Economics of energy corporations

Depletable resources

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1. Depletable/Non-renewable resources
   - Definitions
   - Basic concepts associated with non-renewable fuel use

2. Peak oil debate
   - Definitions
   - Production limitations

Outline

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Depletable resources and scarcity

- A term in Environmental economics / Natural resources economics - in general applicable to anything valuable (anything with a price - recall the basic terms)
  - Scarcity of resources vs. unlimited human needs (recall the non-decreasing property of utility functions)
  - Strictly speaking, every resource is somehow limited (e.g. consider "renewability" of sun?)
    - E.g. Dyson sphere: hypothetical megastructure encompassing a star and capturing most or all of its power output
- Often confused with conventional and unconventional energy sources (though conventional energy sources are often non-renewable)
  - Conventional sources: typically being used since a long time, used frequently
  - Non-conventional sources: not really widespread

Non-renewable and renewable resources, definitions

- (Non-)Renewable resources: most often discussed in relation with energy resources
- Resources classified as "Depletable" (or Non-Renewable): the sum over time of all possible production is finite, or the stock of the resources is not replaceable in a reasonable timeframe
  - Fossil fuels (Crude oil, natural gas, coal) are typical examples
  - (optional classification: Recyclable non-renewable resources: can be partially recovered from their prior use)
- Non-depletable resources: their stock can replenish in time
  - Geothermal, water, wind, solar, biomass(?)

Energy vs. exergy

- The First Law of Thermodynamics: energy can be neither created nor destroyed; but energy can be converted between various forms (energy is not scarce!)
- The Second Law of Thermodynamics: It is impossible to extract all heat from a hot reservoir and use it *all* to do work (a change of state is associated with an increase in entropy - i.e. exergy is 'consumed' in conversion processes, it is mostly lost in the form of low temperature heat)
  - no *perpetuum mobile* is possible.
  - There is a limit on the maximum efficiency of heat engines: $\eta = \frac{\textit{useful energy output}}{\textit{energy input}}$ or Carnot's efficiency: $\varepsilon = \frac{T_S - T_0}{T_S}$, where the T_S is the temperature of energy source and T_0 is the temperature of the sink (the ambient temperature of the heat system).
- Why do people care? Using energy for (thermodynamic) *work*
  - Work performed by a system is the energy transferred by the system to another system → a generalization of the concept of mechanical work in physics
  - In summary: people do not care about the energy, but about exergy (energy that is available to be used)

Exergy relation to fuels

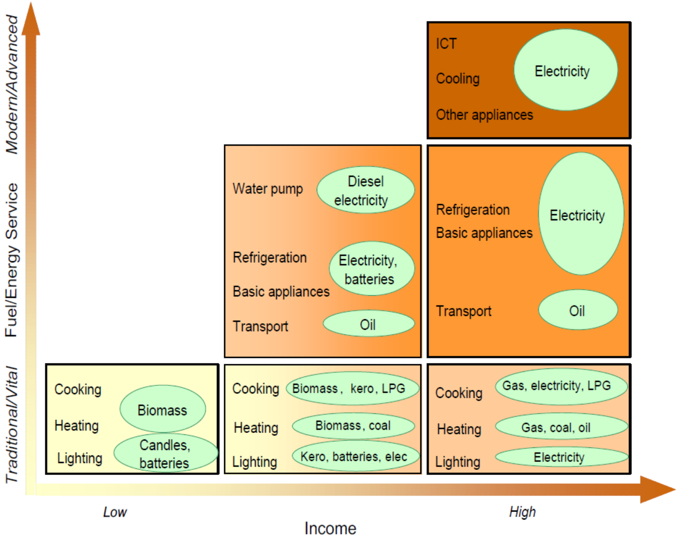
- The quality of energy type: how easily can it be converted to another type (e.g. electricity: easily converted to mechanical work, heat etc.; vs. heat: difficult to convert to electricity)
- Higher quality is associated with more exergy
- *Energy ladder*: Typical progression to increased use of higher quality energy (often associated with higher costs and lower (or internalized) externalities)

Table : Exergy quality indexes of different forms of energy

Form of energy	Quality index (Percentage of exergy)
Potential energy	100
Kinetic e.	100
Electrical e.	100
Chemical e.	about 100
Nuclear e.	95
Sunlight	93
Hot steam	60
District heating	30
Waste heat	5
Heat radiation from Earth	0

Source: Wall (1977), adapted from Davidsson (2011)

Figure : Energy ladder: End uses and fuels used by households at different income levels



