+ Finishing Ch 2.
Lecture 4 13 Jan 2012 Start reading Ch. 3

Lifetime of Fossil Fuels:

So far we looked at energy consumption

To estimate lifetime we need:

- production rate
- amount of fossil fuels remaining

For world as a whole consumption ~ production

Locally consumption ≠ production

e.g. US 2005 production was 13 EJ/year
consumption was 40 EJ/year

the difference was imported

This gap continues to grow as
- US reserves shrink
- US demand increases.

Amount Remaining:

Reserves: fossil fuels that have been discovered and measured

Resources: - reserves and fuels that are expected to become recoverable w/ right market conditions / technology

Details are beyond scope of PHYS 365

Here we wish to make order of magnitude estimates based on simple assumptions.

First look at Table 2-3 from your text (2005)

Recall $1 EJ = 10^{18} J$

- Note that Canada has ~ 10% of world oil resource
- ~~Resource~~ Canada's oil resource is primarily oil sands. ~ Saudi
- World gas resource is comparable to oil
- Canada has ~ 1% of world gas resources
- Coal is huge : known reserves of 20000 EJ
  potential resource almost 10X higher.

Estimating Fossil Fuel lifetime = simplest (and least correct) method

Assume constant production rate at current levels

Aside = let's look at current production levels

Next slide : Fig. 2.4 from text

- Production in EJ ~ equal for gas & coal
  oil is somewhat bigger.
- Canada has only 6% of world production, but this will change.
- USA 13 billion bbl and dropping (slowly)

Next slide : Ranking of oil producers.

- Saudi Arabia is on top, but Canada is chasing fast!
- US produces more, but has much lower resource

Back to estimate of lifetime:

Definitions: $Q(t)$ = amount produced to date

Q_T = total resource (fixed) (EJ) over all time back to $t=0$

$N(t)$ = production rate

$N = \frac{dQ(t)}{dt}$ rate at which resource is being used $= \frac{dQ}{dt}$

Ex Assuming const. $N(t) = N_0$, how long will oil resources last?

Table 2.3 $Q_T = 12000$ EJ

Current production (2005) $N = 164 \frac{EJ}{yr}$

$N_0 = \frac{Q_T}{T}$ T = total time
Q_T = total resource

$T = \frac{Q_T}{N_0} = \frac{12000 \text{ EJ}}{164 \text{ EJ/yr}} = \underline{73 \text{ years}}$

Note: this is for oil only

For coal: $T = \frac{150{,}000 \text{ EJ}}{122 \text{ EJ/yr}} = \underline{1230 \text{ yrs}}$!

Is coal the energy of the future?

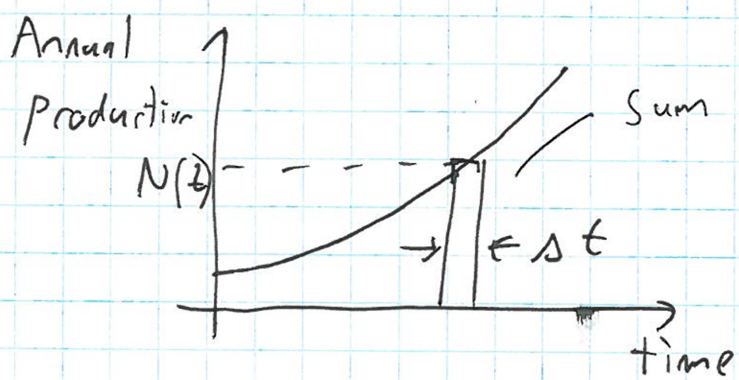
Preceding assumes constant energy use.

How does analysis change with exponential increase in consumption?

Production increases as $N(t) = N_0 e^{kt}$

where $N(t) = \frac{dQ}{dt} \sim \frac{\Delta Q}{\Delta t}$ $\quad \Delta Q$ = amount produced in time Δt

Amount produced in a given time : $\Delta Q = \underbrace{N(t)\Delta t}_{= \text{area of slice}}$

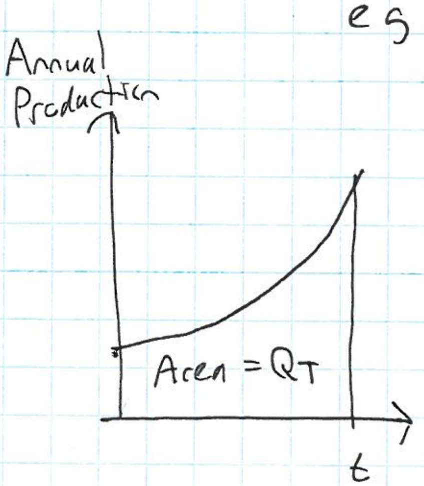


Sum all small areas

Total amount produced is given by integration from some initial time to some final time

eg $\quad Q_T = \int_0^T N(t)\,dt \quad \leftarrow T$ = time to deplete entire resource

