Massachusetts Institute of Technology
22.251 Systems Analysis of the Nuclear Fuel Cycle
Fall 2009

Fuel & Operational Economics - 1

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Regulated Economics

- Exclusive service area for company
- People <u>must</u> buy all their electricity from company
- Company <u>must</u> provide all electricity needed ("obligation to serve")
- Company can <u>only</u> charge what regulators allow

Regulated Economics

Allowed return on unamortized investment (including allowed profit)

+

Allowed operating & maintenance

+

Allowed fuel

=➔

Sales Price of electricity

De-regulated Economics

- No exclusive service area
- Company sells to whom it pleases
- No one has any obligation to buy
- Company can charge what it pleases

De-regulated Economics

Sales price (what the market will bear)

-

Capital related costs

-

Operating, maintenance & fuel costs

= ➡

Profit

Definition of an Asset

Anything that has value for future years

- Plant (reactor, turbine, switchyard, etc) is an asset
- Transmission line is an asset
- Nuclear fuel is an asset

Expense vs Amortization

- When things are “expensed”, their value is recovered in the same year the money is spent
- When things are assets, their cost is recovered year by year over the life of the asset (depreciation)
- O & M is an expense

Cost of Money

When recovering costs over several (many) years, must account for "cost of money"

Cost of money =

- ♦ Cost to borrow (interest) OR
- ♦ Cost of stock (dividends) OR
- ♦ What you could have gotten by investing your own money (opportunity)

Conceptually, cost of money =

- Riskless return rate (includes inflation - often approximated by US Fed funds rate)

+

- Risk premium (this is where nuclear construction got hit in the past)

Verbiage

- “Constant dollars” - neglect inflation
- “Current dollars” - include inflation

Beware Constant $ Analyses

- Cost of asset (once built) doesn't inflate
- Therefore, depreciation doesn't inflate
- Cost of maintaining it does inflate
- Cost of fuel does inflate
- THEREFORE constant dollar analyses distort taxes

Present Value

- $X paid t years from now is equivalent today to

$$\frac{X}{(1+i)^t}$$

For Continuous Payments the value today of $X paid uniformly over the next t years is

$$Xe^{-it}$$

Where Projects Involve Payments at Different Times

- Use present value to convert payments at various times to equivalent dollars all at one time
- Present values “commute”:

  $PV(t1 \Rightarrow t2 \Rightarrow t3) = PV(t1 \Rightarrow t3)$

Cash Flow of a Batch

- Cost of “yellowcake”
- Cost of conversion (to natural UF6)
- Cost of enriching
- Cost of fabrication
- Cost of temporary spent fuel storage
- Cost of ultimate disposal

Unit Cost of Fuel Components

- Yellowcake $/lbU3O8
  - 2.61285 lbU3O8 per kgU
- Conversion $/kgU
- Enriching $/kgSWU
- Fabrication $/assembly, $/kgU
- Storage $/cask, $/assembly
- Disposal ??$/kgU, $/assy, mills/kwh

Today's Unit Costs

- U3O8 ~ $ 45/lb U3O8
- Conversion ~ $ 7/kgU
- Enriching ~ $160/kgSWU
- Fabrication ~ $ 300/kg
- Storage ~ $ 1 million/24 assy cask
- Disposal ???? 1/mill/kwhe

Level Cost

- “annualized” *constant* cash flow that has same present value as actual cash flow
- Level cost is an evaluation tool, not an accounting tool
- Net present value gives same result

Level Nuclear Fuel Cost

- X_j = Cost of fuel component j
- E = electrical energy

$$FC = \frac{\sum_j PV(X_j)}{PV(E)}$$

Batch Fuel Cost

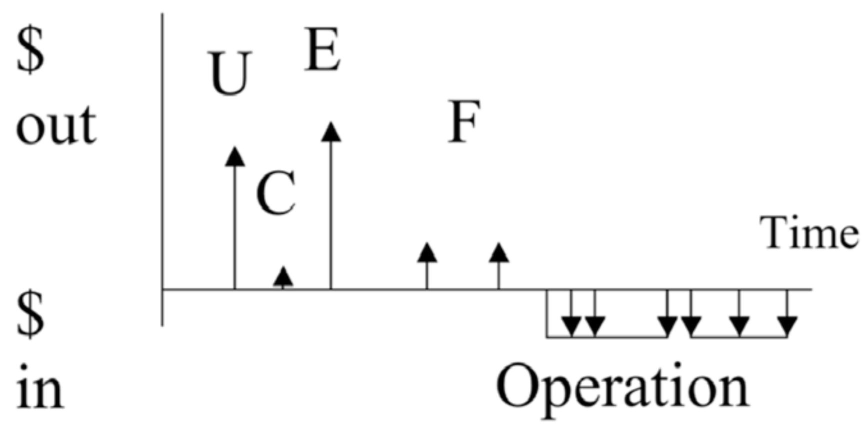
- FC is fuel cost in mills/kwh or \$/MWH
- η is efficiency as fraction
- B is burnup in MWD/kgU (or kgHM)
- Xj is cost of jth component in \$/kgU

$$FC = \frac{41.67 \sum_{j} PV(X_{j})}{\eta PV(B)}$$

Batch Fuel Cost

$$FC = \frac{41.67PV(X)iT}{\eta B\left[1 - e^{-iT}\right]}$$

Cash Flow of a Batch



Example

- Lead times
  - U3O8 1.25 yr
  - Conversion 1 yr
  - Enriching 0.75 yr
  - Fab 0.4 yr
- Irradiation time 4.5 yr
- Cost of money 10%

Example continued

- 4.5 w/o enrichment
- Tails = 0.25 w/o
- Bdis = 50,000 MWD/MTU

Example calcs

- F/P = (4.5 – 0.25) / (0.711-0.25) = 9.22
  - 9.22*2.61 lbU3O8/kgU * $45/lbU3O8
  - $1083 $/kgU
- Conversion $7/kgU
- S/P = 6.88 SWU/kgU * $160 /kgSWU
  = $1101/kgU

PV to start of irradiation

- U3O8 $1083 * $(1.1)^{1.25}$
- Conv $7 * $(1.1)^{1.00}$
- SWU $1101* $(1.1)^{0.75}$
- Fab $300 * $(1.1)^{0.4}$
- Burnup 50,000 * $(1.1)^{-2.25}$

Frontend Fuel Cost

- = (1220+7.7+1183+311.7)/(.333*40350)
- = 8.44 mills/kwh
- = 3.78 (U_3O_8) + 0.02 (Conv) + 3.67 (SWU) + 0.97 (Fab)

Batch Fuel Cost Notes

- Everything must be PV'ed to same instant of time
- Doesn't matter which particular instant
- Conventional to use start of operation (of reactor or of batch)
- Cycle fuel cost is power weighted sum of its batch fuel costs

Useful Data

- 1 mill/kwh = $1 /MWh
- Typical annual reactor generation = ~ 10 million MWh
- So reducing fuel cost by ~ 0.1 mill/kwh saves ~ $1 million per year

How to Reduce Fuel Cost Rate

- Refer to equation FC=dollars/energy
- Commercial: reduce costs in numerator (pay less for same thing)
- Technical: increase burnup or efficiency in denominator (get more from same thing)

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