Source: World Energy Outlook (2002)

Sustainability

- World Commission on Environment and Development (1987) states: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".
  - Life Cycle Exergy Analysis can be used to describe direct and indirect exergy use and generation during the source life cycle
- Sustainability: matching exergy inputs and exergy outputs in the long-run
  - a persistent supply of exergy (e.g. energy from the sun) offsets or compensates for the "exergy" drawn from the finite pool of fuels
- If exergy resources are consumed faster than they are renewed: not sustainable "depletion of resources"
- The use of fossil fuels is often considered not sustainable
  - Because the direct exergy input (e.g. wind) of renewable sources is *disregarded* - if not used, natural exergy flows will be wasted and lost
  - On the other hand, the direct exergy input of fossil fuels is calculated (because it is decreasing the fossil fuel stocks)

Outline

Optimal allocation

- In analogy with consumer's optimization problem, the basic question is: what is the optimal allocation of quantity for consumption, if we gain utility from the consumption and we consume in more than one time period?
  - "How much of the asset should we consume now and how much should we store for the future?"
- Hotelling (1931): one of the most influential theoretical studies of optimal depletion rates and associated pricing rules

Hotelling's pricing rule

- Formally: $max \sum_{t=0}^{T} \beta^t \left(p_t q_t - c\left(q_t\right)\right)$,
  subject to: $R_{t+1} - R_t = -q_t,\ c, q, R \geq 0, \forall t$
  - $\beta^t = \frac{1}{1+r}$ is the discount factor (with r being risk-adjusted interest rate), p is price, q is production, $c\left(q\right)$ are extraction costs, R is the remaining supply of a resource
- Non-renewable, exhaustible resource with completely known stock, no discoveries possible, no alternatives, no recycling, private ownership and constant costs of extraction:
  - the price of the resource will increase at the interest rate over time (Hotelling's 'r-percent' rule: $p_{t+1} = p_t\left(1 + r\right)$)
  - it can be shown the price at any given point in time, price must equal total marginal cost of extraction (the opportunity cost plus the cost of incremental production)

Hotelling's pricing rule

- Application of Hotelling's rule in the late 1970s and early 1980s contributed to (incorrect) predictions of increasing fuel (and non-fuel) commodity prices
- Side result of Hotelling's pricing: the sustainability (welfare levels non-decreasing over time) is only possible for one growth path: zero consumption forever (for any other feasible path consumption and therefore also utility must fall)
- If extraction costs are increasing with time, the opportunity cost of extraction is diminishing. Then the transition to a new source of energy arises due to prohibitive costs rather than physically running out.

Figure : Optimal price path of a depletable resource with constant extraction costs

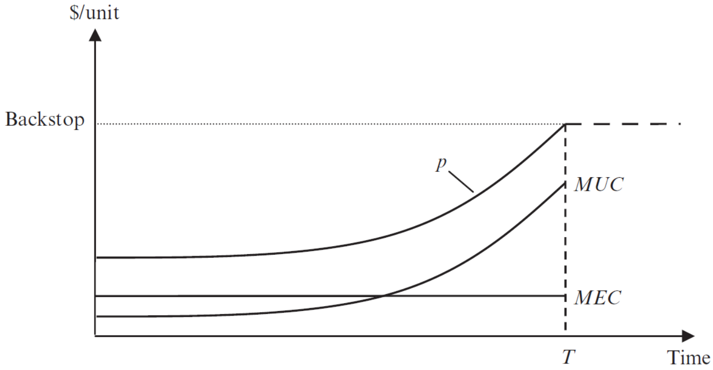
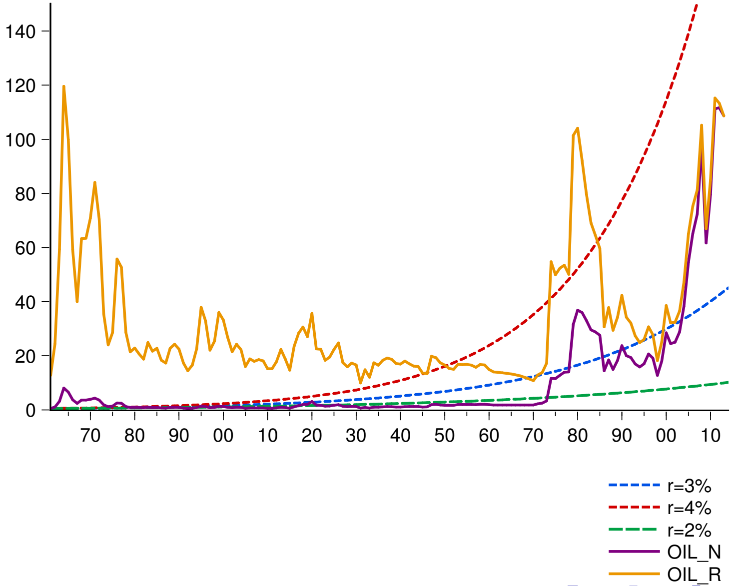


