48 See Charles F. Conway, *The Petroleum Industry; a Nontechnical Guide*, PennWell Publishing, Tulsa, Oklahoma, 1999, Chapter 2, p.88 and Chapter 12, p. 225.

49 See the World Coal Institute website page on Carbon Sequestration, http://www.worldcoal.org/pages/content/index.asp?PageID=414.

Oil typically has some natural gas dissolved in it when it first comes out of the ground. In producing oil, as the oil reaches the lower pressures and temperatures on the surface, the gas bubbles out of it much the way it does in a fizzy drink.[50] This gas may be recovered and sold if the oil field is located near a gas pipeline. If not, the gas may be *reinjected* to help keep up the pressure in the reservoir. In the past, this gas was often simply burned-off (*flared*). Like many countries,[51] New Zealand today does not permit flaring except under exceptional circumstances, such as mechanical breakdowns or the initial set-up and testing of a new well.[52]

On the other hand, in producing natural gas, the gas typically comes out of the ground containing the vapours of various liquid hydrocarbons. These include propane, butane, and a light crude oil-like liquid known as *condensate*. In New Zealand, some condensate is sold separately as 'naphtha', and reported separately from condensate in MED's statistics. All these *natural gas liquids* may be separated from the gas in *gas processing plant* and sold separately. Indeed, it is usually necessary to separate the liquids, since if this is not done, they will tend to condense out in high pressure gas pipelines and cause operational difficulties. But since the liquids tend to be quite valuable, gas producers usually want to recover the liquids in any case.[53] *Wet gas* is gas with a high liquids content.[54] The raw gas as it comes out of the ground may also be mixed with carbon dioxide, which generally also needs to be removed by the gas processing plant. New Zealand's Kapuni gas, for example, is around 42% carbon dioxide.[55]

Analysing quantities of oil can sometimes be confusing as there are two standards of measurement for oil and oil products in international commerce. Oil in the United States is generally measured in a rather strange unit: *barrels* (or *bbl*) of 42 US gallons, or almost exactly 159 litres. The origins of this measure are rather obscure, but two Internet history sites report that in the early days of the U.S. oil industry, oil actually was shipped and sold in barrels of varying sizes. Eventually, the industry standardised

50 See Norman J. Hyne, *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production,* PennWell Publishing, Tulsa, Oklahoma, 2001, Chapter 25, pp. 432

51 See Norman J. Hyne, *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production,* PennWell Publishing, Tulsa, Oklahoma, 2001, Chapter 25, pp. 426.

52 See Crown Minerals, *Minerals Programme for Petroleum,* 1 January 2005, http://www.crownminerals.govt.nz/cms/pdf-library/petroleum-publications-1/mins-prog-for-petroleum-2005.pdf, Section 6.1.

53 See Norman J. Hyne, *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production,* PennWell Publishing, Tulsa, Oklahoma, 2001, Chapter 1, pp. 11-12 and Chapter 21, pp. 368-369.

54 See Martin Raymond and William Leffler, *Oil and Gas Production in Nontechnical Language,* PennWell Publishing, Tulsa, Oklahoma, 2006, Chapter 3, pp. 61.

55 See Ministry of Economic Development, *New Zealand Energy Greenhouse Gas Emissions 1990-2006,* http://www.med.govt.nz/energy/ghg/2007/, p. 23

on the 42 gallon barrel as a unit of measure.[56] In Europe, oil was generally transported in seagoing vessels, so weight (displacement) in *metric tonnes* (or *t*) became the standard for commerce.[57] To add to the confusion, there is no standard conversion factor between barrels and tonnes. As we have seen, crude oil and oil products vary in density, so the conversion depends upon the type of crude oil or oil product. The *BP Statistical Review of World Energy* puts the worldwide average conversion factor for crude oil at 7.33 barrels/tonne.[58]

1.5 Oil Refineries[59]

So now that we have produced the oil, how do we transform it into oil products that people can use? Recall that crude oil is a broad-ranging mixture of hydrocarbons. The oil products that people can use each consist of a much more narrow range of hydrocarbons. How can we separate the various hydrocarbons? Table 1 gives a hint as to the answer: the different boiling points of the different compounds.

One way to separate hydrocarbons would be to use something akin to a moonshiner's still. We could, say, heat the oil to the boiling point of pentane (36.1° C), capture the vapours, and then condense them to obtain molecules that have predominately five carbons. Then we could heat the oil further to the boiling point of hexane (68.7° C), capture the vapours, and condense them to obtain molecules that have predominately six carbons. The word "predominantly" is used here, since crude oil contains many compounds other than those listed in Table 1 (recall that there are 300,000 hydrocarbons), each with a different boiling point. Also, we will never be able to achieve a perfectly uniform temperature in our still, so there will always be some molecules that vaporise too early or too late. However, subject to these imperfections, we could continue this process of raising the temperature and capturing the resulting vapours to obtain each heavier *fraction* of the oil.

The moonshiner's still approach would work, but it is not very efficient. The way the separation is done commercially is to boil the crude oil at a high temperature and

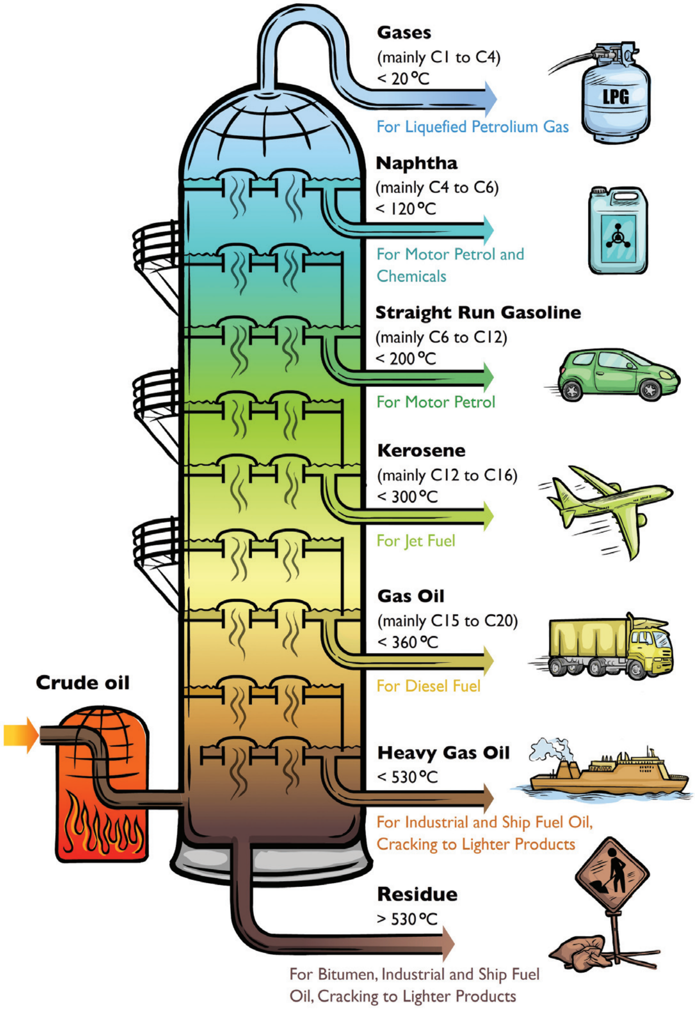
56 See http://www.sizes.com/units/barrel_petr.htm and http://www.oil150.com/essays/2007/08/the-42-gallon-barrel-history.

57 See William L. Leffler, *Petroleum Refining for the Non-Technical Person, Second Edition*, PennWell Books, Tulsa, Oklahoma, 1985, pp. 11-12.

58 See BP, *Statistical Review of World Energy 2008,* http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622, p.44.

59 Unless otherwise noted, the discussion in this chapter is drawn from William L. Leffler, *Petroleum Refining in Non-Technical Language, Third Edition*, PennWell Books, Tulsa, Oklahoma, 2000. Another useful source is the 'Discover Petroleum' pages of the Association for School Science, "Schoolscience" website, http://resources.schoolscience.co.uk/Exxonmobil/infobank/4/2index.htm?2home_f2.htm.

FIGURE 2 DISTILLATION COLUMN



send the vapour up a *distillation column* (or tower) with a set of trays in it, as shown in Figure 2. The trays are stacked in the column much like drawers in a chest of drawers. Each tray is cleverly designed to hold liquids that are kept at a given temperature, with the temperature of each tray getting cooler as one moves up the column. The vapour is forced to bubble through the liquids in each tray. As the vapour bubbles through, hydrocarbons that have a boiling point higher than the temperature of the liquid in the tray tend to condense. Hence, we can draw-off from each tray the crude oil fraction with a given range of boiling points. This process is known as *fractional distillation*.

Distillation can get us raw versions of each of the major oil products. However, here we encounter a serious problem. The market wants mostly the lighter products—petrol, diesel, and jet fuel, in particular—but most crude oils contain a lot of heavier hydrocarbons that are much less in demand and much less valuable. For example, straight distillation of even a light crude oil would generally yield only about a 20–25% petrol fraction. To solve this problem, the next stages of refining are typically *cracking* processes that chemically break-up the molecules in the heavier fractions into lighter molecules. There are a number of ways this can be done, generally involving some combination of heat, catalysts, and hydrogen. Using such processes, a sophisticated refinery can produce 60% or more petrol.[60]

There is a lot more to refining than this, including processes for the converting of hydrocarbon gases into hydrocarbon liquids (the reverse of cracking), for removing impurities such as sulphur, and for altering the chemical structure of some molecules in order to meet product specifications such as octane and vapour pressure. In general, the refining industry has had to become increasingly sophisticated as, on the one hand, government regulations and vehicle manufacturer specifications have required petrol and other oil products to meet higher standards, while on the other hand, the average crude oil being produced worldwide is getting heavier and higher in sulphur, and thus more difficult to process.[61]

New Zealand has reflected this trend, as government regulations have progressively reduced the allowed level of sulphur in fuels since 2002. The limit on sulphur is 50 parts per million (ppm) in petrol effective January 1, 2008 and 10 ppm in diesel effective January 1, 2009.[62] The maximum sulphur content of diesel was as high as 3000 ppm as recently as 2004 although it typically averaged about 2000 ppm.[63]

Sulphur in oil products has been a problem for two reasons. First, it contributes directly to at least two pollutants, particulates and sulphur dioxide, which can pose

60 See the graphs of typical distillation yields and typical refinery yields on the U.S. Energy Information Administration website at http://www.eia.doe.gov/pub/oil_gas/petroleum/analysis_publications/oil_market_basics/ref_image_simple.htm.

61 See the "Refining" page of the U.S. Energy Information website at http://www.eia.doe.gov/pub/oil_gas/petroleum/analysis_publications/oil_market_basics/refining_text.htm#Downstream%20Processing.

62 See press release from Hon. Harry Duynhoven, "Consumers to get cleaner petrol and diesel", August 3, 2006, http://beehive.govt.nz/release/consumers+get+cleaner+petrol+and+diesel+0.

63 See the Ministry of Economic Development, *Lower Sulphur Diesel—What Does This Mean?*, February 2004, http://www.med.govt.nz/templates/Page____10375.aspx. Thanks to Ian Twomey for providing the 2000 ppm average estimate.

health hazards.[64] Sulphur dioxide is also the cause of 'acid rain', which damages forests and ecosystems. 'Acid rain' has been a major problem in Northern Hemisphere countries, but because of our island geography, does not occur in New Zealand.[65] Second, sulphur can reduce the effectiveness of vehicle pollution control systems against other pollutants, sometimes permanently.[66] For this reason, manufacturer standards are increasingly requiring lower sulphur levels in fuel.[67]

64 See Ministry of Economic Development, *Review of Permitted Sulphur Levels Beyond 2006*, May 2005, Section 3.1, http://www.med.govt.nz/templates/MultipageDocumentPage____10382.aspx#P116_21128.

65 See the Ministry for the Environment *Sulphur Dioxide* web page, http://www.mfe.govt.nz/issues/air/breathe/sulphur-dioxide.html.

66 See Ministry of Economic Development, *Review of Permitted Sulphur Levels Beyond 2006*, May 2005, Section 2.1, http://www.med.govt.nz/templates/MultipageDocumentPage____10381.aspx, and Section 3.1, http://www.med.govt.nz/templates/MultipageDocumentPage____10382.aspx#P116_21128.

67 See Ministry of Economic Development, *Review of Permitted Sulphur Levels Beyond 2006*, May 2005, Section 2.2, http://www.med.govt.nz/templates/MultipageDocumentPage____10381.aspx, and Section 3.2, http://www.med.govt.nz/templates/MultipageDocumentPage____10382.aspx#P116_21128.

2 World Oil Resources

Most oil importing countries, including New Zealand, are concerned about the security of their oil supply. These concerns over security have at least two dimensions, both of which stem from some basic facts about oil resources.

First, there is the ever-present danger of short-term disruptions to supply. Much of the world's oil is produced in hostile or remote natural environments, such as offshore and in the arctic, and is therefore vulnerable to disruption from natural disasters and other types of breakdowns in the supply chain. However, of perhaps greater concern is the fact that much of the world's oil resources are concentrated in a few oil exporting countries, where the potential for political disruption is also high. This disruption risk will be examined further in Chapter 7.

Second, there is concern about the long-term sustainability of oil supplies. There are basic questions about the quantity of the world's oil resources that remain unanswered. Part of this problem is natural: we have no way of knowing how much oil remains to be discovered and what tomorrow's exploration and production technologies will bring us. Another part of the problem, however, are the limitations of the available data. With the right kind of international cooperation, these limitations could be greatly alleviated.

The issue of the long-term sustainability of oil supplies is very controversial, and analysing it is beyond the scope of this book. However, this chapter attempts to provide some basic background on world oil resources that anyone who wishes to follow this debate should understand.

2.1 Reserve Estimates

The most common measure of oil resources that one encounters in the oil policy debate are *proved reserves* or in more casual contexts, *reserves*. Several organisations publish estimates of oil reserves by country, including *Oil & Gas Journal*, *World Oil*, and the *BP Statistical Review of World Energy*.[68] Another is the U.S. Central Intelligence Agency's *World Factbook*.[69] The *BP Statistical Review of World Energy* is the most easily accessible, and tends to be the most widely quoted in policy analysis.[70]

68 A table showing most recent reserves according to all three of these sources is published in the U.S. Energy Information Administration, and may be found at http://www.eia.doe.gov/emeu/international/reserves.html.

69 https://www.cia.gov/cia/publications/factbook/rankorder/2178rank.html.

70 BP, *Statistical Review of World Energy 2008*, http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622, p.6.

Precise definitions of 'reserves' vary, but the basic concept behind all of them is that they are supposed to be oil that is known to exist and likely to be producible with a high degree of certainty. For example, BP's definition states that reserves represent oil that "geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing conditions".[71] The term "proved reserves" is sometimes used interchangeably with "P90 reserves", which indicate there should be at least a 90% probability that the quantities actually recovered will equal or exceed the estimate.[72]

There are also other classes of oil reserves; however, these are mostly of interest to petroleum geologists. One does occasionally encounter others in policy analysis, such as P50 reserves (50% probability), also known as proven plus probable. Interestingly, the New Zealand oil reserve statistics given in the Ministry of Economic Development's *Energy Data File* are P50 reserves.[73]

The major organisations that publish reserve estimates are generally reasonably consistent with each other. They differ primarily in their treatment of unconventional oil, such as Canadian tar sands and Venezuelan extra-heavy crude (see Section 2.4 below).

The consistency of the reserve estimates should not be taken to indicate that the numbers are precise. Rather, each of these organisations relies on the same primary sources for their data. Primary sources for the reserve estimates are usually the respective national governments.[74]

Ultimately, reserves are estimates, and despite efforts to standardise definitions, there is a considerable amount of judgement that must be used to resolve the many uncertainties. Some observers have questioned whether this judgement is exercised in a truly objective fashion. For example, in the early 1980s several Middle East countries revised their reserve estimates upwards significantly despite a lack of new discoveries. These revisions occurred in the midst of OPEC negotiations over production quotas. A number of other countries have failed to revise their reserve estimates downward, despite ongoing production and a lack of new discoveries.[75]

71 See the BP *Statistical Review of World Energy 2008,* "Definition and Explanatory Notes" web page, http://www.bp.com/sectiongenericarticle.do?categoryId=9023796&contentId=7044130.

72 A recent document, *Petroleum Resources Management System,* 2007, prepared jointly by the Society of Petroleum Engineers, the American Association of Petroleum Geologists, the World Petroleum Council, and the Society of Petroleum Evaluation Engineers standardizes these definitions of proved reserves. See http://www.spe.org/spe-site/spe/spe/industry/reserves/Petroleum_Resources_Management_System_2007.pdf, p. 10-11.

73 See Ministry of Economic Development, *New Zealand Energy Data File, June 2007,* Section H, http://www.med.govt.nz/energy/edf/2007/.

74 See International Energy Agency, *World Energy Outlook 2004,* p. 90.

75 For a more complete discussion of the issues involved in estimating oil reserves, see International Energy Agency, *World Energy Outlook 2004*, pp. 87-93.

There is no international process for independent verification of reserve estimates. In many countries, such as Saudi Arabia, the underlying engineering and geological data are considered to be proprietary or even a state secret.[76] Unfortunately, this unwillingness to share data leaves a major gap in our understanding of the future of the oil market, which impacts both policymakers and private sector investors.

2.2 Resource Estimates

Oil reserves are often used in the policy debate as indicators of the sustainability of a country's oil production. In particular, a country's *reserve-to-production ratio* (or *R/P ratio*) tells how many years a country would take to produce all its existing reserves at current production rates. In Saudi Arabia, this R/P ratio is currently around 70, in Iraq and in Kuwait it is over 100. On the other hand, in the U.S.A. and China the R/P ratio is around 11 and in the U.K. it is around 6.[77] But is oil production in the U.S.A., China, and the U.K. really less sustainable than in Saudi Arabia, Iraq, and Kuwait?

Although R/P ratios are somewhat indicative of the sustainability of a country's oil production, there are a number of factors that come into play, even putting aside the issue of the accuracy of the reserve statistics. Proving up reserves requires investment, since despite all that modern technology brings to oil exploration, the only way to know if the oil is really there is to drill wells. No oil company deliberately sets out to create a high R/P ratio, since this indicates investment that must sit idle for many years. Countries with high R/P ratios generally get that way because their oil is in a few very large fields that they cannot, or choose not, to produce quickly. Countries that lack these large fields can still produce sustainably if they can continue to discover and develop new fields.

Reserves, unfortunately, tell us nothing about the prospects for a country being able to make new discoveries. What we really want to know is the country's *ultimately recoverable resources* (or *URR*). Unfortunately, formulating such estimates involves dealing with considerably more uncertainties than estimating proved reserves. Geologists can use available geological data to assess the likelihood of finding more oil in a region but, as noted above, short of drilling wells, there is no way to know for sure what is out there. Much of the world has not been well-explored for oil. For example, only about 9,000 oil and gas wells have ever been drilled in Saudi Arabia, and only about 600 have ever been drilled in New Zealand. The comparable figure for the United States is about 4 million—and they are still finding oil there.[78]

76 See Mathew Simmons, *Twilight in the Desert; the Coming Saudi Oil Shock and the World Economy*, John Wiley & Sons, 2005.

77 BP, *Statistical Review of World Energy 2008*, http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622, p. 6.

78 Statistics for Saudi Arabia and the United States from International Energy Agency, *World Energy*

Further complicating the assessment of ultimately recoverable resources are assumptions about technology and the future price of oil. As BP notes on their *BP Statistical Review of Energy* web page:

> "Whilst some consider URR to be fixed by geology and the laws of physics, in practice estimates of URR continue to be increased as knowledge grows, technology advances and economics change. Economists often deny the validity of the concept of ultimately recoverable reserves as they consider that the recoverability of resources depends upon changing and unpredictable economics and evolving technologies."[79]

One key area of uncertainty where economics and technology come into play is the level of recovery. As noted in Section 1.4 above, the industry currently leaves an average of about two-thirds of the oil resource initially in place in the ground. Rising prices and technological improvements should make higher levels of recovery possible in the future.

Several organisations prepare assessments of ultimately recoverable resources. The most prominent in the policy debate, probably because it is the only detailed scientific assessment that is available publicly, is the *World Petroleum Assessment 2000* of the U.S. Geological Survey (USGS).[80] However, the USGS data suffers from three severe limitations for use in policy analysis.

First, one important class of ultimately recoverable reserves, reserve growth, is not estimated at any level other than for the entire world.[81] Reserve growth is additional oil to be added to reserves in existing fields. Reserve growth is expected to be a key component of ultimately recoverable reserves. In fact, on a world-level, USGS estimates that future reserve growth will be almost equal to the amount of undiscovered conventional oil, that is, oil from new fields.[82] Thus, there are no estimates of total ultimately recoverable reserves by country to be had from this source.