$\uparrow$ total resource



$$= \int_0^T N_0 e^{kt}\,dt$$

$$= \frac{N_0}{k} e^{kt} \Big|_0^T$$

$$Q_T = \frac{N_0}{k}\left(e^{kT} - 1\right)$$

ie. $\quad e^{kT} = \frac{k Q_T}{N_0} + 1$

Solving for T : $\quad T = \frac{1}{k} \ln\left(\frac{k Q_T}{N_0} + 1\right)$

Example : Suppose production rate is increasing exponentially with $\lambda = 1.7\%$
$k \sim \lambda = 0.017\ yr^{-1}$

(a) How long will oil reserves last ?

$N_0 = 164\ EJ/yr$ (2005)

$Q_T = 12000\ EJ$

$$T = \frac{1}{k} \ln\left(\frac{k Q_T}{N_0} + 1\right) = \frac{1}{0.017} \ln\left(\frac{0.017/yr \cdot 12000\ EJ}{165\ EJ} + 1\right)$$

$= \underline{\underline{48\ \text{years}}}$ much shorter !

(b) If resource is doubled how much longer will the oil last ?

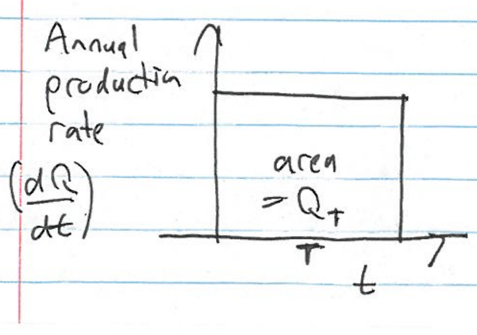
ie $Q_T = 24000\ EJ$

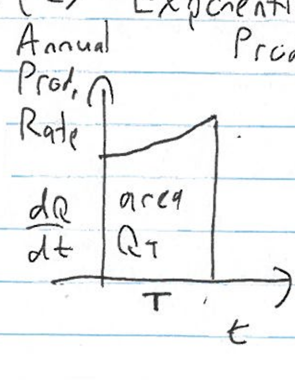
$$T = \frac{1}{0.017} \ln\left(\frac{.017/yr \cdot 24000\ EJ}{165\ EJ} + 1\right) = \underline{\underline{73.2\ yrs}}$$

less than double.

To summarize graphically : we have two models

(1) Fixed production rate or (2) Exponentially Increasing Production Rate





Areas are same so T must be shorter for (2)

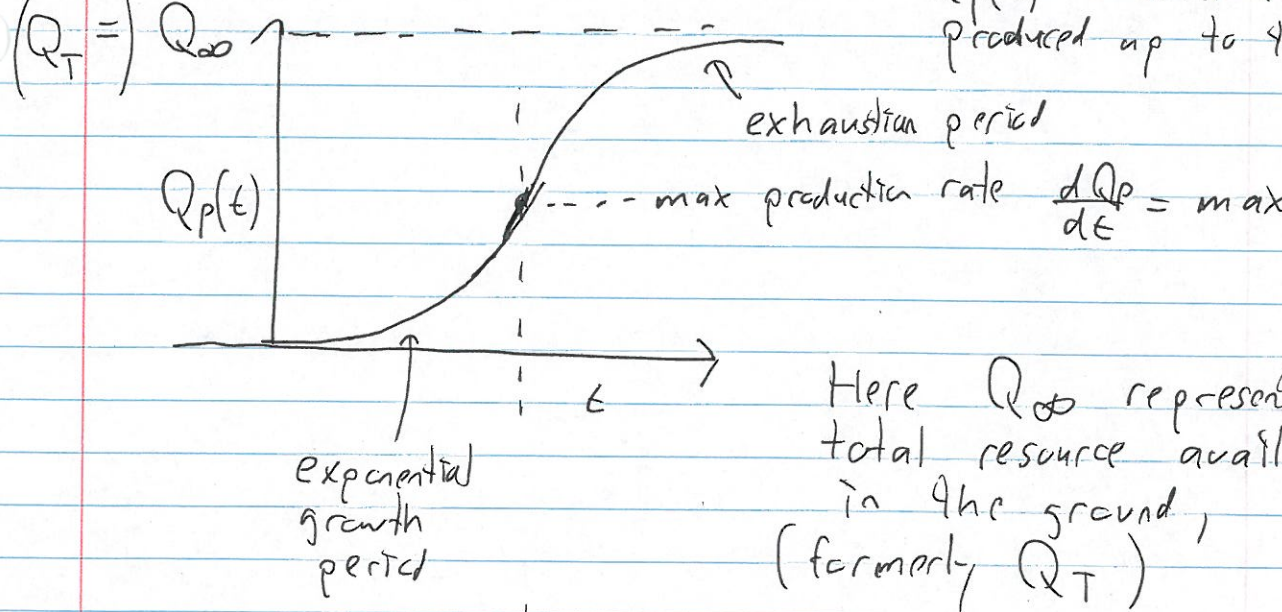
What is wrong with this model?