Figure : Oil price development



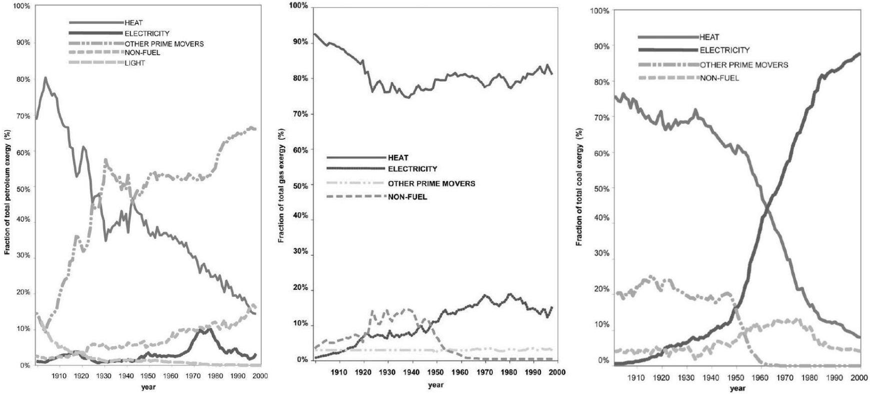
Historical links, "The dismal science of economics"

- Thomas Malthus and the "Iron Law of Population" (An Essay on the Principle of Population, 1796): continued population growth would lead to poverty:
  - Conclusion: the population should be held within resource limits: by positive checks (raising the death rate) and preventive checks (lowering the birth rate)
- William S. Jevons: The Coal Question (1865): coal essential to production, supply limited: "rate of growth will before long render our consumption of coal comparable with the total supply. In the increasing depth and difficulty of coal mining we shall meet that vague, but inevitable boundary that will stop our progress."
  - Coal mined in other areas + partial coal phase-out (by oil and gas)
- The Club of Rome and The Limits to Growth (1972): simulation of exponential economic and population growth with finite resource supplies
  - "Exponential index" of consumption: leading to a prediction of the number of years until the world would "run out" of various resources

Historical links

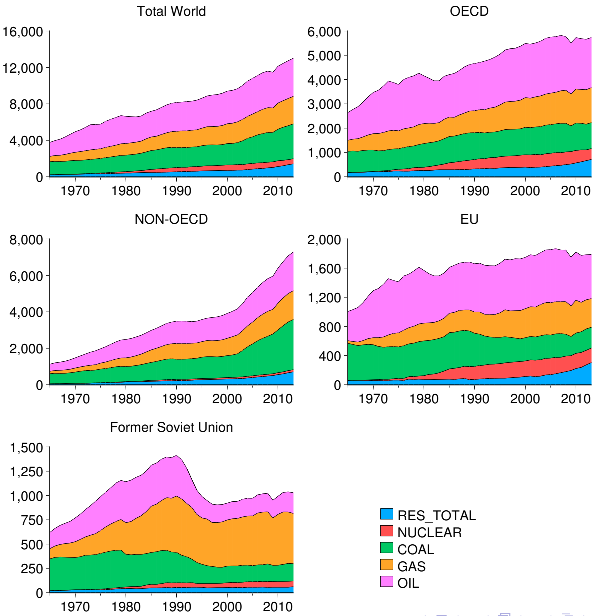
- Environmentalist Paul R. Ehrlich: The Population Bomb (1968): inevitable ecological collapse due to overpopulation
  - "In the 1970s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now"
  - Governments must curb population growth to mitigate (otherwise inevitable) ecological and social disasters.
- Simon–Ehrlich wager: 1980, betting on a mutually agreed-upon price measure of 5 commodities: Simon: prices would decrease,
  - Ehrlich: prices would increase (depletion + scarcity would lead to higher price (shift of market supply to the left and demand to the right)

Figure : Exergy allocation in the past century



Source: Ayres et al. (2003)