Second, the range of uncertainty in the USGS estimates is, not surprisingly, huge. Fortunately, the USGS does give explicit estimates of this uncertainty by providing three assessments. An "F95" assessment represents a 95 percent chance of at least

Outlook 2005, p. 131. Statistic for New Zealand supplied by Mark Aliprantis, Manager, Petroleum and Minerals Investment Unit, Crown Minerals, Ministry of Economic Development.

79 See http://www.bp.com/sectiongenericarticle.do?categoryId=9023799&contentId=7044111.

80 See *U.S. Geological Survey World Petroleum Assessment 2000 – Description and Results* available at http://pubs.usgs.gov/dds/dds-060/.

81 See U.S. Geological Survey, *Analysis of Assessment Results, Chapter AR*, http://energy.cr.usgs.gov/WEcont/chaps/AR.pdf, Table AR-1.

82 See U.S. Geological Survey, *Analysis of Assessment Results, Chapter AR*, http://energy.cr.usgs.gov/WEcont/chaps/AR.pdf, Table AR-1.

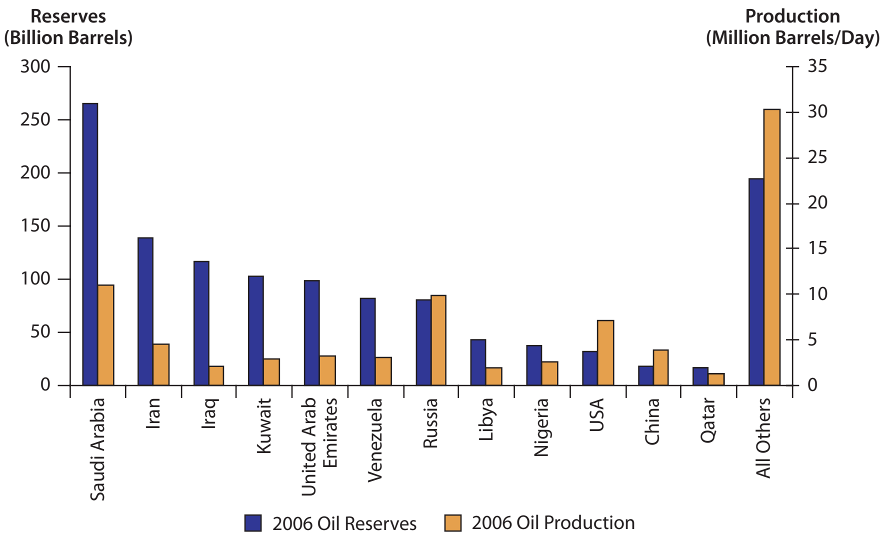
the amount tabulated, an "F50" assessment represents a 50% chance of at least the amount tabulated, and an "F5" assessment represents a 5% chance of at least the amount tabulated.[83] The F95 assessment of undiscovered conventional oil for the entire world outside the United States is 334 billion barrels, while the F5 assessment is 1,107 billion barrels. The F95 assessment of reserve growth outside the United States is 192 billion barrels, while the F5 assessment is 1,031 billion barrels.[84]

Third, the assessment covers only conventional oil. Yet unconventional oil may become an important component of future world supply (see Section 2.4 below).

2.3 Concentration of Oil in a Few Countries

One factor that has made oil so problematic is that oil resources are heavily concentrated in a few countries. Although, as we have seen, there are many uncertainties with the statistics, there is little dispute that the world oil market will be increasingly dependent upon these few countries for the foreseeable future.[85]

FIGURE 3 OIL RESERVES AND PRODUCTION[86]



83 See the region reports at http://pubs.usgs.gov/dds/dds-060/.
84 See http://energy.cr.usgs.gov/WEcont/world/woutsum.pdf.
85 See International Energy Agency, *World Energy Outlook 2007*, p. 81 and Table 1.3.
86 Data from BP, *Statistical Review of World Energy 2008*, http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622, *pp. 6 and 8.*

Figure 3 (above) shows the end 2006 proved reserves and 2006 production of the countries with the 12 largest oil reserves according to the *BP Statistical Review of World Energy*. Saudi Arabia alone has larger reserves than the rest of the world outside these 12 countries.[87] Looking at this list of countries it may be noted that all of them except the USA, China, and Russia have economies that are dominated by oil production. Most of them are developing countries, or would be considered developing countries were it not for their oil. For these reasons, they have a definite national interest in seeing high oil prices. This would not be as true of an oil producing country with a more diverse economy (for example, Australia or Canada), where high oil prices cut both ways.

The concentration of oil in a few countries, combined with a strong national interest in higher oil prices, has made it possible for these countries to significantly influence the price of oil (*market power*). The most well-known change in the oil market since the 1960s has, of course, been the rise of the *Organization of Petroleum Exporting Countries (OPEC)*, and their efforts to promote higher oil prices. OPEC's membership includes 9 of the 12 countries shown in Figure 3—Iran, Iraq, Kuwait, Qatar, Saudi Arabia, the United Arab Emirates, Libya, Nigeria, and Venezuela. Algeria and Indonesia are also members.[88] Russia, the USA, and China, are not members, with the USA and China being two of the world's largest oil importing countries.[89]

A less well-known, but at least equally important change during this period, has been the almost complete replacement of multi-national oil companies by national oil companies, usually state-owned, in most of the major exporting countries. This has put the pace of oil development and production directly in the hands of the exporting country governments, further increasing the market power of these countries.[90] In 2006, the world's five largest oil companies by petroleum liquids production were all national oil companies, led by Saudi Aramco with production of around 11 million barrels/day. The largest multi-national oil company by petroleum liquids production

87 See BP, *Statistical Review of World Energy 2008*, http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622, *p. 6.*

88 See the OPEC website www.opec.org.

89 According to the U.S. Energy Information Administration "Country Profiles" page, http://tonto.eia.doe.gov/country/, in 2006, the U.S. was the largest oil importer in the world, and China was the third largest (Japan was number two). This information is quoted at http://www.infoplease.com/ipa/A0922041.html.

90 The classic book on oil industry history is Daniel Yergin, *The Prize; The Epic Quest for Oil, Money, & Power,* 1993. The more recent past, especially the rise of OPEC since the 1960s, is documented in Francisco Parra, *Oil Politics: A Modern History of Petroleum, I.B. Tauris,* 2004. Parra is a former General Secretary of OPEC.

was BP, ranked number six, with production of about 2.6 million barrels/day.[91] Today, multi-national oil companies find that the lion's share of the world's most promising oil resources are simply off-limits to them.[92]

With national oil companies in exclusive control of the oil resources in many oil producing countries there is a risk that these companies may lack the financial and managerial capabilities needed to increase or even maintain oil production. The International Energy Agency (IEA) has repeatedly expressed concern that levels of investment in oil producing countries will be insufficient.[93] In particular, they note that in countries with national oil companies:

> "Often political and social spending needs grow to the point where oil exploration and development investment is compromised, in turn reducing oil and gas exports."[94]

The upstream oil industry is going to require enormous levels of investment in coming years. Modelling by the IEA estimates that around US$125 billion per year will be required. Three quarters of this will be needed just to maintain current levels of capacity in the face of natural declines as oil is depleted.[95]

2.4 Unconventional Oil

Most reserve and resource statistics that one sees quoted in policy discussions are for 'conventional' oil, and include little or no 'unconventional' oil. While the distinction between 'conventional' and 'unconventional' oil is not a sharp one, today there are three very significant classes of oil that are generally considered to be 'unconventional'. Although each one occurs in a number of countries, the best deposits of each one are heavily concentrated in a single country. And although each one is more expensive, and more energy-intensive, to produce than conventional oil, the quantities available could potentially change the oil resource picture quite dramatically.[96]

91 See Robert Pirog, *The Role of National Oil Companies in the International Oil Market,* Congressional Research Service, 21 August 2007, Tables 1 and 3, http://fas.org/sgp/crs/misc/RL34137.pdf.

92 See International Energy Agency, *World Energy Outlook 2006,* pp. 104-105 and Figure 3.12.

93 The risk of insufficient investment was a theme of International Energy Agency, *World Energy Outlook 2005; Middle East and North Africa Insights;* see especially pp. 160-163 and Chapter 7, and was also discussed again in their *World Energy Outlook 2006,* pp. 104-107.

94 See International Energy Agency, *Medium-Term Oil Market Report,* July 2007, p. 32

95 See International Energy Agency, *World Energy Outlook 2006,* p. 102.

96 This section draws heavily on the paper *Alternative Liquid Fuels: Availability, Economics and Environmental Impacts* by Michael Taylor available on the Ministry of Economic Development website http://www.med.govt.nz/templates/MultipageDocumentTOC____26587.aspx.

2.4.1 Tar Sands and Bitumen

Bitumen is viscous (or tar-like) oil that will not flow in economic quantities to a conventional oil well. In order to extract it from the rock or sands in which it is found, it must first be softened-up, either with heat or chemical solvents. If the "ore" is located close to the surface, it can be mined and the bitumen separated externally. Extraction from deeper deposits is possible using *in situ* techniques, which generally involve injecting steam or solvents into the ground. Once the bitumen has been separated from the rock or sand, it must generally be further processed to produce a 'synthetic crude' that can be shipped by pipeline.

At least two-thirds of the world's bitumen in place is believed to occur in the province of Alberta, Canada.[97] Production is currently around 1.1 million barrels per day (about 1% of the world's oil supply) and growing rapidly.[98] The resource base is enormous by any measure, with a total resource estimated at 2.5 trillion barrels by the International Energy Agency,[99] and an ultimately recoverable component estimated by the Alberta Energy and Utilities Board to be around 310 billion barrels.[100] To put that number in perspective, the proved reserves of Saudi Arabia are 264 billion barrels.[101]

2.4.2 Extra-Heavy Crude

Like bitumen, extra-heavy crude is viscous stuff, but not as viscous as bitumen. It will flow to an oil well, but needs special pumping and heat or chemical stimulation to get a good recovery. Like bitumen, the heavy oil must be further processed once it is extracted in order to obtain a product that can be shipped by pipeline.

Nearly 90% of the world's extra heavy crude is believed to occur in the Orinoco Oil Belt of Eastern Venezuela.[102] Production capacity is currently around 580,000 barrels per day although production is somewhat less than this amount, reportedly due

97 See the World Energy Council "Survey of Energy Resources 2007; Natural Bitumen – Resource Quantities and Geographical Distribution" web page at http://www.worldenergy.org/publications/survey_of_energy_resources_2007/natural_bitumen_and_extraheavy_oil/654.asp.

98 See the Province of Alberta web site *Oil Sands* page http://www.energy.gov.ab.ca/OurBusiness/oilsands.asp.

99 See International Energy Agency, *Resources to Reserves; Oil & Gas Technologies for the Energy Markets of the Future;* 2005, http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1568, p. 75.

100 See National Energy Board, *Canada's Oil Sands; Opportunities and Challenges to 2015: An Update,* June 2006, http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/lsnd/pprtntsndchllngs20152006/pprtntsndchllngs20152006-eng.pdf, p. 2.

101 BP, *Statistical Review of World Energy 2008,* http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622, *p. 6.*

102 See the World Energy Council "Survey of Energy Resources 2007; Natural Bitumen – Resource Quantities and Geographical Distribution" web page at http://www.worldenergy.org/publications/survey_of_energy_resources_2007/natural_bitumen_and_extraheavy_oil/654.asp.

to cutbacks to meet OPEC quotas.[103] As with Canadian bitumen, the resource base is potentially enormous, with a total resource estimated at 1.5 trillion barrels by the International Energy Agency,[104] and a recoverable component currently thought by the Venezuelan government to be around 250 billion barrels.[105]

2.4.3 Oil Shales

"Oil shale" does not actually have any oil in it at all. Rather the rock (which may be, but does not have to be, shale), contains an organic solid material called *kerogen*. The kerogen would have turned into oil if it had been buried deeper and subjected to high temperatures and pressures. However, if the rock is heated to about 500°C, it will produce a low-grade oil known as 'shale oil'. Shale oil may be produced by either surface mining or various *in situ* techniques.

Oil shales occur around the world, but over half are believed to be concentrated in the Western United States, especially the state of Colorado.[106] Oil shales were the subject of an extensive set of U.S. government-sponsored demonstration projects in the 1970s, however, production was found to be not competitive with conventional oil and the projects were shut down in the 1980s.[107] Today there is no commercial production in the U.S., although there are some small operations in other countries.[108] In the U.S., the resource in place is estimated to be 2 trillion barrels.[109]

2.5 Alternatives to Oil

There are a number of potential alternatives to oil. These alternatives are largely beyond the scope of this book. It is, however, worth taking a brief look at those that could be close substitutes for oil as a transport fuel.[110]

103 See U.S. Energy Information Administration, *Country Analysis Briefs; Venezuela*, October 2007, http://www.eia.doe.gov/emeu/cabs/Venezuela/pdf.pdf, p. 6.

104 See International Energy Agency, *Resources to Reserves; Oil & Gas Technologies for the Energy Markets of the Future;* 2005, http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1568, p. 75.

105 See International Energy Agency, *Resources to Reserves; Oil & Gas Technologies for the Energy Markets of the Future;* 2005, http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1568, p. 78.

106 See the World Energy Council "Survey of Energy Resources; Oil Shale Resources" web page at http://www.worldenergy.org/publications/survey_of_energy_resources_2007/oil_shale/649.asp.

107 See International Energy Agency, *Resources to Reserves; Oil & Gas Technologies for the Energy Markets of the Future;* 2005, http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1568, p. 83.

108 See the World Energy Council "Survey of Energy Resources 2007; Table 3.1" at http://www.worldenergy.org/documents/shale_table_3_1.pdf.

109 U.S. Department of Energy, *Strategic Significance of America's Oil Shale Resource, Volume 1*, March 2004, http://www.fe.doe.gov/programs/reserves/npr/publications/npr_strategic_significancev1.pdf, p. 2.

110 These fuels are discussed in the paper Michael Taylor, *Alternative Liquid Fuels: Availability, Economics and Environmental Impacts*, March 2007, http://www.med.govt.nz/templates/MultipageDocumentTOC____26587.aspx.

Alternative transport fuels can be loosely divided into three categories. The first are the more exotic fossil fuels, including liquefied petroleum gas (LPG), compressed natural gas (CNG), and liquids made from coal or gas. The second are biofuels. The third are the alternative energy carriers: electricity and hydrogen.

2.5.1 Fossil Fuel Alternatives

As noted in Section 1.2, LPG and CNG are used today in some modified conventional vehicles. In New Zealand, these fuels are exclusively (in the case of CNG) or primarily (in the case of LPG) sourced from locally-produced natural gas.[111] Since they are lighter fuels than petrol or diesel, they can also offer some greenhouse gas emission reductions compared to conventional oil products.

Diesel or petrol that is compatible with unmodified conventional vehicles can be manufactured from coal or gas using the *Fischer-Tropsch* process. This process was originally commercialised in Germany starting in the 1930s and further developed in South Africa starting in the 1950s. Both Germany and South Africa are oil-poor but coal-rich countries, and both faced curtailment of oil imports due to war (in the case of Germany) and international boycott (in the case of South Africa).[112]

New Zealand has large reserves of *lignite* (soft) coal in Southland, which could potentially be used to produce liquid fuels at a cost that could be competitive with oil products. The greenhouse gas emissions in producing liquids from coal would be considerably higher than for producing and refining oil products. However, carbon capture and storage technology could potentially help to mitigate this.[113] Since the liquids from coal are chemically similar to oil-based fuels, vehicle emissions are similar.

2.5.2 Biofuels

Biofuels are fuels derived from present-day plant or animal matter (*biomass*). The most common biofuels generally fall into two categories: bioethanol and biodiesel.[114]

111 See Ministry of Economic Development, *New Zealand Energy Data File, June 2007*, Table D.15, http://www.med.govt.nz/energy/edf/2007/.

112 For more on the history of the Fischer-Tropsch process, see the brochure *Sasol 50 Years of Innovation* on the Sasol website http://www.sasol.com/sasol_internet/downloads/Sasol%2050%20year%20Brochure_1039069422306.pdf.

113 For an examination of the potential costs and greenhouse gas emissions of producing liquid fuels from lignite in New Zealand with carbon capture and storage, see Martin Garrood and Tony Clemens, *Liquid Fuels from Lignite*, CRL Energy, November 2007, http://www.med.govt.nz/templates/MultipageDocumentTOC____33262.aspx.

114 For more information on biofuels in New Zealand, see Energy Efficiency and Conservation Authority, *Fact Sheet 8 – Biofuels* at http://www.eeca.govt.nz/eeca-library/renewable-energy/biofuels/fact-sheet/biofuel-fact-sheet-05.pdf. For further background on biofuels production economics worldwide see Michael Taylor, *Alternative Liquid Fuels: Global Availability, Economics and Environmental Impacts*, March 2007, Chapter 4, http://www.med.govt.nz/templates/MultipageDocumentTOC____26587.aspx. Unless otherwise noted, the material in this section is drawn from these sources.

Bioethanol is a type of alcohol that may be blended into petrol in small quantities (generally 3–10%, depending upon the vehicle) and used in unmodified petrol vehicles,[115] or used in proportions up to 100% in modified petrol vehicles. Bioethanol is made today in New Zealand from whey, a by-product of milk processing. Overseas, ethanol is produced from a range of feedstocks containing sugar and starch, including corn, wheat and sugar cane.

Biodiesel, the popular term for *fatty acid methyl esters (FAME)*, can be blended with conventional diesel oil and used in most unmodified diesel vehicles in concentrations up to 5%. Modern diesel engines are basically compatible with higher concentrations of biodiesel as well;[116] however, many engine manufacturers currently do not recommend their use. Biodiesel is produced from vegetable oils and animal fats. in New Zealand biodiesel could be made from tallow, an animal fat by-product of the meat industry. Overseas, biodiesel is usually made from vegetable oil, such as rapeseed and soy oils.

Both bioethanol and biodiesel are already being offered commercially in many countries. Biofuels can potentially reduce greenhouse gas emissions and dependence on oil. Carbon dioxide released from the burning biofuels was originally extracted from the atmosphere by growing plants, so net carbon emissions from biofuels are potentially very low. For this reason, the New Zealand government has proposed a biofuels obligation that will require companies that sell petrol or diesel to include a percentage of biofuels in their products. The percentage will increase over time, reaching 3.4% by 2012.[117]

However, the benefits of biofuels have been the subject of controversy. Biofuels require energy to grow and process the feedstocks. Much of this energy currently comes from fossil fuels, which offsets at least some of the environmental benefits.[118] Furthermore, biofuel production may compete with the food production for crops and cropland, thus driving up the price of food and working a hardship on the world's poor. It may also lead to deforestation and other environmental damage, especially in tropical

115 For a discussion of vehicle compatibility issues, see Transport Engineering Research New Zealand Limited, *Enabling Biofuels; Risks to Vehicles and Other Engines,* Ministry of Transport, April, 2006, http://www.mot.govt.nz/assets/NewPDFs/Vehicle-and-Engine-Risks-report-v3.1.pdf.

116 For a discussion of vehicle compatibility issues, see Transport Engineering Research New Zealand Limited, *Enabling Biofuels; Risks to Vehicles and Other Engines,* Ministry of Transport, April, 2006, http://www.mot.govt.nz/assets/NewPDFs/Vehicle-and-Engine-Risks-report-v3.1.pdf.

117 For more information on the biofuels obligation, see *Biofuels Sales Obligation Final Policy Questions and Answers* on the Ministry of Transport website http://www.transport.govt.nz/biofuels-sales-obligation-final-policy-questions-and-answers-1/.

118 See International Energy Agency, *Biofuels for Transport; an International Perspective*, 2004, Chapter 3, http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1262.

countries.[119] Finally, the amount of land that would be required to grow biofuels crops severely limits the potential for today's biofuels to offset oil on a world scale.[120]

Some of the today's problems with biofuels may be solved with improved technology. *Cellulosic* biofuel technology could allow ethanol to be produced from the stalks and stems of almost any plant, significantly reducing the amount of land required and allowing the use of land that is unsuitable for food production.[121] Biofuels (biodiesel or bioethanol) could also be produced from algae. The algae could be grown in special ponds that would produce much more fuel per hectare than conventional biofuels.[122] A variety of alternative chemical and processing approaches are also possible, including using the Fischer-Tropsch process on biomass.[123] The latter would allow the production of a range of fuels that would be chemically almost identical to oil products.