highly unrealistic to assume oil will suddenly stop.

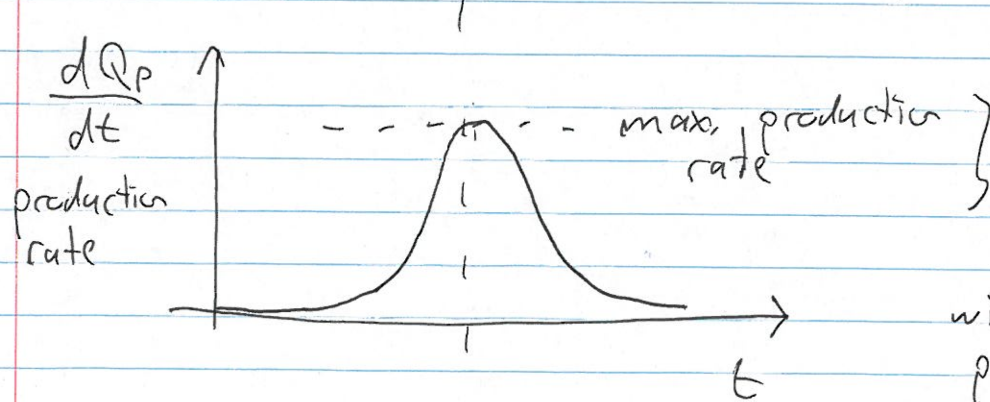
- ignores that oil will become more & more expensive, slowing growth of conventional fuel extraction.
- ignores technological improvements that may increase resources
- ignores demographic, political, environmental factors.

More realistic model: Plot $Q_p(t)$ vs t

where $Q_p(t)$ = total resource produced up to time t



Here Q_∞ represents the total resource available in the ground, (formerly Q_T)



Can we estimate when we will reach this point?

Table 2-3 from McFarland (2005 data, EJ)

Region	Oil Reserves	Oil Resources	Natural Gas Reserves	Natural Gas Resources	Coal Reserves	Coal Resources
World	7500	12000	6000	8000	20000	150000
Canada	1000*	1200	60**	400	140	2700
USA	170	600	180	700	5000	36000

* Mostly oil sands
**68 EJ as of 1 jan2011

Fossil fuel production (EJ/year, 2005)

Region	Oil	Gas	Coal
World	164	105	122
Canada	6.1	7.0	1.5
USA	13	20	24

Table 2.4 (McFarland)

Oil production rate rankings (billion of bbl/year)

Rank	Country	bbl/day
1	Saudi Arabia	10,520,000
2	Russia	10,130,000
3	United States	9,688,000
4	China	4,273,000
5	Iran	4,252,000
6	Canada	3,483,000
7	Mexico	2,983,000
8	United Arab Emirates	2,813,000
9	Brazil	2,746,000
10	Nigeria	2,458,000
11	Kuwait	2,450,000
12	Iraq	2,408,000
13	Venezuela	2,375,000
14	European Union	2,276,000
15	Norway	2,134,000
16	Algeria	2,078,000
17	Angola	1,988,000
18	Libya	1,789,000
19	Kazakhstan	1,610,000
20	Qatar	1,437,000
21	United Kingdom	1,393,000

Source: CIA website, 2011

Oil Sands Production

Canadian Production: Barrels/day

Year	1980	2010	2025
Crude Oil (incl. oil sands)	1.5 million	2.8 million	4.7 million
Oil Sands	0.1 million	1.5 million	3.7 million

Source: CAPP 2011 Can. Assoc. Petrol. Producers