Figure : Energy consumption by types, MTOE

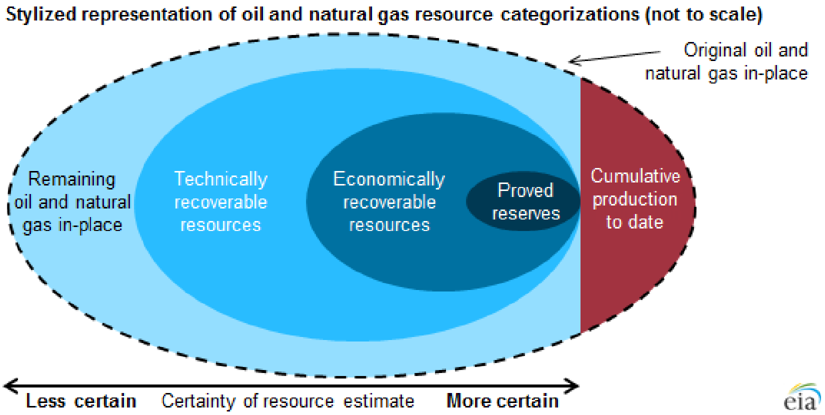


Outline

Reserves vs. resources

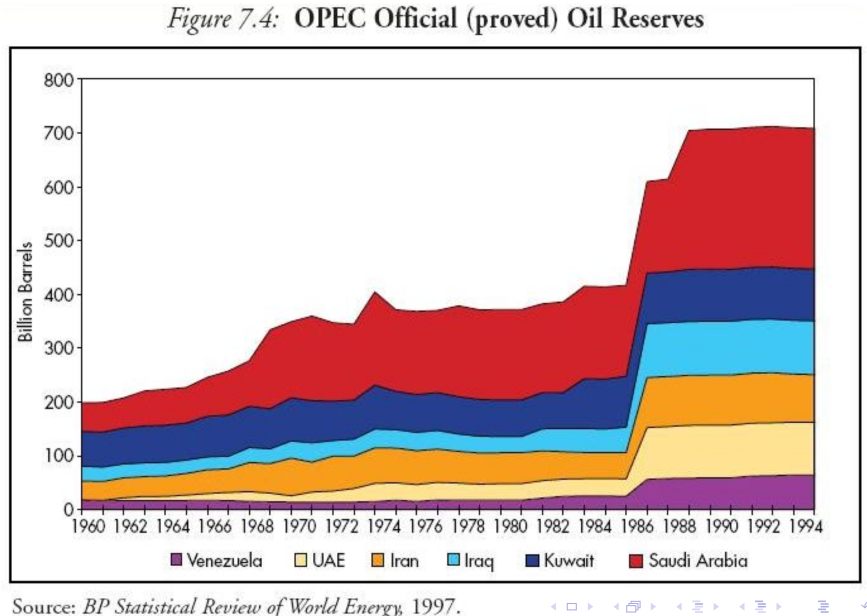
- Oil resources:
  - Contingent resources: quantity of petroleum to be potentially recoverable from known accumulations (but not interesting enough for commercial development - e.g. technical, economical, political or social events
  - Prospective resources: quantity estimated to be *potentially recoverable* from *undiscovered accumulations* in future development
- Oil reserves: quantity of technically and economically *recoverable* petroleum
  - Proven reserves (P90): recoverable under *existing technology* and economic and political conditions; recovarable with at least 90% confidence
  - Unproven reserves: estimates (typically) based on geological data
    - Probable reserves (P50): usually in known accumulations 50% probability of recovery
    - Possible reserves (P10): at least a 10% probability of recovery

Figure : Reserves vs. resources



Source: EIA

Figure : OPEC proven (?) reserves, 1986 jump (after introducin quota system allocation)



What is Peak oil?

- Describes a point in time when the rate of crude oil extraction is at its maximum (following the peak oil is a continuous decline in the extraction rates)
  - Not the same as oil depletion (decreasing reserves, as in Hotelling's rule)
- Rising prices $\neq$ running out of crude oil
  - Rising prices if demand is increasing faster than supply
- It is difficult to assess the rates of both future demand and even more difficult to assess future extraction
  - Note that in reality, Reserves-to-production ratio (R/P ratio, or inverse of depletion rate, in other words years the reserves will last at given rate of extraction) is changing in time as the production continues (for individual wells) - the reserves are always estimated (not known with certainty)
- Nevertheless, given the estimation technique, the timing of Peak Oil does not change radically (within span of decades) with different