2.5.3 Electricity and Hydrogen

Electric vehicles running on renewable electricity are another potentially low emission alternative to oil. The development of electric vehicles has historically been held back by the limited range of their batteries, but a modified version of the conventional hybrid vehicle, the *plug-in hybrid vehicle*, overcomes this limitation.

Plug-in hybrids are similar to today's hybrid vehicles, which are powered by batteries and electric motors as well as internal combustion engines. However, in today's hybrid vehicles the electric motor merely provides extra power for acceleration and hill climbing, allowing use of a smaller, more efficient internal combustion engine that also charges the batteries for the electric motor. In a plug-in hybrid vehicle, the batteries are larger, allowing the vehicle to be exclusively powered by electricity over a limited range. Vehicle users can charge the batteries using ordinary house current, reducing their need for liquid fuel.[124]

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119 See Richard Doornbosch and Ronald Steenblik, *Biofuels: Is the Cure Worse than the Disease?*, Organisation for Economic Cooperation and Development, September, 2007, http://www.oecd.org/dataoecd/9/3/39411732.pdf.

120 See International Energy Agency, *Biofuels for Transport; an International Perspective*, 2004, Chapter 6, http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1262.

121 See the article "Will Cellulosic Ethanol Take Off?", *Technology Review*, 26 February 2007, http://www.technologyreview.com/Energy/18227/.

122 See the article "Algae Based Fuels Set to Bloom", *Technology Review*, 5 February 2007, http://www.technologyreview.com/Energy/18227/.

123 See International Energy Agency, *Biofuels for Transport; an International Perspective*, 2004, Table 3.7, http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1262.

124 For a description of hybrid vehicle technology, see the International Energy Agency's Hybrid Electric Vehicles website, http://www.ieahev.org/hybrid.html.

Plug-in hybrids can be powered by their internal combustion engine when their batteries run low, avoiding the problems with limited range that have historically hindered the acceptance of electric vehicles. But since most vehicles are not regularly driven far, the potential saving in liquid fuel is quite large even if the electric range of the vehicle is limited. A study by the Electric Power Research Institute in the United States found that a plug-in hybrid with a battery range of only 32 km could reduce liquid fuel consumption by 60%.[125]

The technology needed for plug-in hybrids is available today. Hobbyists are already converting production hybrid vehicles into plug-in hybrids by installing larger batteries.[126] So far, car manufacturers have been reluctant to market plug-in hybrids because the larger batteries would add several thousand dollars to the cost of the vehicle. However, General Motors has announced that it may begin production of a plug-in hybrid as early as 2010.[127]

A common misconception is that because the transport use of energy is large relative to electricity use, a large fleet of electric vehicles would be burdensome to New Zealand's electricity system. However, because of their high efficiency and potential to charge during off-peak hours, the impact of electric vehicles on the electricity system could be surprisingly modest.[128]

Hydrogen vehicles would be another low emission alternative to oil. They could be powered by either modified internal combustion engines or fuel cells (which produce electricity from hydrogen through a chemical process). Since hydrogen oxidises to produce only water vapour, hydrogen vehicles would potentially emit no harmful greenhouse gases. Furthermore, hydrogen fuel cell vehicles are 2 to 3 times more efficient than fossil-fuelled vehicles in terms of energy use per kilometre travelled. (Hydrogen powered internal combustion vehicles are of similar efficiency to petrol powered

125 See Lucy Sanna, 'Driving the Solution; The Plug-In Hybrid Vehicle', *EPRI Journal*, Fall 2005, pp. 8-17, http://mydocs.epri.com/docs/CorporateDocuments/EPRI_Journal/2005-Fall/1012885_PHEV.pdf.

126 See 'Take This Car and Plug It', *IEEE Spectrum*, July 2005, http://ieeexplore.ieee.org/iel5/6/31432/01460339.pdf?tp=&arnumber=1460339&isnumber=31432, pp. 10-13. There are do-it-yourself plug-in hybrid conversion kits offered commercially. For more information, see the California Cars Initiative website http://www.calcars.org/howtoget.html.

127 See press release "Saturn Vue Green Line Plug-in Hybrid SUV May Begin Production in 2010", 14 January 2008, on the General Motors website http://www.gm.com/explore/fuel_economy/news/2008/hybrids/plug_in_vue_011008.jsp.

128 See Erwan Hemery and Bruce Smith PowerPoint presentation *Electrons for Petrol; Impact of Plug-In Hybrids on the NZ Electric Grid* at http://www.electricitycommission.govt.nz/pdfs/opdev/modelling/vehicles/PHEV.pdf.

vehicles.)[129] Honda has announced plans for retail marketing of a fuel-cell hydrogen vehicle in Southern California in 2008 on a limited basis.[130]

Like electricity, hydrogen must be produced from other sources of energy. Therefore, the overall environmental benefits of hydrogen vehicles depend upon how the hydrogen is produced. There are at least three potential ways to produce hydrogen in New Zealand: from coal, from gas, or from electricity. For the coal and gas options, carbon capture and storage technology could be used to minimise emissions. Actual production of hydrogen could take place either at centralised plants or at the filling station.[131]

2.6 Summing Up – The Uncertain Future of Oil

This chapter has given the reader a taste for some of the issues that make the long-term sustainability of oil production such a controversial issue. The key issues in assessing the situation probably boil down to the following four questions:

- ***How much oil is out there?*** Oil does not become 'reserves' until the wells are actually drilled. There are huge ranges of uncertainty in ultimate recoverable resources (URR) estimates.
- ***Are published statistics accurate?*** Proved reserve statistics are inconsistently calculated, and in some cases of dubious accuracy. There is usually no way to independently verify these figures.
- ***How feasible is unconventional oil?*** There are enormous resources of unconventional oil, including tar sands from Canada, extra-heavy oil from Venezuela, and shale oil from the United States, some of which is already being commercially produced. But how much of these resources can be economically developed?
- ***How soon will alternatives to oil become economic?*** Major technological advances could make the whole question of oil's exhaustibility a moot point.

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129 See Ruben Smit and Andrew Campbell, *Cost and Impacts of a Transition to Hydrogen Fuel in New Zealand,* CRL Energy, June 2007, p. 3, http://www.med.govt.nz/templates/MultipageDocumentTOC____35564.aspx.

130 See press release "Honda Debuts All-New FCX Clarity Advanced Fuel Cell Vehicle", 14 November 2007, on the Honda website http://world.honda.com/news/2007/4071114All-New-FCX/.

131 For an analysis of each of these options, see Ruben Smit and Andrew Campbell, *Cost and Impacts of a Transition to Hydrogen Fuel in New Zealand,* CRL Energy, June 2007, http://www.med.govt.nz/templates/MultipageDocumentTOC____35564.aspx.

3 Exhaustible Resource Economics

Many people assume that markets tend to under-value exhaustible resources by failing to give due recognition their exhaustible nature.[132] The assumption is a natural one to make, since if markets for exhaustible resources worked the same way as the markets presented in most introductory economics classes, they would have this defect. But exhaustible resource markets are different, and the differences are not generally taught in introductory economics classes. Therefore, it is worth stepping back and taking a look at the basic economics of exhaustible resources here.[133]

The key message of this section is that markets for exhaustible resources can, in fact, work. How well they work in practice depends, like all markets, upon the presence of the proper prerequisites, including the existence of enforceable property rights, sufficient numbers of participants to permit competition, and the unimpeded flow of market information. But there is no fundamental reason why markets for exhaustible resources should fail.

This in-principle lack of market failure for exhaustible resources is a significant insight to bear in mind when analysing energy policies. It explains why economists tend to be sceptical of arguments that government intervention in energy markets is needed if these arguments are based simply on the fact that oil is an exhaustible resource or a belief that its production is about to go into decline. There are other market failures, however, which provide grounds for intervention that are quite respectable with economists. These include the fact that greenhouse gas emissions are not properly priced by the market, as well as several barriers that lead to insufficient incentives to invest in energy efficiency.[134] The general topic of when government intervention in a market is or is not justified is the central question of the branch of economics known as *welfare economics*, and is clearly beyond the scope of this book.

132 For a rare example of an academic who appears to take this view, see Bob Lloyd, "The Commons Revisited: the Tragedy Continues", *Energy Policy,* 2005, pp. 5806-5818, http://www.physics.otago.ac.nz/eman/documents/commons%20revisited%20tragedy%20continues.pdf.

133 The basic theory presented here was first published in Harold Hotelling, "The Economics of Exhaustible Resources." *Journal of Political Economy*, April 1931, 39(2), pp. 137-175. For this reason it is often referred to as "Hotelling's Theory of Exhaustible Resources".

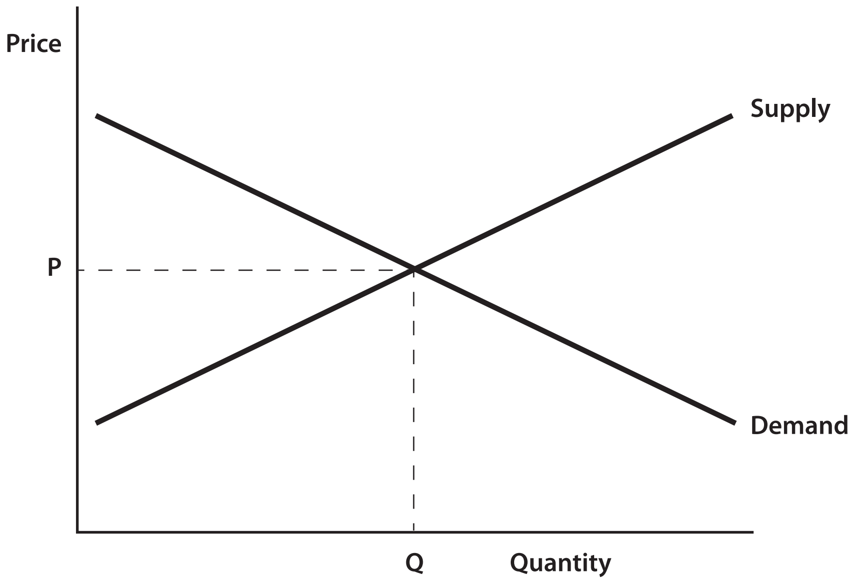
134 For a brief discussion of these market failures see Ministry of Economic Development, *Benefit-Cost Analysis of the New Zealand Energy Strategy,* November 2007, p. 2-2, http://www.med.govt.nz/templates/MultipageDocumentTOC____31983.aspx.

The model laid out in this chapter describes how people should behave to make best use of their available resources. It does not purport to describe how people actually go about making resource development decisions, which is usually quite different. The fact that there are significant differences between the two does not invalidate the model. The same discrepancies exist throughout economics. For example, introductory economics classes teach that producers should seek to set marginal revenue equal to marginal cost. However, if one suggests this approach to a real-world marketing manager one is likely to get funny looks (the author experienced this first-hand in his younger days as a consultant).

3.1 Decision Making for a Renewable Commodity

Due to the exhaustible nature of oil, the forces that set its price are quite different from an ordinary renewable commodity like, say, wheat. With a renewable commodity, the more of it that must be produced, the more it will cost per unit. To grow additional wheat, for example, one must draw in land that is increasingly less suitable for growing wheat, or give the existing wheat-growing land increasingly intensive, and expensive, care and handling.

FIGURE 4 SUPPLY AND DEMAND FOR A RENEWABLE COMMODITY



There is also a demand response to price. The more wheat that has to be sold, the less people are willing to pay per unit. As the price drops, more people are willing to buy, or existing buyers are willing to buy more. If we plot the supply and demand for wheat (see Figure 4), the point where the two curves intersect is where supply equals demand. This will be where the market sets the price and quantity of wheat produced.

If you are a wheat farmer and you expect the price for wheat to be P, you will increase your production of wheat until the last unit of wheat you produce has a cost equal to P. You won't produce any more, since you would lose money on each additional unit of wheat beyond this point. This is what is taught in Economics 101.

There is one point about markets for renewable commodities that deserves special mention here though, since it also transfers over to exhaustible commodities. In a properly functioning market there are never any "shortages". That is, anyone who can afford to pay the going price can always buy. This implies that, at least as long as the market is allowed to function freely, there can never be a "shortage" of oil, no matter how quickly the supply depletes.

The belief that oil markets do not function is often reinforced with recollections of car-less days in New Zealand or images of cars queuing up for petrol in the United States during the oil crises of the 1970s. Those situations clearly represented a true shortage. However, these shortages were the result of government price controls on petrol in both countries,[135] which did not allow prices to rise to the point where supply could equal demand. Once these price controls were removed in the early 1980s, the shortages disappeared, and have not reappeared despite several significant supply shocks.

3.2 Decision-Making for an Exhaustible Resource

The situation gets a little more complicated if you are an oil producer rather than a wheat farmer. To keep it simple, let us assume you have inherited an oil well capable of producing a cumulative total of 1,000 barrels of oil at no cost. How much oil should you sell? At first glance the answer is not obvious the way it was for the wheat farmer. You have no cost to compare to the current price and you will make the same profit per barrel no matter how much you sell. The trick here is to recognise that for an exhaustible resource, you have to ask a subtly different question. Unlike the wheat

135 These price regulations in New Zealand are discussed in Michael Pickford and Cameron Wheeler, *The Petrol Industry: Deregulation, Energy and Competition, NZ Trade Consortium Working paper No. 12,* New Zealand Institute of Economic Research, 2001, http://www.nzier.org.nz/Site/Publications/NZTC/NZ_trade.aspx, p. 9-11.

farmer, there is a time dimension to your decision. The question you should ask is how much should you sell now? This being an exhaustible resource, you can sell now, or you can sell later, but you can't do both.

A rational businessperson will do a calculation. First, you estimate the amount of money you would have at various points in the future if you sold the oil now and invested the proceeds as best you could. Then you estimate what you think will happen to the price of oil in future years and calculate what is going to happen to the value of your 1,000 barrels at these same points in time if you leave it in the ground. If the amount of money you expect to make by waiting for the oil price to rise is greater than the amount you could make on the alternative investment, you should leave the oil in the ground. If you could make more on the investment than by leaving the oil in the ground, then you should sell the oil now. This is the basic "oil in the ground vs. money in the bank" calculation that drives all rational business decisions on exhaustible resources, although clearly, in the real world, there are a lot more complications.

3.3 The Impact of Extraction Costs

Let us examine one such complication now. Suppose you own the mineral rights to some land. You believe you could drill on it and produce 1,000 barrels of oil at a cost of $50 per barrel. For simplicity, let us assume you could sell all the oil the minute the drilling is completed and there is no uncertainty as to whether you will find oil. The question then becomes, should you drill now?

Again, you estimate the amount of money you could make each year over the next few years if you drilled now, sold the oil, and invested the money in something else. This time, the amount you would have left to invest for each barrel you sold would be the price of the oil per barrel minus the $50 it cost to produce it. Let us call this value, the price minus the production cost, the *rent* on the oil. "Rent" may seem like a funny term to use, since it has nothing to do with the rent one might pay on a flat. The "rent" here is something more akin to what most people think of as "profit". However, "profit" is not the right word either, since it is the net proceeds you are going to get from selling your interest in a valuable non-renewable asset—oil. That's why we need a different word, and economists have chosen to call it "rent".

To determine if you should drill now you need to calculate how much you could make from drilling now and investing the rent. Then you calculate how much you could make from waiting and drilling later when you may expect the oil price to be higher. As a rational businessperson you should do whichever alternative makes you more money. If you expect the price of oil to go down, or at least not to go up, you should definitely drill now. If you expect the price of oil to rise rapidly, then holding your oil in the ground becomes the best investment you could make and you should definitely drill later.

To make this calculation a little clearer, here is a numerical example. Suppose the price of oil is currently $100.00 per barrel and you expect it to increase by $5.00 a barrel each year for the foreseeable future. Suppose that the cost of drilling is $50 per barrel and that the best alternative investment you could make would pay an 8% return each year. Under these assumptions, you should drill in Year 4. In Year 4, the rent will be worth $65 per barrel ($100 initial price + $5 x 3 years – $50 drilling cost), which means that if you drilled in Year 4, by Year 5 your investment will grow to $70.20 per barrel ($65 + 65 x 8%). This is just slightly better than the $70 it would be worth if you left it in the ground for another year and drilled in Year 5. (See Appendix Section A.1 for a more conclusive demonstration.)

Notice that the market did not have you simply ripping the resources out of the ground as quickly as possible with no regard for the future. Instead, you made a rational decision, trading off the future return you could earn by leaving the oil in the ground against the future return you could earn by investing the proceeds. The future has been properly taken into account.

3.4 The Impact of Higher Extraction Costs

This numerical example can be used to illustrate three more interesting features of exhaustible resources. First, if the cost of drilling is higher, you should wait longer to drill, and vice versa. To see this, assume the cost of drilling is $55/barrel rather than $50. Now you will want to drill in Year 5, as it takes an extra year to get to the point where the rent is $65 per barrel ($100 initial price + $5 x 4 years – $55 drilling cost) and the calculations work out as they did in the previous example. (See Appendix Section A.2 for a more conclusive demonstration.)

Waiting longer when extraction costs are higher is a universal property of exhaustible resources. It is a 'sensible' market property in that it says that it will be most profitable to extract the cheaper resources first, while the more expensive resources will be deferred to later. This is a result that makes good intuitive sense, in that it accords with our notion of efficiency, and also accords with what we observe in the real world.

3.5 The Impact of Rising Oil Prices

Second, if you expect the price of oil to rise more rapidly, you should drill later, and vice versa. Assume that you expect the oil price to increase in the future at a rate of $10 per year, rather than the $5 per year originally assumed, and that the cost of drilling is $50/barrel as originally assumed. Now, you should wait and drill in Year 9 rather than in Year 4. In Year 9, the rent will be worth $130 per barrel ($100 initial price + $10 x 8 years – $50 drilling cost), which means that if you drilled in Year 9, your investment would grow to $140.40 per barrel ($130 + 130 x 8%) in Year 10, just slightly better than the $140 you could get if you waited a year and drilled in Year 10. (See Appendix Section A.3 for a more conclusive demonstration.)

Again, waiting longer when prices are rising more rapidly is a universal property of exhaustible resources. A more rapid expected increase in the resource price increases the percentage growth in the rent each year, making holding oil in the ground more attractive relative to other investments, and leading resource owners to defer drilling.

This, too, is a 'sensible' property, since it tells us that the market naturally provides a greater economic incentive to conserve resources for the future if the resources are expected to become more valuable in the future. If resources are being exploited in an unsustainable manner, such that prices are bound to rise quickly in the future, rational resource owners will see that they can make money by deferring their production until prices rise. While this "withholding" of production has sometimes been given a bad reputation in the popular press, in a properly functioning market, it serves a very valuable conservation function. The lower supply today will drive up prices today, reducing demand, and thereby insuring that resources will continue to be available for the future.

There is another useful property of exhaustible resource markets that falls out of this analysis—as resource owners defer production, prices today will rise to reflect the anticipated higher prices in the future. After all, no rational businessperson is going to sell something cheaply today that he/she knows is going to be worth a lot more in the future. Today's price therefore reflects tomorrow's anticipated price. There should be no sudden changes in price <u>except</u> for causes that market participants never anticipated.

3.6 The Impact of Lower Interest Rates

Finally, consider what happens if the interest rate on the alternative investment were lower. This makes holding your oil in the ground more attractive relative to investing it in something else, again causing you to defer drilling. Assume that you expect the interest on your alternative investment to be 6% instead of 8% and that oil prices are rising by $5 per year as originally assumed. Now, you should wait to Year 8 to drill. In Year 8, the rent will be worth $85 per barrel ($100 initial price + $5 x 7 years – $50 drilling cost), which means that if you drilled in Year 8, your investment will grow to $90.10 per barrel ($85 + 85 x 6%) by Year 9, just slightly better than the $90 it would be worth if you waited and drilled in Year 9. (See Appendix Section A.4 for a more conclusive demonstration.)

Waiting longer when interest rates are lower is perhaps the most surprising and non-intuitive result of exhaustible resource economics. It is also a bit harder than our first two relationships to immediately label as a "sensible" effect. However, from a broader social perspective, it does make sense. High interest rates mean that financial capital is in short supply and if you have some capital the market can use it very productively. So you should convert more oil into financial assets today. Low interest rates mean just the opposite—financial capital is in abundant supply and more of it cannot be used very productively. So you should hold more of your oil for the future. Here 'interest rates' refers to real interest rates—that is, interest after subtracting off inflation.