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Hubbert peak theory

- In 1956 M. King Hubbert (geologist at Shell Oil Company) formulated a prediction: US oil peak production will peak roughly around 1970.
  - The world's oil peak expected to happen in 1995

$$Q_t = \frac{\bar{Q}}{1 + ae^{bt}}$$

- NOT an economic theory, but physical description of the production life (note what variables are entering the calculations)
  - To calculate the peak, collect annual production (P) and cumulative production (Q)
    - Fit linear regression (i.e. $\frac{P}{Q} = a + b.Q$), and compute $Q*$, such that $\frac{P}{Q} = 0$), $Q*$ thus indicates maximum cumulative production that will ever be achieved
  - Essentially Hubbert curve (showing P over time) is a derivative of logistic oil accumulation function
    - Assumes the rate of change of annual oil production is known,the equation of the oil production curve is the derivative of the logistic equation

Hubbert peak theory - calculation

- To determine the curve, collect annual production (P) and cumulative production (Q) and fit linear regression (i.e. $\frac{P}{Q} = a + b.Q$), then compute $Q*$, such that $\frac{P}{Q} = 0$)
  - $Q*$ thus indicates maximum cumulative production that will ever be achieved
- If we rewrite the linear relationship as$P = a.Q + b.Q^2$, and if $P = 0 \rightarrow Q = Q_T$, then $b.Q_T^2 = -aQ_T$ or $b.Q_T = -a$, thus $Q_T = -\frac{a}{b}$ or $b = -\frac{a}{Q_T}$
  - we can substitute to original equation: $P = a.Q - \frac{a}{Q_T}.Q^2 \rightarrow$ $P = aQ\left(1 - \frac{Q}{Q_T}\right)$
    - term $\left(1 - \frac{Q}{Q_T}\right)$ represents the fraction of oil that is remaining to be produced

Hubbert peak theory, empirical evidence

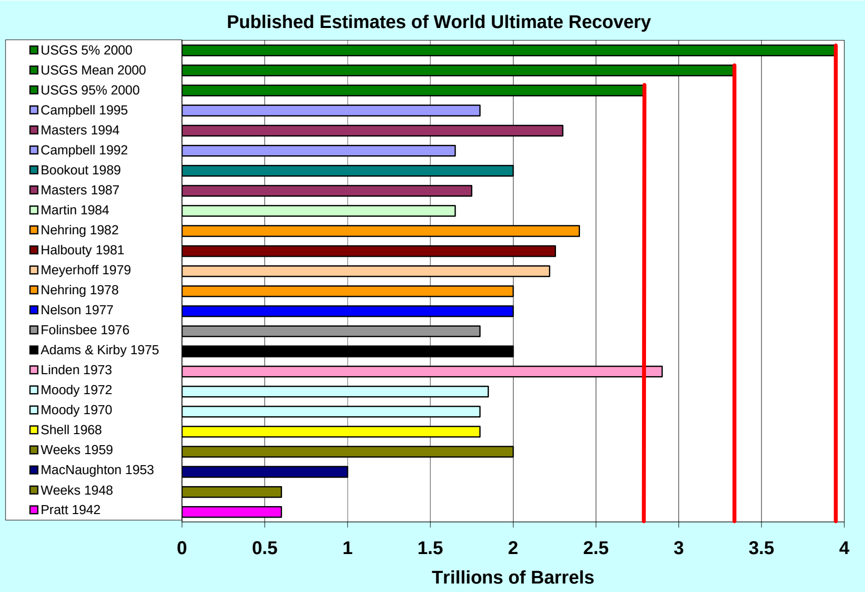
- The empirical results are controversial
  - historically, the oil was supposed to already reach the peak several times
  - not all peak theory studies follow the simple curve fitting method originally suggested by Hubbert
- Estimates of depletion (point of falling reserves): even more difficult
  - there is no way for precise measurement (especially for unconventional oil reserves)
    - In 2004, Shell had to adjust its balance sheet by 20% (which could not be classified as proven reserves at the time)
    - In 2012, SandRidge Energy Inc. adjusted reserve forecasts from from 456 000 barrels per well to 422 000 barrels per well; In 5 months, it readjusted to 369 000 barrels
  - volumes typically announced by producer / owner of the oil field - an incentive to overestimate (e.g. to draw additional investors and/or "satisfy" the stakeholders) - see the OPEC reserves jump

Figure : Oil peak estimates

Published	By	Peak Year/Range	Published	By	Peak Year/Range
1972	ESSO	About 2000	1999	Parker	2040
1972	UN	By 2000	2000	Bartlett	2004 or 2019
1974	Hubbert	1991-2000	2000	Duncan	2006
1976	UKDOE	About 2000	2000	EIA	2021-2167; 2037 most likely
1977	Hubbert	1996	2000	IEA (WEO)	Beyond 2020
1977	Ehrlich, et al.	2000	2001	Deffeyes	2003-2008
1979	Shell	Plateau by 2004	2001	Goodstein	2007
1981	World Bank	Plateau around 2000	2002	Smith	2010-2016
1985	Bookout	2020	2002	Campbell	2010
1989	Campbell	1989	2002	Cavallo	2025-2028
1994	Ivanhoe	OPEC Plateau 2000-2050	2003	Greene, et al.	2020-2050
1995	Petroconsultants	2005	2003	Laherrère	2010-2020
1997	Ivanhoe	2010	2003	Lynch	No visible peak
1997	Edwards	2020	2003	Shell	After 2025
1998	IEA (WEO)	2014	2003	Simmons	2007-2009
1998	Campbell/Laherrère	2004	2004	Bakhitari	2006-2007
1999	Campbell	2010	2004	CERA	After 2020
1999	Odell	2060	2004	PFC Energy	2015-2020

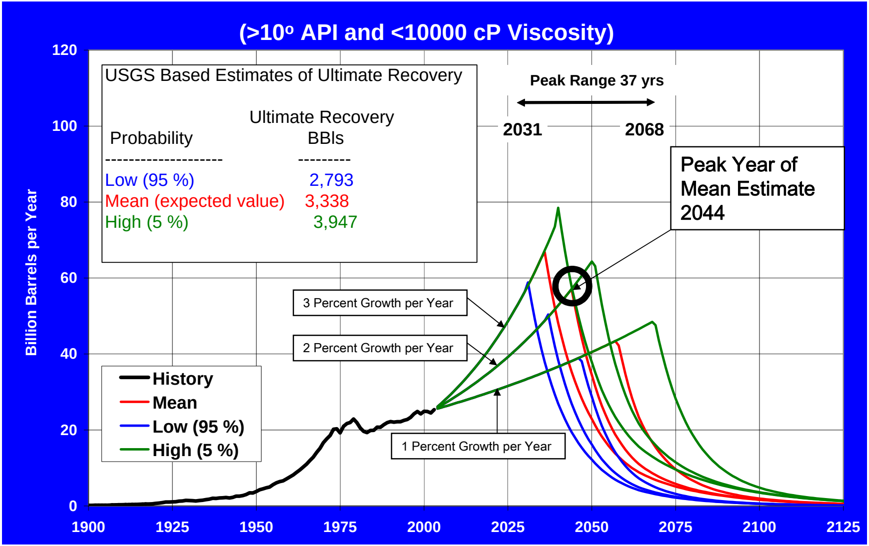
Source: Caruso (2005)

Figure : World ultimate recovery estimates



Source: Caruso (2005)

Figure : Peak estimate, EIA, source: Caruso (2005)



Source: Caruso (2005)

Figure : Oil production

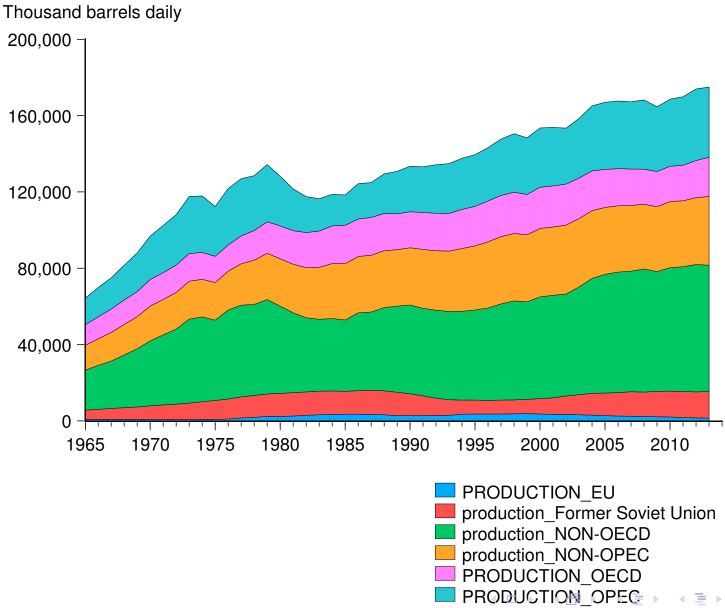


Figure : Oil proved reserves