Although there were clearly other precipitating factors, an economist might argue that it may be no coincidence that the price spikes for oil in the 1970s came at a time of double-digit inflation worldwide and low or negative real returns in financial markets. Many producers, including some Middle East governments, may have decided quite rationally that oil in the ground was a better patrimony than dollars in the bank.[136] And today, oil prices are again rising rapidly in the face of low or even negative real interest rates in Japan, the U.S., and Europe. Is there a cause and effect relationship here?

3.7 The Impact of Technological Improvement

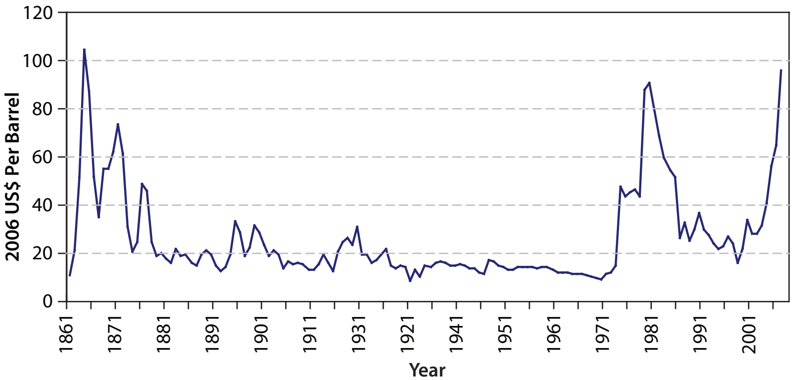
Another complication worth mentioning is technological improvement. The story as presented so far would lead one to believe that prices of exhaustible resources must rise over time, otherwise no one would have any reason to hold them for the future. However, technological improvements change the picture, making stable or declining prices consistent with orderly exploitation of an exhaustible resource. To

136 Thanks go to Dale Nesbitt for this insight. See his paper, "Realities of North American and World Natural Gas Markets or 'Nesbitt's Maxims' About Gas Markets", 2002, available at http://www.altosmgmt.com/pub.asp.

see this in the example, just note that a drilling cost that declines by $5 per year in the face of a stable oil price has exactly the same impact on resource rent as a price that increases at a rate of $5 per year in the face of a stable drilling cost. So, in addition to the original assumptions, the example discussed in Section 3.3 (and Appendix Section A.1) also shows what happens if the oil price is stable at $100 and drilling costs start at $50 and decline by $5 per year thereafter. Again, the rational businessperson should wait to drill in Year 4, even though prices are not rising.

This, too, is a "sensible" result. Improvements in technology mean that exhaustible resources are not quite as "exhaustible" as one might initially think, nor must they necessarily rise in price over time. Actually, the history of the oil industry is one of a continuing tug-of-war between resource exhaustion and improving technology. The cheap, close-to-market oil discovered in the early years of the industry has depleted. However, improvements in technology have continually enabled the industry to exploit resources in more remote or difficult to access locations, to exploit lower quality resources, and to improve the recovery rates of all resources. As a result, there have historically been long periods when oil prices have declined, at least after adjusting for inflation.

FIGURE 5: HISTORICAL OIL PRICES 1861–2007[137]



137 Data taken from historical data downloadable from the *Statistical Review of World Energy* page on the BP website at http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2007/STAGING/local_assets/downloads/spreadsheets/statistical_review_full_report_workbook_2007.xls, except for 2007, which was the 31 December 2007 closing price for the near-month NYMEX 'light sweet crude oil' contract, as per the U.S. Energy Information Administration website http://tonto.eia.doe.gov/dnav/pet/hist/rclc1d.htm.

Figure 5 shows historical oil prices since 1861, adjusted to 2006 US dollars. As can be seen, prices of oil were fairly stable in the US$10-25 range for around ninety years up to 1970. Technology was clearly winning over depletion in this interval. Since the 1970s, prices have been higher and much more volatile. Some of this is the result of the shift in control over oil resources to the oil exporting countries discussed in Section 2.3, but one might also argue that depletion has been winning over technology.

3.8 The Real World

One can properly argue that the theory outlined in this section is significantly different from the ways things work in the real world. Very few countries have privately-owned mineral rights for oil (as we will see in the Chapter 5, not even New Zealand). Rather in most countries, the timing and pace of resource development is politically determined. The dominance of a few national governments and their national oil companies over crude oil production discussed in Section 2.3 mean that the oil market is arguably less than fully competitive. And, as we have seen in Section 2.1 and 2.2, there are serious limits on the resource information available. Nevertheless, the theory presented in this section suggests that, if oil markets do not properly value the future, the problem lies in real-world departures from market principles, rather than anything inherent in the operation of markets themselves.

It is not obvious what impact these departures from market principles have on the pace of resource exploitation. One might argue that short-term political pressures, and an immediate need for cash in many oil producing countries, would lead to a faster pace of oil development than would be economic.

However, it is difficult to make a compelling case for overexploitation. The rise of petroleum nationalism, the ability of oil producing countries to exercise market power either individually or through OPEC, and the funding and managerial limitations faced by many national oil companies (see Section 2.3), all tend to slow the pace of oil exploitation relative to what would be economic.[138]

138 See the discussion of national oil companies in the Middle East and North Africa in International Energy Agency, *World Energy Outlook 2005; Middle East and North Africa Insights,* p. 161.

4 Oil and Financial Markets

Prices of crude oil and oil products are quite volatile, yet the firms that produce and consume them have huge medium- and long-term commitments that must be planned around a certain level of prices. For example, a company thinking of developing an oil field (and their financial backers and lenders) may not be willing to accept the risk that crude oil prices could plunge. On the other hand, an airline or a trucking company may not want to accept the risk that oil prices might soar. A refiner or other intermediate processor is doubly exposed to volatility in both their input and output prices.

Clearly, there are deals that can be done here to reduce the risks for both parties. And indeed, there is a whole sector of the finance industry designed to serve the market for *energy risk management*. The information that comes out of this sector can provide insight into what is happening in the oil industry, and what the market thinks may happen in the future.

4.1 Oil Trading

Spot markets are the simplest, but most risky, market for crude oil or oil products. Spot markets are very much akin to the way most consumers buy oil products—participants buy for immediate delivery at the current price. There are dozens of active spot markets around the world for various grades of crude oil and various oil products. The prices in these markets tend to be closely linked, since traders quickly find any opportunities to profit from price differentials that do not accurately reflect transport costs or other differences in value.[139]

The spot markets for certain crude oils, known as *marker crudes*, tend to act as barometers for the overall market level. Prices for other crudes are typically negotiated with reference to the quoted prices of these marker crudes.[140] Three marker crudes are especially prominent. The first is *West Texas Intermediate (WTI)*, which (despite the name) is a light sweet crude oil, delivered at Cushing, Oklahoma, USA. The second

139 Spot markets are discussed in Energy Information Administration, *Derivatives and Risk Management in the Petroleum, Natural Gas, and Electricity Industries*, October 2002, Chapter 3, http://www.eia.doe.gov/oiaf/servicerpt/derivative/chapter3.html.

140 For a discussion of the use of marker crudes see the "Crude Benchmark Analysis" pages of the Platt's website, http://www.platts.com/Oil/Resources/News%20Features/crudeanalysis/index.xml. See also the "International Crude Oil Pricing" page of the Australian Institute of Petroleum website, http://www.aip.com.au/pricing/crude.htm.

most prominent is Brent Crude, also a light sweet crude (but not as light at WTI), from the UK North Sea, deliverable at the Shetland Islands.[141] The third is Dubai crude, also known as Fateh, a medium heavy sour crude from the Middle East.[142] However, production of Dubai crude has been in a steep decline in recent years, so Oman crude, also a heavy sour crude,[143] has become increasingly prominent in price calculations.[144] A less-prominent marker crude worth mentioning because of its importance in Asia, Australia, and New Zealand is Tapis, a light sweet crude from Malaysia.[145]

Key oil product spot markets serve much the same role for oil products that marker crudes serve for crude oil. They provide a reference that tends to influence product prices over a wide region. Key oil product spot markets centre on the New York Harbour, Northwest Europe (primarily Rotterdam), and Singapore.[146] Spot market crude and product prices are sometimes quoted in the financial news media, but more comprehensive compilations are available in specialised publications such as Platts[147] or Argus,[148] as well as the website of the International Energy Agency[149] and the U.S. Energy Information Administration.[150]

At the other extreme from spot markets, *futures markets* provide a highly structured method to manage risk. These markets allow participants to contract for future delivery of oil or oil products at a price agreed-upon today. If the spot price at the time

141 See the "Pricing Differences Among Various Types of Crude Oil" web page on the website of the U.S. Energy Information Administration, http://tonto.eia.doe.gov/ask/crude_types1.html.

142 See Jorge Montepeque, "Sour Crude Pricing: A Pressing Global Issue", *Middle East Economic Survey,* v XLVIII, no. 14, 4 April 2005, http://www.mees.com/postedarticles/oped/v48n14-5OD01.htm. The author is Global Director, Market Reporting, for Platts.

143 See the "Introduction to the Oman Contract" page on the Dubai Mercantile Exchange website http://www.dubaimerc.com/omancontract.html

144 See Jorge Montepeque, "Sour Crude Pricing: A Pressing Global Issue", *Middle East Economic Survey,* v XLVIII, no. 14, 4 April 2005, http://www.mees.com/postedarticles/oped/v48n14-5OD01.htm.

145 See the discussion of Australian benchmark crudes in Reserve Bank of Australia, *Statement of Monetary Policy,* "Box B: Recent Developments in Oil Prices", August 2007 http://www.rba.gov.au/PublicationsAndResearch/StatementsOnMonetaryPolicy/Boxes/2007/2007_08_b_box.pdf. See also presentation by Richard Hale on the Hale & Twomey website, "The Market for New Zealand Oil", Petroleum Conference 2006, http://www.haletwomey.co.nz/publications/docs/060307-market-nz-oil.ppt#1, which mentions Tapis as the key marker crude for the region.

146 See Energy Information Administration, *Derivatives and Risk Management in the Petroleum, Natural Gas, and Electricity Industries*, October 2002, Chapter 3, http://www.eia.doe.gov/oiaf/servicerpt/derivative/chapter3.html.

147 http://www.platts.com/.

148 http://www.argusmediagroup.com/.

149 See http://omrpublic.iea.org/pricescrude.asp?cruderegion=%25.

150 See http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_d.htm.

of delivery turns out to be lower than the contract price, then the seller comes out ahead; if the spot price at the time of delivery turns out to be higher than the contract price, then the buyer comes out ahead. The terms for each *futures contract* (including commodity specifications, delivery date, and other conditions) are standardised, and the commodity price for each contract is continually adjusted through trading on exchanges, much like share trading. As with the share market, buyers and sellers deal with each other anonymously. The exchange or its clearinghouse guarantees contract performance. Futures markets are government regulated in order to assure honesty and financial integrity.[151]

No money changes hands when a futures contract is initially established, although both the buyer and the seller must post a substantial cash *margin* to ensure that they can meet their financial obligations. The funds in these margin accounts often earn interest.[152] At the close of each day, if the price of the contract has increased, the buyer's account is credited with the corresponding gain while the seller's account is credited with the corresponding loss. If the price of the contract has decreased, the payments flow the other way. This daily process is known as *marking to market*. Typically, buyers and sellers will close out (by selling or buying back, respectively) their positions prior to the delivery date. Physical delivery of the contracted commodity is rare in futures markets (one reference says less than 2% of the time).[153] In some futures markets, physical delivery is not even a possibility as a cash settlement is made at the cessation of trading based on the spot market price.[154]

The most prominent crude oil futures contract is the New York Mercantile Exchange (or NYMEX) "Light Sweet Crude" contract, for which WTI is one of the deliverable crudes.[155] Because NYMEX prices are easily accessible, the price for the NYMEX light sweet crude contract closest to delivery is frequently quoted in the news media as "the price of oil". Another futures contract, this one for Brent Crude, is traded on the

151 For an overview of futures markets, see National Futures Association, *Opportunity and Risk; an Educational Guide to Trading Futures and Options on Futures,* 2006, http://www.nfa.futures.org/investor/OppRisk/OppRisk.pdf.

152 See Theodore E. Day and Craig M. Lewis, "Margin Adequacy Standards: An Analysis of the Crude Oil Futures Market", *The Journal of Business,* v. 77, no.1, 2004, footnote 12, http://www.journals.uchicago.edu/doi/pdf/10.1086/379863.

153 For a description of the mechanics of oil futures markets see Steven Errera and Stewart L. Brown, *Fundamentals of Trading Energy Futures & Options,* PennWell Books, Tulsa, Oklahoma, 1999, Chapter 2.

154 See, for example, the description of the ICE Middle East Sour Crude Futures Contract on the ICE website https://www.theice.com/productguide/lookupProduct.do, which settles based on the Singapore spot price for Dubai crude.

155 See the "Pricing Differences Among Various Types of Crude Oil" web page on the website of the U.S. Energy Information Administration, http://tonto.eia.doe.gov/ask/crude_types1.html.

Intercontinental Exchange (or ICE) in London.[156] A recent addition, as of 1 June 2007, is the Oman Crude Contract, traded on the Dubai Mercantile Exchange (DME).[157] All three contracts can be traded 5–6 years ahead of delivery.[158]

Beyond futures contracts, there are many *over the counter (OTC)* risk management products. These products are the result of private arrangements between buyers and sellers, usually facilitated by brokers or other financial intermediaries. They are largely unregulated, and buyers and sellers must generally manage the counterparty credit risks themselves. OTC products include *forward contracts*, *options*, and *swaps*, all of which are types of *derivatives*.[159] Some crude oil and oil product options are also traded on exchanges.[160] The major advantage of the OTC products is that they are available in a huge variety to meet virtually any need.

4.2 Market Efficiency and Financial Markets

Quotations from oil futures markets provide us with a ready potential source of forecasts of future crude oil and oil product prices. But how good are they as price forecasts for policy analysis? This answer to the question hinges heavily on one's views about the *efficiency* of financial markets.

The efficiency of financial markets is one of the central questions of financial economics. A financial market that is efficient is defined as one in which everything that is known about the potential future price of a security is already reflected in its price today. Therefore, in an efficient market, one cannot expect to benefit from analysis.

Market efficiency has been most widely studied and discussed in the context of the share market. Here, the efficient market hypothesis would hold that everything that is known about the future value of a company's shares is already reflected in the price of the shares. This implies that, even though shares in some companies may have more risk than others, after adjusting for the risks (that is, after recognising that riskier shares should have correspondingly higher returns), the outlook for future returns on

156 See the ICE website https://www.theice.com/homepage.jhtml.

157 See press release 'Dubai Mercantile Exchange Announces First Official Selling Price (OSP) After Historic Launch', 1 June 2007 on the DME website http://www.dubaimerc.com/archives_2007.html.

158 See the description of the NYMEX light sweet crude contract on the NYMEX website http://www.nymex.com/CL_spec.aspx. See the description of the Brent crude futures contract on the ICE website https://www.theice.com/homepage.jhtml. See the description of the Oman crude contract on the DME website http://www.dubaimerc.com/contractSpecOq.html.

159 A description of these products may be found on the Platt's website at http://www.platts.com/Risk/factfile/index.html. See also Energy Information Administration, *Derivatives and Risk Management in the Petroleum, Natural Gas, and Electricity Industries*, October 2002, Chapter 2, http://www.eia.doe.gov/oiaf/servicerpt/derivative/chapter2.html.

160 See Steven Errera and Stewart L. Brown, *Fundamentals of Trading Energy Futures & Options*, PennWell Books, Tulsa, Oklahoma, 1999, Table 1-2.

the shares of every company should be the same. How can this be, one might ask? Clearly, some companies have more favourable outlooks than others. However, the efficient market hypothesis would hold that the market will push down the market value (share price x number of shares) of the companies with poor prospects, and inflate the market value of the companies with good prospects, to the point where the risk-adjusted outlook for future returns on their shares are much the same.

Although the hypothesis seems a bit counter-intuitive at first, the logic as to how things could work out this way is quite compelling. Suppose that someone has developed a new method for share trading that allows him or her to systematically 'beat the market'. Before too long, word of the method would become generally known and lots of people would be using it. But once lots of people start using the method, share prices in companies favoured by the method would rise and share prices in companies not favoured by the method would fall. Once this adjustment happens, the risk-adjusted outlook for all shares becomes the same again, and the method would cease to beat the market anymore. Conclusion: it is impossible to sustainably beat the market.

If the efficient market hypothesis is really true, the implications for the finance industry are profound. Investors can be comfortable picking shares at random, or more sensibly, buying shares of low-fee index funds that simply buy and hold a cross-section of the shares in the market, and thereby mimic the performance of the broader market. They can stop wasting their time and money on advice from people who claim to help them beat the market.

There is a great deal of empirical work that tends to support the efficient market hypothesis for the share market. The most compelling is perhaps the extensive evidence that actively-managed mutual funds, that is, those run by managers who seek to beat the market, generally deliver performance no better or even worse than a broad share index, despite their much higher fees.[161] On the other hand, there have been a number of studies that have shown apparent anomalies with the efficient market hypothesis—for example that small company shares tend to do better, after adjusting for risk, than large company shares, that 'value' shares do better than 'growth' shares, or that shares do better in January than in other months—although it is not clear that one can actually make money exploiting these apparent anomalies.[162]

161 For an entertaining discussion of this literature, as well as the efficient market hypothesis generally, see Burton G. Malkiel, *A Random Walk Down Wall Street; The Time-Tested Strategy for Successful Investing,* W.W. Norton & Company, New York, 2007, especially pp. 164-170 and 267-270. The author is an economics professor at Princeton University and former member of the U.S. Council of Economic Advisors.

162 See Burton G. Malkiel, *A Random Walk Down Wall Street; The Time-Tested Strategy for Successful Investing,* W.W. Norton & Company, New York, 2007, Chapter 11.

The market efficiency question is, of course, not a black and white one—there are varying definitions and possible degrees of market efficiency. It is the author's view that markets are at least efficient enough in practice that one should be very sceptical of anyone who claims to have a method to 'beat the market'. As a more cynical acquaintance puts it "There are only three places left in the world where they don't believe markets are efficient: North Korea, Cuba, and Wall Street."

4.3 Oil Futures Markets as Predictors of Spot Oil Prices

Oil futures markets are also financial markets, and one might also hypothesise that, like the share market, oil futures markets are reasonably efficient as well. The underlying logic is, again, fairly compelling. Specifically, assume someone has developed a method to systematically predict oil prices better than the futures markets. Anyone who uses the method can, of course, make lots of money trading oil futures. Due to its obvious profitability, word of the method is likely to become known, and attract a wide following. Once it does, however, the futures market prices for oil will adjust to match those of the new method, and the method will lose its advantage. At that point, the futures market is once again restored to efficiency in the sense that there is no method that can systematically predict oil prices better than the futures market itself.

Market efficiency provides a compelling argument for using futures prices as a basis for oil price forecasting in policy analysis. Basically, one can argue that futures market prices should already reflect the best information and analysis that is out there. This certainly does not mean that futures prices will always turn out to be 'right' in the sense that they are accurate predictors of the spot price. The future is inherently uncertain. What it does mean is that one should be very sceptical of anyone who claims to be able to predict future spot market prices better than the futures markets.

There is one frequently-raised objection to the use of oil futures prices in policy analysis that needs to be addressed. This stems from the observation that at any given time, the entire strip of futures prices for oil tends to move in line with the current spot prices, so futures prices never 'predict' a spike in the spot price even when one eventually occurs. This is true, and there is a good reason for it. If futures prices ever showed a big spike relative to the current spot price, a guaranteed method for 'beating the market' would immediately become possible.

The method is to simply use the futures market to lock-in a sale at the high future sale price, and at the same time buy oil in the spot market today to cover the sale. Now store the oil and deliver it when the futures contract expires. As long as the spike in price is at least large enough to cover what it will cost to store the oil and make a normal return on the capital invested in the oil, one could make a market-beating return with no financial risk at all.

Clearly, the futures market cannot allow such a market-beating opportunity to develop. If it ever did, lots of people would attempt to profit from it, and as they did so, either the price for the future would be bid down or the spot price today would be bid up. The futures price and the spot price would then move back into alignment.[163]

The fact that oil prices in the futures markets never show price spikes can leave the misleading impression that the futures markets are simply ignoring upcoming tightness in the physical market that analysts may be generally expecting. This is not the case. Rather, the way futures markets reflect expected upcoming tightness is through a rise in the entire strip of prices, including the current spot price. For although we are accustomed to thinking of the futures market as a derivative of the spot market, the actual causality often works the other way: expectations about the future (as reflected in futures prices) drive the current spot price.

There is another way to look at this lack of price spikes in the futures market quotations that is even more intuitive. Suppose you own a barrel of oil, and the market (as reflected in the futures market prices) is expecting its price to rise rapidly. You would not be very smart to sell it cheaply today. Instead, you will hold out for a higher price, thus helping to drive up the spot price. And so it is that today's spot prices may already reflect any upcoming tightness that is widely expected, even though it is not obvious from looking at the strip of futures market quotations.

4.4 Oil Futures Markets and "Normal Backwardation"

There is, however, one more objection to oil futures markets as predictors of the spot price which has more substance. The beginning of this chapter discussed how companies that produce oil or oil products might want to use futures markets to guarantee the price they will receive in the future, while companies that consume oil or oil products (such as airlines and truck lines) might want to use futures markets to guarantee the price they will have to pay in the future. Both are hedging their risks, and are therefore known as *hedgers*. But what if there is an uneven match between buyers and sellers who need to hedge their risks? One reason this might be the case is that companies that sell oil and oil products are very exposed to price risk, since oil and oil products are usually their principle output. On the other hand, for companies (not to mention consumers) that buy oil and oil products, they are just one of a

163 This arbitrage between spot and futures prices is discussed in Hendrick S. Houthakker and Peter J. Williamson, *The Economics of Financial Markets,* Oxford University Press, New York, 1996, Section 10.2.2.

number of inputs, often a minor one. Also, companies that sell oil and oil products are more exposed to risk because they face costs that are largely fixed if the price of oil drops, while companies that buy oil and oil products can generally pass through some or all of the increase to their customers if the price of oil rises. Hence, hedgers are more likely to want to sell in the oil futures markets than to buy.

Whenever there is an uneven match in the futures market between hedgers who wish to take 'buy' and 'sell' positions, the gap can be met by speculators. These are people who are taking positions in the futures market only in hopes of making money. This sounds bad, and indeed speculators have often been given a bad name in the media. But speculators serve a valuable role in making up for any uneven matches between hedgers, and thereby allowing the market to operate much more smoothly.

However, speculators will accept risk only if they expect to be rewarded. In particular, speculators will only be willing to buy in the oil futures market if they believe the current futures price is less than what the corresponding spot price will be on the delivery date. Hence, the Theory of Normal Backwardation argues that futures prices should systematically under-predict the spot price.

The empirical evidence for the Theory of Normal Backwardation for futures markets in general is mixed.[164] The author's interpretation of the specific research devoted to oil futures is that there is evidence to support the theory for oil futures, although it is certainly not conclusive.[165]

Does this mean that futures prices are not good predictors of spot prices? Clearly, the answer depends upon how large the downward bias in futures prices tends to be. The author would argue that the bias should be fairly small in the long run. After all, if it were large, buying oil futures would become an easy way to 'beat the market', which would attract lots of speculative buyers, which would drive down the size of the bias. Conclusion: while downward bias due to normal backwardation is worth noting, its real-world significance to the price projections used in policy work is probably limited.

164 The Theory of Normal Backwardation is discussed in Hendrick S. Houthakker and Peter J. Williamson, *The Economics of Financial Markets,* Oxford University Press, New York, 1996, Sections 10.3 and 10.4.

165 See Cindy W. Ma, "Forecasting Efficiency of Energy Futures Prices", *Journal of Futures Markets,* v. 9, no. 5, 1989, pp. 393-419; Richard Deaves and Itzhak Krinsky, "Risk Premiums and the Market for Crude Oil Futures", *Energy Journal,* v. 13, no. 2, 1992, pp. 93-117; Neil Kellard, et al, "The Relative Efficiency of Commodity Futures Markets", *Journal of Futures Markets,* v. 19, no. 4, 1999, pp. 413-432; Sergey V. Chernenko, Krista B. Schwarz, and Jonathan H. Wright, "The Information Content of Forward and Futures Prices: Market Expectation and Market Risk", *International Finance Discussion Papers, Federal Reserve Board,* Number 808, June 2004, http://www.federalreserve.gov/pubs/IFDP/2004/808/ifdp808.pdf; Mark W. French, "Why and When Do Spot Prices of Crude Oil Revert to Futures Price Levels", *Finance and Economics Discussion Series, Divisions of Research & Statistics and Monetary Affairs, Federal Reserve Board,* June 2005, http://www.federalreserve.gov/pubs/feds/2005/200530/200530pap.pdf.

5 New Zealand's Oil Industry

Although New Zealand is heavily dependent on imported oil, it does have a modest indigenous oil industry. In 2007, New Zealand produced about 14.9 million barrels of oil and another 1.4 million barrels of LPG.[166] This is less than Saudi Arabia produces in two days,[167] but since New Zealand's population is small, it does still meet about a third of New Zealand's demand.[168] New Zealand's production is growing rapidly, however, with 2007 production roughly double that of 2006.[169] There are two new fields, Pohokura and Tui, which entered production in 2006 and 2007, respectively. There are two additional fields expected to be in production by 2010: Maari and Kupe. The four fields together are expected to add 140 million barrels of reserves.[170] And there is good potential that significantly more may be discovered over the next few years.

5.1 New Zealand's Crown Estate

In New Zealand, the Crown today owns all petroleum resources regardless of the ownership of the land. Under English Common Law, rights to petroleum were held by the landowners where the land was privately owned. However, the Petroleum Act of 1937 effectively nationalised these rights.[171] Privately-owned mineral rights still exist in New Zealand for some minerals, but not for petroleum, gold, silver, and uranium.[172]

166 The 2007 oil production figure will be published in Table D2.b of the upcoming 2008 edition of MED's *New Zealand Energy Data File*. 'Oil' includes crude oil, condensate, and naphtha. LPG are figures from the 'Energy Data' section of MED's website, http://www.med.govt.nz/upload/37370/A-oil-tables-14.xls, which shows 2007 LPG production as 118.1 kt. According to MED, *New Zealand Energy Data File*, June 2007, http://www.med.govt.nz/energy/edf/2007/, Table L.2b, LPG 60/40 has a density of 0.534 kg/litre. This implies 2007 production of 118.1 kt x 1,000,000 kg/kt / (0.534 kg/litre x 159 litres/barrel) = 1.39 million barrels.

167 See BP, *Statistical Review of World Energy 2008,* http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622, p. 6, which shows that in 2007 Saudi Arabia was producing about 10 million barrels per day.

168 A self-sufficiency figure of 32% will be published in the introduction to the oil section of the upcoming 2008 edition of MED's *New Zealand Energy Data File*. 'Oil' includes crude oil, condensate, and naphtha.

169 See Ministry of Economic Development, *New Zealand Energy Data File*, June 2007, http://www.med.govt.nz/energy/edf/2007/, Table D.2b, which shows 2006 oil production as 6.8 million barrels.

170 See press release from Rt. Hon. Helen Clark, "Tui Area Oil Development", 16 August 2007, http://www.beehive.govt.nz/speech/tui+area+oil+development.

171 For a legal history of petroleum mineral ownership in New Zealand, see the Waitangi Tribunal, *Petroleum Report,* http://www.waitangi-tribunal.govt.nz/reports/view.asp?reportid=a181419d-48ad-4ecf-98bc-439454654765, especially chapters 3 and 4.

172 See Rob Harris (editor), *Handbook of Environmental Law,* Royal Forest and Bird Protection Society of New Zealand, Wellington, 2004, p. 279.

Petroleum rights have been a sensitive issue for Maori, with the Waitangi Tribunal concluding "that the expropriation of the pre-existing Maori rights to petroleum arose from a context riddled with breaches of the Treaty", and recommending "that the Crown and affected Maori groups negotiate for the settlement of petroleum grievances".[173] The government did not accept this recommendation arguing that "Crown policy and legislation regarding petroleum were a valid exercise of the Crown's Treaty rights in 1937 and remain so."[174]

The Crown mineral estate, including petroleum, is administered by the Crown Minerals Group in the Ministry of Economic Development. Crown Minerals administers a three-stage permitting process, with separate permits required to prospect, explore, and mine for petroleum. Winning an exploration permit is probably the key step for any company wishing to produce oil in New Zealand, since the holder of an exploration permit is generally entitled to an exclusive right to explore for petroleum on a given block of land, and to apply for a mining permit to produce any oil it may discover. Prospecting permits, on the other hand, are not exclusive and do not grant the holder any subsequent rights. [175]

Crown Minerals offers exploration permits for specific blocks of land on an irregular basis, as authorised by the Minister of Energy.[176] An "Indicative Petroleum Exploration Permit Blocks Offers Schedule" is published on the Crown Minerals website giving areas of proposed future block offers but not the actual blocks or specific timing of the block offers.[177]

The blocks are allocated by competitive tender. Generally, blocks are allocated by 'staged work programme' bidding, which means that bids are evaluated based on a variety of criteria related to the quality of the applicant's proposed work programme and the ability of the applicant to carry it out successfully.[178] For areas of high

173 See the "Petroleum Report Summary Page" on the Waitangi Tribunal website http://www.waitangi-tribunal.govt.nz/reports/summary.asp?reportid=%7BA181419D-48AD-4ECF-98BC-439454654765%7D.

174 See press release from Hon. Pete Hodgson, "Government Response to Waitangi Tribunal's Petroleum Report", 21 November 2003, http://www.beehive.govt.nz/release/government+response+waitangi+tribunal039s+petroleum+report.

175 See the "What are the different types of permits" page on the Crown Minerals website http://www.crownminerals.govt.nz/cms/petroleum/permits-content/permits-how-do-i-apply-faqs-1/what-are-the-different-types-of-permits.

176 See the *Minerals Programme for Petroleum 2005* available on the Crown Minerals website at http://www.crownminerals.govt.nz/cms/pdf-library/petroleum-legislation-1/mins-prog-for-petroleum-2005.pdf, sections 5.4.5-5.4.15.

177 See http://www.crownminerals.govt.nz/cms/petroleum/blocks-offers/indicative-petroleum-exploration-permit-blocks-offers-schedule.

178 The allocation process for Staged Work Programme Bidding is described in the *Minerals Programme for Petroleum 2005* available on the Crown Minerals website at http://www.crownminerals.govt.nz/cms/pdf-library/petroleum-legislation-1/mins-prog-for-petroleum-2005.pdf, sections 5.4.14-5.4.38.

prospectivity, the rules also allow a cash bonus bidding system, where the block is allocated to the applicant making the highest cash bid.[179]

Applications for exploration permits are also accepted for available land not already under permit, block offer, or in the Indicative Petroleum Exploration Permit Blocks Offers Schedule. Provided the proposed work programme is satisfactory, these will be awarded on a 'Priority in Time' basis—that is, first come, first served.[180]

If oil is found, and a mining permit obtained, a royalty of 5% of the net revenues or 20% of the accounting profit, whichever is higher, is generally charged on any oil production.[181] In addition to a mining permit, there are several other requirements that a company seeking to produce oil must satisfy: if the land is privately-owned, access to the land must be secured from the landowner or the company must own the land themselves; all necessary resource consents under the Resource Management Act must be obtained; and any other necessary permits (such as building consents) must be obtained.[182]

5.2 New Zealand's Undersea Jurisdictions

Crown Minerals has a lot of land on which to potentially issue exploration permits. Most of this is not 'land' in the ordinary meaning of the word but undersea territory. Under the United Nations Law of the Sea Convention, New Zealand administers a sequence of jurisdictional rights over its surrounding waters:

- **Territorial Waters** (12 nautical miles from land) – Here New Zealand has 'full sovereign rights' subject to a few restrictions, such as the obligation to allow vessels from other nations 'innocent passage'.
- **Contiguous Zone** (24 nautical miles from land) – In this part of the Exclusive Economic Zone (see next bullet) New Zealand may continue to enforce laws related to customs, taxes, immigration, and sanitation.

179 The allocation process for Cash Bonus Bidding is described in the *Minerals Programme for Petroleum 2005* available on the Crown Minerals website at http://www.crownminerals.govt.nz/cms/pdf-library/petroleum-legislation-1/mins-prog-for-petroleum-2005.pdf, sections 5.2.1-5.2.2.

180 The Priority in Time application process is described in the *Minerals Programme for Petroleum 2005* available on the Crown Minerals website at http://www.crownminerals.govt.nz/cms/pdf-library/petroleum-legislation-1/mins-prog-for-petroleum-2005.pdf, sections 5.4.39-5.4.44.

181 See the "Royalty Regime" page on the Crown Minerals website http://www.crownminerals.govt.nz/cms/petroleum/legislation/royalty-regime?searchterm=Petroleum%20Royalty.

182 See Rob Harris (editor), *Handbook of Environmental Law,* Royal Forest and Bird Protection Society of New Zealand, Wellington, 2004, p. 281-282.

- **Exclusive Economic Zone or EEZ** (200 nautical miles from land) – Here New Zealand has 'sovereign rights'– a more limited jurisdiction than sovereignty – for the purposes of exploring and exploiting, conserving and managing natural resources of the waters, seabed, and subsoil.
- **Continental Shelf** (to outer edge of continental margin) – 'Sovereign rights' (as for the EEZ) for the purpose of exploring and exploiting the natural resources of the seabed and subsoils (including immobile organisms which live on or under the seabed/subsoil), but not fish or the water itself.[183]

In all of these areas, New Zealand has ownership of any petroleum. Because New Zealand is surrounded by water with no nearby neighbours, this is a huge area. New Zealand's EEZ and Continental Shelf are approximately 20 times New Zealand's land area, or about three-quarters the size of Australia.[184] Comparing nations of the world by land area combined with territorial waters and EEZ, New Zealand would rank as the tenth largest country in the world.[185] New Zealand recently completed a 10-year project to delineate its Continental Shelf boundaries, and submitted these to the United Nations Commission on the Limits of the Continental Shelf (CLCS) in 2006. The Continental Shelf around New Zealand extends out quite far, and is expected to add almost another 50% to New Zealand's "area".[186] The CLCS is not expected to conclude its consideration of New Zealand's submission until mid-2008.[187]

5.3 New Zealand's Oil Resources

The big question is, of course, how much oil is there in this huge area? This is not an easy question to answer.

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183 See the chart "Jurisdictional boundaries and areas defined by the United Nations Convention on the Law of the Sea (UNCLOS) and under domestic legislation" on the Ministry for the Environment website http://www.mfe.govt.nz/issues/oceans/jurisdictional.html.

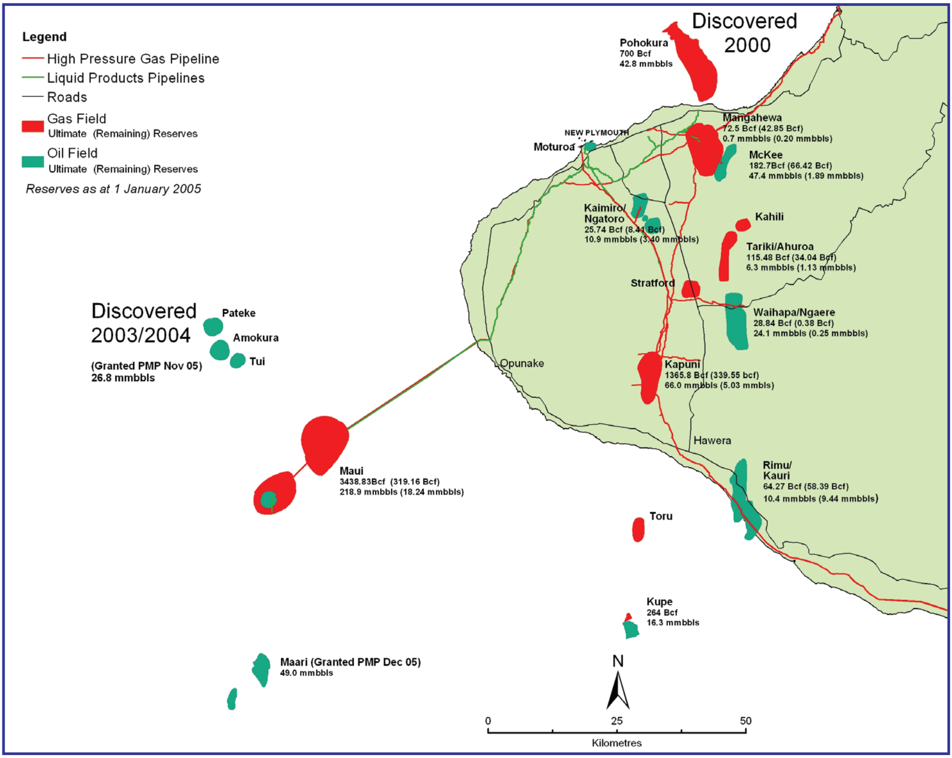
184 See "NZ's Offshore Territory—Turning Uncertainty Into Opportunity", *CAE InfoDirect*, New Zealand Centre for Advanced Engineering, Issue 42, November 2007, http://www.caenz.com/info/publications/newsletters/other_pubs.html#Back, p. 6-7; see also "Introduction to Offshore Options" page on the Ministry for the Environment website http://www.mfe.govt.nz/publications/oceans/offshore-options-jun05/html/page3.html.

185 See the chart in the Wikipedia article "Exclusive Economic Zone" http://en.wikipedia.org/wiki/Exclusive_economic_zone.

186 See the Land Information New Zealand *New Zealand Continental Shelf Report*, Newsletter 8, April 2006, http://www.linz.govt.nz/docs/hydrography/currentprojects/continentalshelf/newsletter-apr06.pdf.

187 See the MFAT "New Zealand's Continental Shelf and Maritime Boundaries" web page at http://www.mfat.govt.nz/Treaties-and-International-Law/04-Law-of-the-Sea-and-Fisheries/NZ-Continental-Shelf-and-Maritime-Boundaries.php.

FIGURE 6 TARANAKI OIL AND GAS FIELDS[188]



All of New Zealand's oil production today is from the Taranaki region. Figure 6 shows the oil and gas fields of the Taranaki region. In 2007, over 90% of New Zealand's oil production came from the Tui, Pohokura, Maui, and Kapuni fields.[189]

The Taranaki Basin is only moderately explored compared to basins worldwide, despite evidence that there is significant potential for further discoveries.[190] The Taranaki Basin covers about 100,000 square kilometres, but there have only been about 350 exploration wells drilled there since 1955.[191] One paper by Christopher

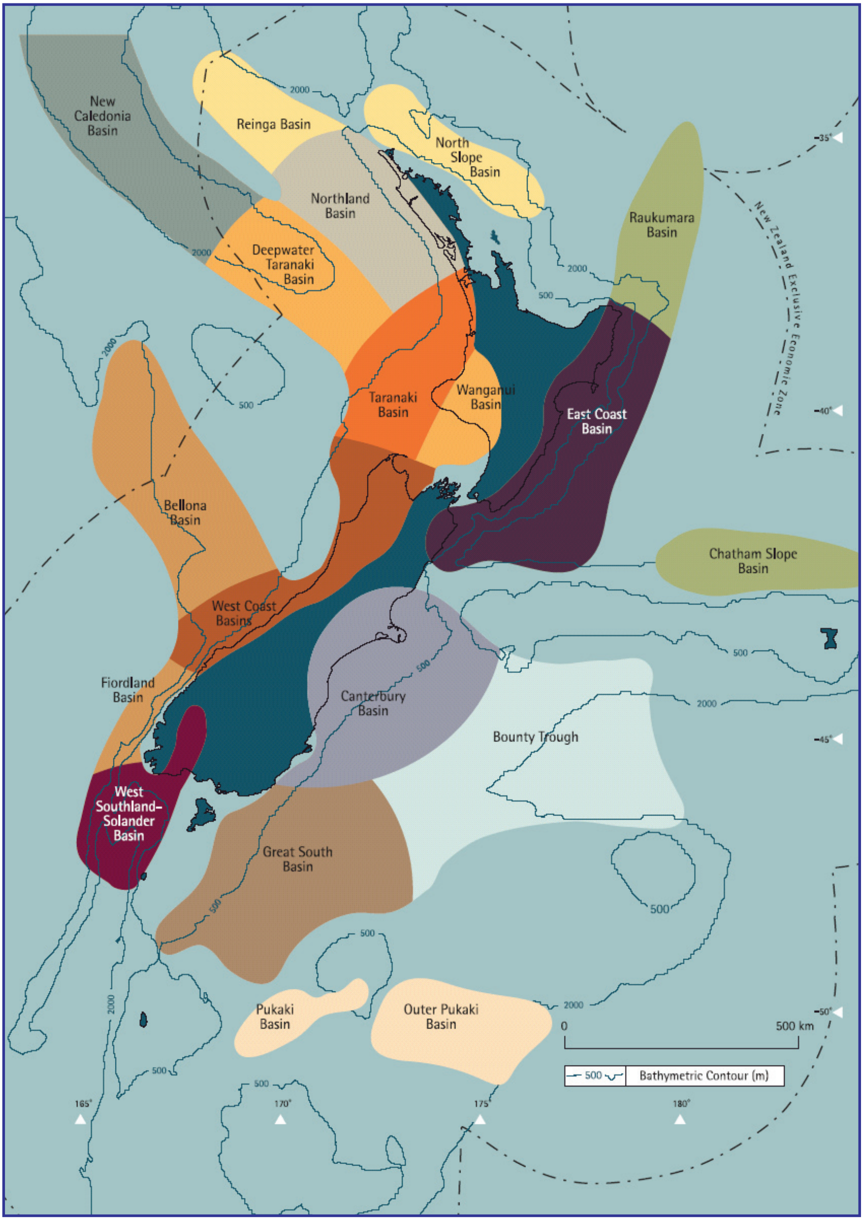
188 From the Crown Minerals website http://www.crownminerals.govt.nz/cms/images-old/petroleum/full-size-images/taranaki_infrastructure_basin_map.gif.

189 The 2007 oil production figures will be published in Table D2.b of the upcoming 2008 edition of MED's *New Zealand Energy Data File*. 'Oil' includes crude oil, condensate, and naphtha.

190 See the Crown Minerals 'Petroleum Basins' web page http://www.crownminerals.govt.nz/cms/petroleum/petroleum-basins.

191 See the Crown Minerals 'Taranaki Basin' web page http://www.crownminerals.govt.nz/cms/petroleum/petroleum-basins/taranaki-basin.

FIGURE 7 NEW ZEALAND PETROLEUM BASINS[192]



192 From the Crown Minerals website http://www.crownminerals.govt.nz/cms/pdf-library/petroleum-basins-1/NZ_hydrocarbon_basins.pdf.

Uruski of the Institute of Geological and Nuclear Sciences and Peter Baillie of TGS-NOPEC Geophysical Company[193] suggests that the Deepwater Taranaki Basin could contain as much as 20 billion barrels of trapped oil. Uruski was quoted in a media article as saying that "If 50 percent is ultimately discovered, perhaps five billion barrels may be produced from that basin."[194] This would give New Zealand an amount of oil larger than the UK's current North Sea reserves.[195]

As shown in Figure 7, there are several other petroleum basins. However, to quote a Crown Minerals publication,

> "Northland, the offshore West Coast, Canterbury, Western Southland and the Great South Basin are barely explored yet have strong similarities with Taranaki in their petroleum systems and the quality of structural leads."[196]

The number of exploratory wells drilled outside Taranaki so far is extremely small. There have been 38 wells drilled in the East Coast Basin, only two of them offshore. In none of the other basins have more than 11 total wells or 8 offshore wells been drilled.[197] However, even with the limited exploration, an onshore gas discovery was made in the East Coast Basin in 1998, while sub-commercial discoveries have also been made in the offshore Canterbury and Great South basins.[198]

Given the apparently attractive geology in New Zealand, why the low level of exploration? Much of it probably relates to the limited size of the gas market in New Zealand. Oil and gas are generally found together, with gas being commonly viewed in the industry as the consolation prize when oil is not discovered. A modest New Zealand gas discovery would find a ready market in New Zealand, but, if the gas were outside the Taranaki Basin, only after an extensive investment in pipeline infrastructure. Such an investment might or might not be economic. A larger gas discovery might depress gas prices in New Zealand too much, making it more attractive to invest in a liquefied natural gas (LNG) plant to allow the gas to be exported. However, the cost of building and operating the LNG plant would significantly cut into the value of the gas

193 Chris Uruski and Peter Baillie, "Petroleum systems of the Deepwater Taranaki Basin, New Zealand", presentation to the New Zealand Petroleum Conference 2002, http://www.crownminerals.govt.nz/cms/petroleum/conferences/conference-proceedings-2002-1#taranaki.

194 See "Deep Kiwi Waters Hold Promise", AAPG Explorer, October 2006, http://www.aapg.org/explorer/2006/10oct/new_zeal.cfm.

195 See BP, *Statistical Review of World Energy 2008*, http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622, p.6, which shows end 2007 UK oil reserves of 3.6 million barrels.

196 See Ministry of Economic Development, Crown Minerals, *New Zealand's Petroleum Basins,* 2004, p. 3, http://www.crownminerals.govt.nz/cms/petroleum/publications.

197 See the Crown Minerals "Petroleum Basins" web pages on each basin http://www.crownminerals.govt.nz/cms/petroleum/petroleum-basins.

198 See the "Overview" page of the Crown Minerals website http://www.crownminerals.govt.nz/cms/petroleum/overview.

at the wellhead. Thus a gas discovery in New Zealand is perceived in the industry as having considerably less value than a gas discovery where a large market for the gas is close at hand. This is an important consideration, since the industry tends to view New Zealand's geology as gas-prone, rather than oil-prone.[199]

An additional impediment is that many of the best potential drilling sites in New Zealand are distant from shore, in deep water, and exposed to severe sea and weather conditions. These factors, combined with New Zealand's general remoteness, make drilling in New Zealand an expensive proposition. However, rising oil and gas prices worldwide and improved industry technology combine to make the economics of New Zealand exploration more attractive than it has been in the past.[200] Currently, interest centres on the Great South Basin southeast of the South Island, where Crown Minerals recently awarded exploration permits to two consortiums of oil companies who are expected to spend $1.2 billion on exploration.[201]

5.4 The New Zealand Oil Product Market

The New Zealand market for oil products is supplied by four major oil companies, BP, Chevron (marketing as Caltex), Mobil (an affiliate of ExxonMobil) and Shell, as well as one independent, Gull.[202] Oil products are supplied by New Zealand's only refinery situated at Marsden Point near Whangarei[203] and from direct imports, primarily from Australia, Singapore,[204] and North Asia.

The Marsden Point refinery[205] is owned by the New Zealand Refining Company (NZRC). NZRC is 73% owned by the four major oil companies, with the remaining 27% held by institutional and individual investors (the company is listed on the New Zealand Stock Exchange). The refinery is unusual for the Asia-Pacific region in

199 For a discussion of New Zealand's current exploration situation, see Geoff Cumming, "Black Gold or a Fool's Errand", *New Zealand Herald,* 28 July 2007, http://www.nzherald.co.nz/author/story.cfm?a_id=88&objectid=10454288.

200 For a discussion of issues inhibiting exploration in New Zealand see GNS News Release "Comparisons Stack Up Well for Offshore Taranaki, Geoscientist Says", 27 March 2003, http://www.gns.cri.nz/news/release/taranaki.html.

201 See press release from Hon. Harry Duynhoven, "Great South Basin oil and gas quest set to begin", 11 July 2007, http://www.beehive.govt.nz/release/great+south+basin+oil+and+gas+quest+set+begin+0.

202 See Ministry of Economic Development, *New Zealand Energy Data File*, June 2007, http://www.med.govt.nz/energy/edf/2007/, Figure D.1 for an overview of the New Zealand oil product supply chain.

203 See Ministry of Economic Development, *New Zealand Energy Data File*, June 2007, http://www.med.govt.nz/energy/edf/2007/, p. 33.

204 See Ministry of Economic Development, *New Zealand Energy Data File*, June 2007, http://www.med.govt.nz/energy/edf/2007/, p. 125.

205 Unless otherwise noted, information about the Marsden Point refinery is quoted or drawn from Covec, Hale & Twomey, and Exergi Consulting, *Heavy Industry Energy Demand, August 2006,* Chapter 5, http://www.med.govt.nz/templates/MultipageDocumentTOC____21873.aspx.

that it is a tolling operation that charges a fee for its customers (primarily the four major oil companies) to process their oil. This is in contrast to the usual arrangement where each oil company owns a refinery and it is an integrated part of the processes involved in getting the oil products to market. In 2006 products sourced from the NZRC refinery provided about 70% of New Zealand's demand.[206]

While the refinery is significant in the New Zealand market, it is a small refinery by international standards. NZRC capacity is approximately 110,000 bbl/day, which is a fraction of the size of some of the major Asian export refineries: South Korea has one with a capacity of 817,000 bbl/day, for example.[207] However NZRC has an advantage in the New Zealand market due to its location. Crude oil is imported into New Zealand on ships of up to 140,000 tonnes. While these often come from a greater distance than product imports (the Middle East is a major supplier), product imports are typically supplied on ships of 35,000 tonnes. The greater scale of crude shipments means that it is more cost effective to ship crude than product giving NZRC a competitive advantage for supplying New Zealand of between US$0.50–US$1.00/barrel versus a refinery in another location. However this competitive advantage tends to work in reverse if NZRC exports, which is why it is commercially prudent for NZRC to avoid investment in capacity surplus to the New Zealand market requirement.

Of the crude and feedstock processed at NZRC typically around 50-60% will come from the Middle East, 30–40% from the Far East/Northern Australia with the balance supplied by domestic production. New Zealand's domestic production tends to be lighter and sweeter (and therefore higher price) than needed by NZRC.[208] Therefore, in 2007, 86% of New Zealand-produced crude oil, condensate, and naphtha were exported.[209]

A refinery-owned pipeline transports about a third of the refinery's production to bulk storage facilities at Wiri in South Auckland to supply the Auckland area, which is New Zealand's major market for oil. Another pipeline carries jet fuel from Wiri to Auckland International Airport. Most of the rest of New Zealand receives its oil

206 See Ministry of Economic Development, *New Zealand Energy Data File*, June 2007, http://www.med.govt.nz/energy/edf/2007/, Table D.5. This calculation includes 'International Transport' in New Zealand demand.

207 See the U.S Energy Information Administration "South Korea – Oil" page, http://www.eia.doe.gov/emeu/cabs/South_Korea/Oil.html.

208 See Covec and Hale & Twomey, *Oil Security; Final Report*, February 2005, http://www.med.govt.nz/upload/25065/adjusted-final.pdf, p. 12.

209 Based on 2007 oil production and export figures to be published in Table D.3 of the upcoming 2008 edition of MED's *New Zealand Energy Data File*. 'Oil' includes crude oil, condensate, and naphtha.

products from coastal tankers supplying port depots. Each port depot has storage facilities from which the products may be distributed by truck to service stations and other major users.[210] Direct product imports are delivered to these same locations. Gull has its own storage facilities at Tauranga.[211]

Oil companies compete with each other in the consumer market. However, they do have some common interests. Oil product shipped from the refinery is carried in two ships. These are scheduled and managed by a single company, Coastal Oil Logistics Limited, on behalf of the four oil majors.[212] The four oil majors also pool their storage throughout the country, with each company allowed to draw product from any location subject to limits primarily related to each company's contribution to the combined stock.[213]

5.5 Investigations of Market Competitiveness

Naturally, with so few competitors supplying the oil product market, as well as the shared use of the refinery and the other common interests described above, the oil companies must be very careful to avoid any appearance of anti-competitive behaviour. With the exception of one apparently isolated incident, they have so far avoided any problems with the law.

Competition law in New Zealand is governed by the Commerce Act of 1986, with enforcement handled by the Commerce Commission.[214] The Commerce Commission itself has conducted only one inquiry into the overall oil products market since the mid-1990s. This was an investigation of petrol price increases between July and November 1999. The timing of the companies' announcements of the price increases, and the manner in which they were communicated, apparently raised suspicions of collusive behaviour. However, the Commission's report concluded:

> "that there is no evidence of collusive behaviour amongst the oil companies and that their respective price rises, though closely following or matching each other, can be justified by the substantial increases in the cost of crude oil and imported petrol, and

210 See Ministry of Economic Development, *New Zealand Energy Data File*, June 2007, http://www.med.govt.nz/energy/edf/2007/, p. 34.

211 See Covec and Hale & Twomey, *Oil Security; Final Report*, February 2005, http://www.med.govt.nz/upload/25065/adjusted-final.pdf, p. 13.

212 See the Coastal Oil Logistics Limited website http://www.coll.co.nz/Article.aspx?ID=119.

213 See Covec and Hale & Twomey, *Oil Security; Final Report*, February 2005, http://www.med.govt.nz/upload/25065/adjusted-final.pdf, p. 14.

214 See the Commerce Commission website "Business Competition" page, http://www.comcom.govt.nz/BusinessCompetition/Overview.aspx.

> the operation of competitive pressures. However the time period between some of the announcements of price increases and the implementation of those increases might be argued to be price signalling."[215]

Another investigation with a more limited scope, but the only one that resulted in the Commission actually charging the oil companies with wrongdoing, was a case alleging that three of the major oil companies had colluded in 1996 to withdraw an offer of a free car wash to customers who spent $20 or more on fuel at some of their Auckland service stations. The High Court ordered the companies to pay a combined total of $1.175 million in penalties for price-fixing.[216]

Two other official investigations into the competitive situation in the New Zealand oil industry are worthy of note. In 1997 the Ministry of Commerce (a predecessor agency to the Ministry of Economic Development) engaged Australian consultants ACIL Economics and Policy Pty Ltd to investigate whether a perceived lack of price competition in the New Zealand market for petroleum products could be explained by barriers to entry for new competitors. Examples of such barriers might include access to port storage facilities and contractual arrangements with independent retailers.[217] However, the study concluded that:

> "there are no persistent long run barriers to entry into the New Zealand downstream oil industry…Any intervention to facilitate entry would introduce inefficiencies into the market."[218]

In 2001, the Ministry of Economic Development (MED) received complaints that independent petrol retailers were having difficulty remaining in business due to inequitable wholesale pricing by the oil companies. The MED responded by engaging the New Zealand Institute for Economic Research (NZIER) to examine the role of independent retailers in the retail petrol market.[219] NZIER's report acknowledged

215 See Commerce Commission memorandum J3484 from Nicky Beechey to Geoff Thorn, "Investigation Report into Petrol Price Increases July-November 1999", 20 December 1999 available from the Commerce Commission Library.

216 See "Caltex, Mobil and Shell were price fixing: High Court imposes $1.175 million penalties" in the Commerce Commission's newsletter *Fair's Fair*, Issue No. 61, March 2000, http://www.comcom.govt.nz/Publications/ArchivedPublications/ContentFiles/Documents/ffmar2000.pdf, p. 3. A more detailed summary of the case of Commerce Commission vs. Caltex New Zealand Ltd, (1999) 9 TCLR 305, is available from Brookers On-Line, http://www.brookersonline.co.nz.

217 See ACIL Economics & Policy Pty Ltd, *Barriers to Entry to the New Zealand Downstream Oil Market,* Ministry of Commerce, August 1997, http://www.med.govt.nz/upload/20284/acil2.pdf, p. 9.

218 See ACIL Economics & Policy Pty Ltd, *Barriers to Entry to the New Zealand Downstream Oil Market,* Ministry of Commerce, August 1997, http://www.med.govt.nz/upload/20284/acil2.pdf, p. 7-8.

219 See the "Review of the Role of Independent Petrol Retailers" page on the Ministry of Economic Development website http://www.med.govt.nz/templates/ContentTopicSummary____10384.aspx.

that independent retailers were disadvantaged in terms of pricing arrangements compared with wholesaler-owned retailers, and that most of the low volume sites could close.[220] However, NZIER took the view that the closure of low volume sites, which were primarily owned by independents, was economically efficient. They concluded that:

> "the rationalisation of petroleum retailing is not reducing overall competition and thus not wasting resources or harming consumers. As a result, no intervention is warranted."[221]

220 See New Zealand Institute for Economic Research, *The Decline of Independent Petrol Retailing; Rationalisation or Predation?*, Report to the Ministry of Economic Development, April 2002, http://www.med.govt.nz/upload/20465/report.pdf, Section 3.5.

221 See New Zealand Institute for Economic Research, *The Decline of Independent Petrol Retailing; Rationalisation or Predation?*, Report to the Ministry of Economic Development, April 2002, http://www.med.govt.nz/upload/20465/report.pdf, Executive Summary.

6 Oil: The Consumer Side

Some basic statistics illustrate the importance of oil to New Zealand consumers and explains why oil has become so problematic. New Zealand currently relies on oil for 51% of its *consumer energy*. [222] Spot prices for crude oil in current U.S. dollars have increased by more than a factor of eight between 1998 and 2008.[223] Liquid fuels, virtually all of which are derived from oil, account for 51% of New Zealand's *greenhouse gas emissions* from energy use.[224]

6.1 Elasticity of Demand

The response of demand for a product to a change in price is typically measured in terms of *elasticity of demand*. Elasticity of demand is the percentage change in demand that results from a one percent increase in price. So, for example, if a one percent price increase in a commodity results in a one-half percent decrease in demand, the elasticity would be -0.5. Products which are 'necessities' typically have small (nearer to zero) elasticities of demand, while products that are 'luxuries' have bigger (that is, more negative) elasticities of demand. Another factor which makes oil so problematic is that transport fuel tends to fall into the 'necessity' category for many people, and therefore displays a notoriously low elasticity of demand. This implies that if a policymaker wishes to limit transport fuel demand with price-based mechanisms, such as fuel taxes, the price increases will have to be quite large to have a significant impact on demand.

A recent review of New Zealand consumer response to petrol price changes for Land Transport New Zealand by consultants Booz-Allen-Hamilton[225] (BAH) provides the first comprehensive study of petrol price elasticity in New Zealand. BAH estimated the elasticity of demand for petrol at -0.15 for the short-term (less than 1 year) and

222 See Ministry of Economic Development, *New Zealand Energy Data File*, June 2007, http://www.med.govt.nz/energy/edf/2007/, Table A.4a.

223 1998 WTI spot price of US$14.39/barrel from BP, *Statistical Review of World Energy 2008*, http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622, p. 16. Price quote of US$129/barrel as of 21 May 2008 from Bloomberg.com http://www.bloomberg.com/markets/commodities/energyprices.html.

224 See Ministry of Economic Development, *New Zealand Energy Greenhouse Gas Emissions 1990-2006*, http://www.med.govt.nz/energy/ghg/2007/, Table 2.1

225 David Kennedy and Ian Wallis (Booz-Allen-Hamilton (NZ) Ltd.), *Impacts of Fuel Price Changes on New Zealand Transport*, Land Transport Research Report 331, 2007, http://www.landtransport.govt.nz/research/reports/331.pdf.

-0.20 for the medium-term (greater than two years). One would expect the medium and long-term elasticity to be larger (more negative) than the short-term elasticity, since consumers may respond to price increases by making changes that take time, such as buying a more fuel-efficient vehicle or moving closer to where they work.

Elasticities are useful in that they can be used to provide rough estimates for how consumers will respond to a change in price. One might assume that if the elasticity indicates that a one percent increase in price results in an e percent decline in demand (that is, an elasticity of -e), then a 10 percent increase in price would result in a 10e percent decline in demand. This is not, however, correct. The reason is that the percentage changes in demand have to be compounded, much like bank interest. The correct calculation is:

$$\text{New Demand/Old Demand} = (\text{New Price/Old Price})^{e}.$$

So, for example, if the short-term elasticity is -0.15 (as the BAH study found), then one might estimate the impact of doubling petrol prices as:

$$\text{New Demand/Old Demand} = 2.0^{-0.15} = 0.9013.$$

That is, a doubling of petrol prices (a 100% increase) results in only about a 10% (100 – 90.13%) short-term reduction in petrol demand! Even over the medium-term, where the elasticity of demand would be -0.2:

$$\text{New Demand/Old Demand} = 2.0^{-0.2} = 0.8706,$$

or about a 13% reduction in demand.

The BAH demand elasticity estimates tend to be low compared to estimates for other countries.[226] However, one would expect demand elasticities in New Zealand to be lower than in many countries, since New Zealanders have fewer attractive alternatives to driving (such as public transport and cities suited to walking and cycling) than residents of many other countries. These elasticities suggest that attempting to limit demand for transport fuel through price-based measures would be challenging.

6.2 Fuel Taxation

New Zealand is unusual in having very different tax regimes for petrol and diesel vehicles. Petrol vehicles are taxed primarily through cents/litre taxes on petrol. Current levels of these taxes are as shown in Table 2. Beginning 1 July 2008, all petrol

226 See the discussion of fuel price elasticities in Ministry of Economic Development, *New Zealand's Energy Outlook to 2030; Final Publication,* September 2006, http://www.med.govt.nz/energy/eo/2006/, Section 6.4

tax revenue will be dedicated to the National Land Transport Fund, rather than a share being used as general Crown revenue.[227]

TABLE 2 PETROL TAXES IN NEW ZEALAND AS OF 30 JUNE 2008[228]

Tax	Amount	Use of Funds
Excise Duty on Motor Spirits	42.524 cents/litre	18.708 cents/litre Crown Revenue 23.816 cents/litre National Land Transport Fund for roads and public transport
Petroleum Fuels Monitoring Levy	0.025 cents/litre	Fuels Quality Monitoring and Enforcement (see Section 6.4)
Accident Compensation Corporation (ACC) Levy	7.33 cents/lire	ACC
Local Authority Petroleum Tax	0.66 cents/litre	Local Authority General Revenue

LPG and CNG used by road vehicles are also subject to cents/litre taxes, although at a considerably lower rate,[229] reflecting a historical policy preference for these fuels for energy security and air quality reasons. All fuels are subject to 12.5% goods and services tax (GST) on the sale price, including any cents/litre taxes.[230]

Diesel fuel, on the other hand, is subject only to a 0.33 cents/litre Local Authority Tax, a 0.025 cents/litre Petroleum Fuels Monitoring Levy,[231] and 12.5% GST on the sale price. This explains why diesel fuel is generally significantly cheaper than petrol when

227 See press release from Hon. Annette King, "Fuel Excise Duty Will Revenue Will All Be Used on Land Transport", 25 July 2007, http://www.beehive.govt.nz/release/fuel+excise+duty+revenue+will+all+be+used+land+transport.

228 Tax rates are taken from Ministry of Economic Development website "Duties, Taxes, and Direct Levies on Motor Fuels" page, http://www.med.govt.nz/templates/Page____12961.aspx. The Petroleum Fuels Monitoring Levy is explained in Ministry of Transport, *Biofuels Sale Obligation Discussion Document,* September 2006, Glossary, http://www.transport.govt.nz/glossary/. Other use of funds are explained in speech by Roger Toleman, Deputy Secretary for Transport, *Fund and Deliver,* 5 September 2003, http://www.transport.govt.nz/toleman050903/.

229 See Ministry of Economic Development website "Duties, Taxes, and Direct Levies on Motor Fuels" page, http://www.med.govt.nz/templates/Page____12961.aspx.

230 See the AA Website "Petrol Tax" page, http://www.aa.co.nz/about/issues/fuel-taxes-fines-charges/Pages/PetrolTax.aspx.

231 See the Ministry of Economic Development website "Duties, Taxes, and Direct Levies on Motor Fuels" page, http://www.med.govt.nz/templates/Page____12961.aspx.

sold in New Zealand. However, all diesel vehicles are subject to Road User Charges (RUC) based on the type of vehicle and distance travelled on public roads. Electric vehicles would also be subject to RUC, as their fuel is not 'taxed at the source' like petrol, LPG, and CNG.[232] For a light vehicle (two axles with single tyres 3 tonnes or less in gross weight) the current RUC is $32.79 per 1000 km including GST.[233] For vehicles subject to RUC, a 'distance licence' must be purchased and displayed in the vehicle windscreen covering the kilometres currently shown on the vehicle's odometer or (for heavy vehicles) hubodometer.[234]

Fuel taxes and road user charges are a primary (although not the only) source of funding for building and maintaining road and transport facilities.[235] However, discussing New Zealand's transport funding policies is well beyond the scope of this book. In general, New Zealand's petrol taxes are significantly lower than most European countries and South Korea, roughly comparable to Japan, Australia, and Canada, and considerably higher than the United States and Mexico.[236]

How did New Zealand end up with such disparate systems for taxing petrol and diesel? RUC was introduced in 1977 to replace a conventional tax on diesel fuel that had become difficult to administer due to the fact that roughly half of all diesel fuel was used off-road. These off-road users had to pay the diesel tax and then seek a refund. The RUC system is much more amenable to excluding this off-road usage from tax: non-vehicle use is not subject to RUC and hubodometers may simply be switched-off when a vehicle is used off-road (although it is estimated that some 4–6% of RUC revenue is lost due to evasion).[237]

6.3 Price Monitoring and Reporting

Section 4.1 discussed the role that key oil product spot markets serve in providing a reference for product prices over a wide region. Prices for fuels in New Zealand,

232 See Land Transport New Zealand, *Factsheet 38: Road User Charges: 1-6 Tonne Vehicles,* November 2007, http://www.landtransport.govt.nz/factsheets/38.html.

233 See Land Transport New Zealand, *Road User Charges,* April 2007, http://www.ltsa.govt.nz/publications/docs/road-user-charges.pdf, Tables III and IV.

234 See Land Transport New Zealand, *Road User Charges,* April 2007, http://www.ltsa.govt.nz/publications/docs/road-user-charges.pdf, p.7.

235 See the Land Transport New Zealand website "How Land Transport NZ is Funded" page, http://www.ltsa.govt.nz/funding/nltp/funding.html.

236 See the MED website for a chart of Petrol Prices and Taxes in OECD Countries, http://www.med.govt.nz/upload/35799/Graph%20-%20International%20-%202007-12.pdf. This chart is updated regularly as a part of the International and Domestic Petrol and Diesel Price Comparisons shown at http://www.med.govt.nz/oil/prices/weekly/.

237 See speech by Roger Toleman, Deputy Secretary for Transport, *Fund and Deliver,* 5 September 2003, http://www.transport.govt.nz/toleman050903/.

and the entire East Asia-South Pacific region, are generally based on the price of the product in the Singapore spot market. Singapore has developed this role as it is one of the world's largest refining centres, and thus generally the marginal supplier to countries such as New Zealand that cannot refine all the products they need locally. One would thus normally expect product prices in New Zealand to equal the Singapore spot price, plus freight and insurance from Singapore, plus importer's costs and margin, plus the taxes discussed in the preceding section. As a rule of thumb, the import cost, which includes the Singapore price plus freight and insurance to New Zealand, accounts for about 50% of the retail price of petrol. Taxes account for another roughly 40%. Importer's cost and margin, which includes domestic transportation, distribution, and retailing costs, as well as wholesaler's and retailer's profit, accounts for the final 10%.[238]

MED calculates and publishes estimates of import cost, importer's margin, and fuel taxes on a weekly basis.[239] Consultants Hale & Twomey publish similar data weekly on their web site.[240] Estimates of import cost are based on published price quotes for product in Singapore, plus estimated shipping and insurance costs. Retail price estimates are based on Statistics New Zealand surveys. Taxes are based on actual tax rates. The residual is the importer's margin.[241] New Zealand product specifications do not exactly match those of the products for which prices are published in Singapore, so adjustments to reflect quality are required. The emergence of supermarket discounting schemes and biofuels[242] also tends to cloud the picture slightly.

6.4 Product Quality Regulation

Fuel quality in New Zealand is governed by a set of regulations[243] as well as by the industry's own specifications. These regulations include factors that affect the performance of fuel, such as the octane number, as well as limits for components that

238 See the table of "Weekly Average Components of Regular Petrol Price Graph" on the Ministry of Economic Development web site at http://www.med.govt.nz/templates/MultipageDocumentPage____20158.aspx.

239 See the "International and Domestic Petrol and Diesel Price Comparisons" on the Ministry of Economic Development website at http://www.med.govt.nz/oil/prices/weekly/.

240 See the Hale & Twomey "Market Update" page, http://www.fuelpricemonitor.co.nz/demo.html.

241 For a discussion of the methodology, see Hale & Twomey, *Review of Importer Margin Calculations*, prepared for the Ministry of Economic Development, March 2006 (unpublished).

242 See Hale & Twomey, *Importer Margin Review*, August 2007, http://www.med.govt.nz/upload/52044/Importer-Margin-2007.pdf.

243 See the "Fuel Quality" page on the Ministry of Economic Development website http://www.med.govt.nz/templates/StandardSummary____350.aspx.

could be harmful to the environment or to public health, such as lead and sulphur. The regulations are the Petroleum Products Specifications Regulations.[244]

Monitoring the nation's fuel quality is the responsibility of the Energy Safety Service, a group within the Ministry of Economic Development. It routinely tests petrol and diesel samples from around the country to ensure that the fuel available to consumers complies with the regulations.

New Zealand's product quality standards, such as for sulphur (see Section 1.5), put New Zealand among the countries with the highest product quality standards in the Asia-Pacific region (the others are Australia, Hong Kong, Japan, and South Korea) and are similar to the European and American standards. Since refineries are generally only upgraded when their home markets require improved products, there are currently only a limited number of refineries in the region from which New Zealand can import product. This limitation complicates the logistics of importing product from overseas, especially in the event of a supply disruption. However, in the event of a severe disruption, there would be some room to address the problem with a temporary modification of product specifications.[245]

244 See the Parliamentary Counsel Office website "New Zealand Legislation: Regulations" page http://www.legislation.govt.nz/regulation/public/2002/0210/latest/DLM136661.html.

245 Covec and Hale & Twomey, *Oil Security; Final Report*, February 2005, http://www.med.govt.nz/upload/25065/adjusted-final.pdf, Section 2.3.1.

7 Oil Security and the International Energy Agency

The world oil market has experienced a number of oil supply disruptions since the early 1970s, including the Arab Oil Embargo of 1973–74, the Iranian Revolution of 1979, the subsequent Iran-Iraq war beginning in 1980, the Gulf War of 1990-1991, the Iraq War beginning in 2003, and Hurricane Katrina of 2005. The world oil market remains inherently vulnerable to disruption. This vulnerability is driven by heavy dependence upon politically unstable countries, as well as long and fragile supply chains that can be disrupted by both man-made and natural events. International efforts to manage this vulnerability for the OECD countries are coordinated by the *International Energy Agency (IEA)* of which New Zealand is a member. This section introduces the work of the IEA, and New Zealand's obligations as a member.

7.1 The International Energy Agency

Recognising that the vulnerability of the oil market to disruption was an issue that needed to be addressed through international cooperation, sixteen of the world's major oil consuming countries agreed on an International Energy Program (IEP) in November 1974. The key goals of the agreement were:

- To maintain and improve systems for coping with oil supply disruptions
- To promote rational energy policies in a global context through co-operative relations with non-Member countries, industry and international organisations
- To operate a permanent information system on the international oil market
- To improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use
- To promote international collaboration on energy technology
- To assist in the integration of environmental and energy policies.[246]

The agreement established the International Energy Agency (IEA) to coordinate these efforts.[247]

New Zealand was not an initial signatory, but acceded to the agreement in December 1976.[248] Today, the IEA has 27 member countries, all of which are also members of

246 See International Energy Agency, *IEA; an Overview*, 2007, http://www.iea.org/about/docs/iea2007.pdf.

247 The text of the International Energy Program agreement may be found at http://www.iea.org/about/docs/IEP.PDF.

248 See Richard Scott, *The History of the International Energy Agency; the First 20 Years; Volume 1*, International Energy Agency, http://www.iea.org/textbase/nppdf/free/1990/1-ieahistory.pdf, p. 75.

the *Organisation for Economic Cooperation and Development (OECD)*.[249] All member countries are 'industrialised' countries, and most of them are significant importers of oil.

Today, the wider functions of the IEA include:

- Monitoring oil and gas markets to help member countries respond promptly and effectively to changes in market conditions; well-known IEA publications include, the annual *Medium-Term Oil Market Report*, *Natural Gas Market Review*, and *World Energy Outlook*, as well as the monthly *Oil Market Report*.
- Performing a peer-review of member countries' energy policies every four years;
- Undertaking analysis and cooperative efforts in the development of policies for energy efficiency, energy diversification (electricity, natural gas, coal, renewable energy sources) and the integration of environmental concerns into energy policies.
- Performing studies of energy-related developments in energy producing and consuming countries throughout the world in order to examine the global context for policy decisions.
- Through *IEA Implementing Agreements* offering a framework for cooperative energy research and development efforts;
- Performing policy and technology analysis related to climate change;
- Producing a comprehensive database of energy statistics on 130 countries (the IEA publishes 10 annual and 2 quarterly statistical publications, as well as a variety of electronic services).[250]

7.2 The IEA and Oil Security

However, the IEA's most basic function remains its original one of promoting preparedness for oil supply disruptions. The three major elements of this effort are as follows:

- **Reserve Stocks**. Each member country must maintain an emergency self-sufficiency in oil supplies. This is typically achieved by holding "emergency reserve" oil stocks equivalent to at least 90 days of net oil imports.
- **Demand Restraint**. Each member country must have ready a program of oil demand restraint measures that will enable it to rapidly reduce its final consumption in an oil supply emergency situation. The International Energy Programme (IEP)

249 A list of IEA members may be found on the IEA website at http://www.iea.org/Textbase/about/membercountries.asp. This page notes that all are members of the OECD.

250 See International Energy Agency, *IEA; An Overview*, 2007, http://www.iea.org/about/docs/iea2007.pdf.

provides for two levels of demand restraint: a 7% reduction in demand if supply is reduced by 7% and a 10% reduction in demand if supply is reduced by 12%.

- **Allocation Plans.** In the event of a 12% reduction in supply, oil sharing arrangements are triggered, whereby all IEA members share available supplies to ensure 'equal pain'.[251] Under the International Energy Agreement, every IEA member is required to have a National Emergency Sharing Organisation (NESO). It exists to make arrangements for sharing oil supplies between member countries in the event of a severe emergency. In New Zealand, this is a committee of oil industry representatives chaired by the Ministry of Economic Development. New Zealand also uses the NESO committee to assist with invoking lower level or non-IEA emergency measures.[252]

There have been only two times when a significant stock drawdown has been orchestrated by the IEA: the Gulf War in 1991 and Hurricane Katrina in 2005.[253] Historically, the IEA has tended to deal with disruptions informally in a manner tailored to each situation. The IEA has developed responses through consultation and cooperation, and avoids allocation except as a last resort.[254]

7.3 New Zealand's Oil Security

In principle, threats to New Zealand's oil security could come from events internal to New Zealand or external to New Zealand. A 2005 review of New Zealand's oil security by Covec and Hale & Twomey concluded that the risk of a major disruption to New Zealand's internal oil infrastructure was well below 1% per year (less than 1 in every 100 years).[255] However, the risk of an external disruption is up to 10 times greater.[256] The IEA would normally be expected to respond to the latter type of disruption.

251 See Covec and Hale & Twomey, *Oil Security; Final Report*, February 2005, http://www.med.govt.nz/upload/25065/adjusted-final.pdf, pp. 2-3. See also *Cabinet Paper on Oil Security*, March 2005, paragraph 33, http://www.med.govt.nz/upload/25128/cabinet.pdf.

252 See Ministry of Economic Development, *Discussion Paper: Options for Government Response to an Oil Supply Disruption,* September 2006, paragraph 4.3, http://www.med.govt.nz/upload/40000/oers-discussion-document.pdf.

253 See International Energy Agency, *Summary of IEA Collective Action of 2005,* 8 March 2006, IEA/SEQ(2006)5, p. 2 (not available publicly on line) and International Energy Agency *Fact Sheet on IEA Oil Stocks and Emergency Response Potential",* 2004, http://www.iea.org/Textbase/Papers/2004/factsheetcover.pdf.

254 See Covec and Hale & Twomey, *Oil Security; Final Report*, February 2005, http://www.med.govt.nz/upload/25065/adjusted-final.pdf, p.4.

255 Covec and Hale & Twomey, *Oil Security; Final Report,* February 2005, http://www.med.govt.nz/upload/25065/adjusted-final.pdf, Section 2.6.6.

256 Covec and Hale & Twomey, *Oil Security; Final Report,* February 2005, http://www.med.govt.nz/upload/25065/adjusted-final.pdf, Section 2.6.

Regardless of the type of event, the New Zealand government has broad emergency powers to deal with oil supply disruptions. The Petroleum Demand Restraint Act 1981 authorises regulations for the purpose of restraining demand, reducing consumption, or ensuring the equitable distribution of petroleum products in New Zealand. The government may introduce these regulations if petroleum products are or are likely to be in short supply in New Zealand or within any specified part of New Zealand. The International Energy Agreement Act 1976 provides for maintaining reserve supplies. It also provides for ministerial directions and emergency regulations to control the production, acquisition, distribution, supply, or use of petroleum, if it appears that New Zealand's IEA obligations require the taking of emergency measures. The latter Act even states that no emergency regulation made under the Act "shall be held invalid because it is, or authorises any act or omission which is, repugnant to, or inconsistent with, any Act (other than this Act)".[257]

The government is currently in the process of developing an oil disruption response plan. A September 2006 discussion paper[258] proposed possible measures. On the supply side, these included drawing down stocks, a surge in domestic production (assuming this is possible), and a relaxation of fuel specifications. On the demand side, these included voluntary measures, a 'fixed sales requirement' to discourage hoarding (consumers must buy a minimum amount of petrol each time they fill up), lowered speed limits, fuel switching, and (in extreme situations) rationing.

Until 2006 New Zealand relied on indigenous oil production and normal commercial stocks to meet the IEA reserve stocks requirement. However, declining indigenous production and increasing demand left New Zealand well short of the 90 day requirement. The government decided that New Zealand would meet its IEA storage obligation by tendering for companies to hold stock on behalf of the Crown. The reserve stocks are in addition to normal commercial stocks and are controlled separately. Criteria for the release of reserve stocks ensures that the stocks may only be released to meet New Zealand's obligations to the IEA or because there is a reduction or threatened reduction of petroleum supplies in New Zealand. The reserve supplies are not available where the primary purpose is for price management or for assisting any particular supplier.[259]

257 See Statutes of New Zealand, *International Energy Agreement Act 1976*, http://www.legislation.govt.nz/act/public/1976/0155/latest/DLM440510.html.

258 See Ministry of Economic Development, *Discussion Paper: Options for Government Response to an Oil Supply Disruption*, September 2006, http://www.med.govt.nz/upload/40000/oers-discussion-document.pdf.

259 See Ministry of Economic Development, *Discussion Paper: Options for Government Response to an Oil Supply Disruption*, September 2006, http://www.med.govt.nz/upload/40000/oers-discussion-document.pdf, p. 15.

The first tender was held in 2006 and as a result stock was held in Australia, the UK, and the Netherlands in 2007. No tenders to hold stock in New Zealand were received. A further tender was held in 2007 and in 2008 stock is also being held in Japan. The Government entered into bilateral arrangements with the governments of Australia, Japan, the UK, and the Netherlands to ensure the stocks will be available in an emergency and to enable the stocks to be counted towards New Zealand's IEA obligations. [260]

260 See press releases by Hon. David Parker "Oil Reserves Target Met", 19 December 2006, http://www.beehive.govt.nz/release/oil+reserves+target+met and "Oil Stocks Agreement Signed with Japan", 5 November 2007, http://www.beehive.govt.nz/node/31199.

APPENDIX A

Example Tables Illustrating Exhaustible Resource Decision Making

This Appendix demonstrates the results discussed in Section 3 more comprehensively with tables.

In each table, the diagonal shows the rent (value of oil in that year per barrel minus drilling cost per barrel) one would get that year from drilling in that year. Each cell below the diagonal shows the value one would have in subsequent years if one invested that rent at the assumed rate of interest. The bottom row is the key result—the value of the investment at the end of year 10 if one drilled in each year. The optimum decision is to drill in the year that gives one the highest value in year 10.

A.1 Impact of Extraction Costs

TABLE A1

Initial oil price	$100/barrel
Drilling cost	$50/barrel
Annual increase in oil price	$5.00/barrel
Return on alternative investment	8.00%

Value of investment at end of year per barrel produced

Year valued	Year of Production									
	1	2	3	4	5	6	7	8	9	10
1	50.00	X	X	X	X	X	X	X	X	X
2	54.00	55.00	X	X	X	X	X	X	X	X
3	58.32	59.40	60.00	X	X	X	X	X	X	X
4	62.99	64.15	64.80	65.00	X	X	X	X	X	X
5	68.02	69.28	69.98	70.20	70.00	X	X	X	X	X
6	73.47	74.83	75.58	75.82	75.60	75.00	X	X	X	X
7	79.34	80.81	81.63	81.88	81.65	81.00	80.00	X	X	X
8	85.69	87.28	88.16	88.43	88.18	87.48	86.40	85.00	X	X
9	92.55	94.26	95.21	95.51	95.23	94.48	93.31	91.80	90.00	X
10	99.95	101.80	102.83	**103.15**	102.85	102.04	100.78	99.14	97.20	95.00

Table A1 above corresponds to the assumptions of Section 3.3. Oil is initially priced at $100 per barrel, and increases in price by $5 per barrel each year. There is a drilling cost of $50 per barrel. Once one has produced the oil, the rent earns interest of 8% per year. The table shows that one obtains the highest value at the end of Year 10 by waiting three years and drilling in Year 4. Drill earlier than this and one loses out because the value of the rent on oil in the ground is rising faster than 8%. Drill later than this and one loses out because the value of the rent on oil in the ground is rising more slowly than 8%.

A.2 Impact of Higher Extraction Costs

Table A2 below corresponds to the assumptions of Section 3.4. The assumptions are the same as in section A.1, except this time, there is a drilling cost of $55 per barrel instead of $50 per barrel. The table shows that one obtains the highest value at the end of Year 10 by waiting four years (instead of three) and drilling in Year 5. Due to the higher extraction costs, one should wait an additional year.

TABLE A2

Initial oil price	$100/barrel
Drilling cost	$55/barrel
Annual increase in oil price	$5.00/barrel
Return on alternative investment	8.00%

Value of investment at end of year per barrel produced

Year valued	Year of Production									
	1	2	3	4	5	6	7	8	9	10
1	45.00	X	X	X	X	X	X	X	X	X
2	48.60	50.00	X	X	X	X	X	X	X	X
3	52.49	54.00	55.00	X	X	X	X	X	X	X
4	56.69	58.32	59.40	60.00	X	X	X	X	X	X
5	61.22	62.99	64.15	64.80	65.00	X	X	X	X	X
6	66.12	68.02	69.28	69.98	70.20	70.00	X	X	X	X
7	71.41	73.47	74.83	75.58	75.82	75.60	75.00	X	X	X
8	77.12	79.34	80.81	81.63	81.88	81.65	81.00	80.00	X	X
9	83.29	85.69	87.28	88.16	88.43	88.18	87.48	86.40	85.00	X
10	89.96	92.55	94.26	95.21	**95.51**	95.23	94.48	93.31	91.80	90.00

A.3 Impact of Increasing Oil Price

Table A3 below corresponds to the assumptions of Section 3.5. The assumptions are the same as Section A.1 except this time the oil price is assumed to escalate at a rate of $10 per year, rather than the $5 per year originally assumed. Now, one should wait eight years and drill in Year 9 rather than in Year 4. The more rapid expected increase in the resource price makes holding oil in the ground more attractive relative to other investments, and leads one to defer drilling for five extra years.

TABLE A3

Initial oil price	$100/barrel
Drilling cost	$50/barrel
Annual increase in oil price	$10.00/barrel
Return on alternative investment	8.00%

Value of investment at end of year per barrel produced

Year valued	Year of Production									
	1	2	3	4	5	6	7	8	9	10
1	50.00	X	X	X	X	X	X	X	X	X
2	54.00	60.00	X	X	X	X	X	X	X	X
3	58.32	64.80	70.00	X	X	X	X	X	X	X
4	62.99	69.98	75.60	80.00	X	X	X	X	X	X
5	68.02	75.58	81.65	86.40	90.00	X	X	X	X	X
6	73.47	81.63	88.18	93.31	97.20	100.00	X	X	X	X
7	79.34	88.16	95.23	100.78	104.98	108.00	110.00	X	X	X
8	85.69	95.21	102.85	108.84	113.37	116.64	118.30	120.00	X	X
9	92.55	102.83	111.08	117.55	122.44	125.97	128.30	129.60	130.00	X
10	99.95	111.06	119.97	126.95	132.24	136.05	138.57	139.97	**140.40**	140.00

A.4 Impact of Interest Rates

Table A4 below corresponds to the assumptions of Section 3.6. The assumptions are the same as Section A.1 except that a lower rate of interest on the alternative investment of 6% instead of 8% is assumed. Now one should wait seven years and drill in Year 8 rather than Year 4. The lower interest rate makes holding oil in the ground more attractive relative to other investments, and leads one to defer drilling for an extra four years.

TABLE A4

Initial oil price	$100/barrel
Drilling cost	$50/barrel
Annual increase in oil price	$5.00/barrel
Return on alternative investment	6.00%

Value of investment at end of year per barrel produced

Year valued	Year of Production									
	1	2	3	4	5	6	7	8	9	10
1	50.00	X	X	X	X	X	X	X	X	X
2	53.00	55.00	X	X	X	X	X	X	X	X
3	56.18	58.30	60.00	X	X	X	X	X	X	X
4	59.55	61.80	63.90	65.00	X	X	X	X	X	X
5	63.12	65.51	67.42	68.90	70.00	X	X	X	X	X
6	66.91	69.44	71.46	73.03	74.20	75.00	X	X	X	X
7	70.93	73.60	75.75	77.42	78.65	79.50	80.00	X	X	X
8	75.18	78.02	80.29	82.06	83.37	84.27	84.80	85.00	X	X
9	79.69	82.70	85.11	86.98	88.37	89.33	89.89	90.10	90.00	X
10	84.47	87.66	90.22	92.20	93.68	94.69	95.28	**95.51**	95.40	95.00

Appendix B Glossary

API Gravity — A measure of the density of a hydrocarbon. Defined as:

$$^{\circ}API = \frac{141.5}{\text{specific gravity}} - 131.5$$

Barrel of Oil — 42 US gallons or about 159 litres

Bbl — *Barrel of oil*.

Biodiesel — Diesel fuel derived from present day plant or animal sources.

Bioethanol — A form of alcohol derived from present day plant or animal sources. May be blended in low concentrations with petrol and used in conventional petrol vehicles, or used in higher concentrations in especially modified petrol vehicles.

Biofuel — Usually refers to liquid fuel derived from present day plant or animal sources, including *biodiesel* and *bioethanol*.

Biomass — Present day plant or animal matter that can be used as fuel.

Calorific Value — The energy content of a fuel can be measured as the heat released on complete combustion. It can be expressed as an upper (or *gross*) value and a lower (or *net*) value. The difference between the two is the energy consumed in evaporating the water created in the combustion process.

Cap Rock — *Impermeable* rock, which prevents oil from *migrating* further.

Carbon Capture and Storage — A technology under which *carbon dioxide* is extracted from raw natural gas or the flue gases of power plants or industrial facilities and injected back into geological structures, such as depleted oil and gas reservoirs, un-minable coal beds, or deep saline aquifers.

Carbon Dioxide — CO_2, a naturally occurring gas, which is also a by-product of burning *fossil fuels* and *biomass*, as well as of land-use changes and other industrial processes. It is the most important of the man-made *greenhouse gases*.

Carbon Sequestration — Any process for removing *carbon dioxide* from the atmosphere. May be natural (such as forests) or artificial (see *Carbon Capture and Storage* above).

Cellulosic Biofuels — *Biofuels* produced from cellulose found in the stalks and stems of most plants.

Cetane Number	A measure of the tendency of a fuel to self-ignite when heated; an attractive characteristic for diesel fuel.
CH_4	*Methane*. The simplest hydrocarbon and the principle component of natural gas. Also, a *greenhouse gas* released from some natural and man-made sources.
CNG	*Compressed Natural Gas*.
CO_2	*Carbon dioxide*, which is the most important man-made *greenhouse gas*.
Commercial	In energy statistics, the commercial sector usually includes non-manufacturing business establishments such as hotels, motels, restaurants, wholesale businesses, and retail stores. It also includes health care, social, educational, and government establishments.
Compressed Natural Gas	Or *CNG*. Natural gas which has been compressed, or contained under pressure, in a small volume. CNG is used as a fuel by some vehicles. It is also a potential competitor to *LNG* as a way of shipping natural gas over relatively short distances, such as from Australia to New Zealand.
Compression Ratio	In an internal combustion engine, the ratio of the volume of the cylinder at the bottom of its stroke to the volume of the cylinder at the top of its stroke.
Condensate	A liquid similar to a light crude oil that is produced in vapour form with *natural gas*, and may be condensed from the gas.
Consumer Energy	Energy in the form consumed by final users. Also sometimes known as Final Energy. Not *primary energy*.
Cracking	A chemical process for breaking-up heavier *hydrocarbon* molecules into lighter molecules
Crude Oil	Oil as it is originally produced.
Derivative	A financial security whose value depends upon the value of something else (such as the spot price of *crude oil*).
Distillation Column	A device for separating oil into its *fractions* by *fractional distillation*; typically the first stage of a refinery.
Downstream	The transportation, refining, and marketing side of the oil industry.
EECA	Energy Efficiency and Conservation Authority. See www.eeca.govt.nz.

Efficient Market	Refers to the degree to which the market prices reflect everything that is known. In a perfectly efficient market, it is impossible to profit from analysis.
Elastic Demand	Refers to a situation where demand is highly responsive to changes in price, usually either because there are other products that are close substitutes or because the product is not considered by buyers to be that essential.
Elasticity	A measure of the responsiveness of demand to price. Measured as the percentage change in quantity demanded in response to a one percent increase in price. Usually negative in sign.
Energy Risk Management	The sector of the finance industry that helps clients manage the risk of energy price fluctuations.
Enhanced Recovery	More sophisticated techniques for improving recovery from an oil reservoir than *secondary recovery*; these include injection of steam or chemicals; also known as *tertiary recovery*.
Exploration Well	A well drilled to explore for oil or gas; also known as a *wildcat well*.
FAME	*Fatty Acid Methyl Esters*
Fatty Acid Methyl Esters	A family of *biofuels* made from plant or animal fat; the scientifically correct term for *biodiesel*; often abbreviated *FAME*.
Flaring	Burning-off gas that is produced with oil; typically done when there is no nearby market for the gas.
Fischer-Tropsch	A well-known chemical process for synthesising liquid fuels from gas, coal, or biomass.
Fossil Fuels	Coal, *natural gas*, *LPG*, and fuels derived from *crude oil* (including petrol and diesel). They are called fossil fuels because they have been formed over long periods of time from ancient organic matter. Not *Renewable*.
Fraction	The range of compounds in crude oil that vaporise between any two temperatures.
Fractional Distillation	The separation of oil into *fractions* through a distillation process. Accomplished using a *distillation column*.

Forward Contract	A privately-arranged agreement under which a commodity will be delivered at a future date for a predetermined price.
Futures Contract	A standardised agreement transacted on a *futures market* under which a commodity (or its cash value) will be delivered at a future date for a predetermined price.
Futures Market	An exchange where *futures contracts* are traded.
Gas Processing Plant	A plant for treating raw *natural gas*; may remove marketable *hydrocarbons* like ethane and *natural gas liquids*, as well as impurities such as *carbon dioxide*.
GJ	Gigajoules. 10^9 joules. A generic unit of energy. See *Metric System Multiples*.
Greenhouse Gases	Atmospheric gases that increase the earth's temperature by absorbing outgoing infrared radiation from the earth's surface. Man-made greenhouse gases that have a direct effect are *carbon dioxide* (CO_2), *methane* (CH_4) and *nitrous oxide* (N_2O). Indirect greenhouse gases, which react to form direct greenhouse gases in a relatively short time, include carbon monoxide (CO), other oxides of nitrogen (NO_x), and non-methane volatile organic compounds (NMVOCs). Water vapour (H_2O) is also a greenhouse gas, however, its concentration in the atmosphere is naturally regulated.
Gross Energy	See *Calorific Values*.
Heat of Compression	Heat generated when a gas is compressed.
Heavy Hydrocarbon	*Hydrocarbons* composed of larger, chemically heavy, molecules, such as coal, heavy crude oil, and heavy fuel oil.
Hedger	One who takes a position in a financial market in order to reduce his/her risk. Not a *speculator*.
Hydrocarbon	In policy analysis (as opposed to chemistry) this term refers to *fossil fuels*, including gas, oil, and coal. These substances consist primarily of hydrogen and carbon.
IEA	*International Energy Agency*.
IEA Implementing Agreements	An agreement among *IEA* member and non-member governments and other organisations to pool resources to foster research, development and deployment of particular technologies.[261]

261 See the International Energy Agency "Technology Agreements" web page http://www.iea.org/textbase/techno/index.asp

Impermeable Rock	Rock which is not *permeable*; that is, through which oil and gas cannot *migrate*.
Inelastic Demand	Refers to a situation where demand does not respond much to changes in price, generally because the product is considered a 'necessity'.
In Situ	Describes a technique for recovering a resource, such as bitumen, without having to physically dig the resource-bearing material, such as tar sands, out of the ground.
International Energy Agency	This *IEA* helps coordinate the energy policies of its member countries. Membership consists of 26 primarily oil-importing industrialised countries including New Zealand. See www.iea.org.
Kerogen	The scientifically correct name for the organic material in 'oil shale' from which synthetic crude oil may be produced.
Kilowatt (kW)	A unit of electrical power equal to 1000 watts. See *Metric System Units*.
Kilowatt-hour (kWh)	Unit of electrical energy equal to 0.0036 *GJ*.
Light Hydrocarbon	*Hydrocarbons* consisting of smaller, chemically light molecules, such as natural gas, condensate, light crude oil, and petrol.
Lignite	Low grade coal. Also known as soft coal or brown coal.
Liquefied Natural Gas	Or *LNG*. *Natural gas* which has been converted to a liquid by chilling it to extremely low temperatures. Natural gas is frequently moved by ship in the form of LNG. Not to be confused with *Natural Gas Liquids* or *Liquefied Petroleum Gas*.
Liquefied Petroleum Gas	Or *LPG*. A generic name for mixtures of propane butane, and isobutene, or pure propane. LPG is a gas at room temperature, but is a liquid under pressure.
LNG	*Liquefied Natural Gas*.
LPG	*Liquefied Petroleum Gas*.
Margin	Collateral deposited to guarantee that a party to a financial agreement, such as a *futures contract*, will meet his/her obligations under the agreement.
Marker Crude	A type of *crude oil* whose spot price commonly serves as a reference for pricing other types of crude oil.

Market Power	The ability of a market participant to influence the price of a product.
Marking to Market	Settlement of any gain or loss incurred by participants in a *futures contract*; generally performed daily.
MED	Ministry of Economic Development. See www.med.govt.nz.
Megawatt (MW)	One million watts. One megawatt is enough power to supply the peak electricity needs of about 500 houses. See *Metric System Multiples*.
Methane	CH_4, the simplest *hydrocarbon* and the principle component of *natural gas*. Also, a *greenhouse gas* released from some natural and man-made sources.
Metric System Multiples	1,000 = 10^3 = kilo (k) 1,000,000 = 10^6 = mega (M) 1,000,000,000 = 10^9 = giga (G) 1,000,000,000,000 = 10^{12} = tera (T) 1,000,000,000,000,000 = 10^{15} = peta (P) 1,000,000,000,000,000,000 = 10^{18} = exa (E)
Metric Tonne	1000 kilograms
Migrate	Natural movement of oil through *reservoir rocks* away from its *source rock*.
Mt	Million tonnes. See *Metric Tonne* and *Metric System Multiples*.
Natural Gas	Consists mainly of *methane* occurring naturally in underground deposits.
Natural Gas Liquids	Liquids that come out of the ground in vapour form with *natural gas*; may include propane, butane, and *condensate*. Not to be confused with *Liquefied Natural Gas*.
Net Energy	Refer to *calorific values*.
New Zealand Refining Company	Owner and operator of the Marsden Point Refinery.
NZES	New Zealand Energy Strategy.
NZRC	*New Zealand Refining Company*.
Nitrous Oxide	N_2O, a *greenhouse gas*.
Octane Number	A measure of the tendency of a fuel to resist self-ignition when heated; an attractive property for petrol.

OECD	*Organisation for Economic Co-Operation and Development*.
OPEC	Organization of the Petroleum Exporting Countries. This is an international organisation that helps coordinate the energy policies of its member countries. Membership consists of Algeria, Angola, Ecuador, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the UAE, and Venezuela. See www.opec.org.
Option	An agreement that gives one party the right (but not the obligation) to buy or sell a commodity at a future date for a prearranged price.
Organisation for Economic Co-Operation and Development	An international organisation whose membership consists of 30 industrialised countries including New Zealand. See www.oecd.org.
OTC	*Over-the-Counter*
Over-the-Counter	A privately arranged financial transaction—not through a *futures market* or other organised exchange.
pa	Per annum.
Permeable	A rock with well-connected pores, thus allowing a fluid, such as oil, to *migrate* through it.
Plug-In Hybrid	A hybrid vehicle with an extra large battery so it can be charged from the grid and operated entirely on battery power when desired.
PJ	Petajoules. 10^{15} joules. A generic unit of energy. Approximately: 1 PJ = 278 GWh of electricity 1 PJ = 44,000 tonnes of sub-bituminous coal 1 PJ = 21,000 tonnes of petrol 1 PJ = 26 Mm^3 Maui gas.
Porosity	A measure of the amount of void spaces in a rock. A rock must be porous and *permeable* for oil to *migrate* through it.
Primary Energy	Energy as it is first obtained from natural sources. Does not include electricity or refined petroleum products.
Reinjection	Pumping the gas that was produced with the oil back into the reservoir to help maintain pressure and increase oil recovery

Renewable	A form of energy that can be produced indefinitely without depleting the supply. Includes hydro, wind, geothermal, wave, tidal, and solar energy. Not *Fossil Fuels*.
Rent	The payment received for some asset net of its cost of production.
Reserves-to-Production Ratio	The ratio of proved reserves of oil to annual production of oil. Same as *R/P Ratio*.
Reservoir	A subsurface pool of oil and/or gas contained in *reservoir rock*.
Reservoir Rock	*Porous* and *permeable* rock through which oil and gas can migrate.
R/P Ratio	The *Reserves-to-Production Ratio*.
Secondary Recovery	Initial measures to help maintain the pressure in an oil or gas reservoir, and thereby improve recovery, typically by injecting water. Compare to *tertiary* recovery.
Seep	A place where oil or gas naturally escapes to the surface of the earth.
Seismic Survey	A technique for determining the structure of the rocks in a particular area through analysing how they reflect sound waves.
Sour Crude	*Crude oil* that is high in sulphur.
Source Rock	Rock in which oil or gas is formed.
Speculator	One who takes a position in a financial market in hopes of profit. Not a *hedger*.
Spot Market	A market where a product is sold for immediate delivery.
Swap	An arrangement where the parties agree to a future exchange of cash flows; for example, they may agree to pay each other based on the difference in the spot price between two types of *crude oil* on a certain future date.
Sweet Crude	Crude oil that is low in sulphur.
Takeback Effect	The tendency of consumers to increase their purchases of energy when energy efficiency is improved due to the perceived lower cost of energy services (such as kilometres driven or warmer homes)

t	Metric tonne of oil (see *Metric Tonne*)
Tectonics	The geological process by which large scale motion of the earth's continental and oceanic plates affects the structure of the earth's crust.
Terawatt-hour (TWh)	Unit of electrical energy, equal to 1000 GWh. See *Metric System Units*.
Tertiary Recovery	More sophisticated techniques than *secondary recovery* for improving recovery from an oil reservoir; these include injection of steam or chemicals; also known as *enhanced recovery*.
Thermal Generation	The generation of electricity by heat, usually from burning *fossil fuels* but also including geothermal generation.
Trap	A geological structure that can accumulate oil or gas.
Theory of Normal Backwardation	A theory which argues that prices in futures markets should be systematically low relative to ultimate spot prices.
Ultimately Recoverable Resources	The amount of oil that it will ultimately be possible to produce.
Upstream	The exploration, drilling, and production side of the oil industry.
URR	*Ultimately Recoverable Resources*.
Water Cut	Water that is produced along with oil.
Welfare Economics	The branch of economics that studies how to maximise the welfare of a society.
West Texas Intermediate	The most well-known grade of *crude oil* deliverable against the NYMEX light sweet crude oil futures contract.
Wet Gas	Gas with a high content of *Natural Gas Liquids*.
Wildcat Well	A well drilled to explore for oil or gas; also known as an *exploration well*.
WTI	*West Texas Intermediate*

Oil: An Introduction for New Zealanders

Oil is New Zealand's largest and arguably most problematic energy source. Policies related to oil have wide impacts, including those on the economy, the environment, consumers, foreign affairs, and transport planning. Because of their wide impact, issues related to oil frequently attract great public interest and, sometimes, contentious debate. Yet oil is also a sophisticated industry, and to usefully contribute to the dialogue requires a certain level of technological, economic, and institutional knowledge that can appear daunting to the newcomer.

Oil: An Introduction for New Zealanders is designed to provide an easy-to-read background briefing for anyone who will be dealing with oil-related policy issues. These include elected officials, business leaders, non-governmental organisation leaders, researchers, students, and concerned citizens. The book does not attempt to analyse any policy issues, but rather to provide basic information that will be useful to anyone who does.

Topics covered include oil production and refining technology; the uncertainties surrounding statistics on world oil reserves and resources; the management of New Zealand's own oil resources; the structure and regulation of New Zealand's oil industry; and New Zealand's involvement with international efforts to promote oil security. A chapter on 'Oil and Financial Markets' focuses on the question of whether quotes from futures markets provide a good means to predict the future price of oil. A chapter on 'The Economics of Exhaustible Resources' focuses on the question of whether government intervention in the oil market can be justified on the basis that oil is an exhaustible resource.

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ISBN 978-0-478-31670-4 (paper)
ISBN 978-0-478-31671-1 (PDF)
ISBN 978-0-478-31672-8 (HTML)

Ministry of Economic Development
Manatū Ōhanga