Week 8

Project Cost Estimating (2)

Engineering Economics

457.307 Construction Planning and Management

Department of Civil and Environmental Engineering

Seoul National University

Prof. Seokho Chi

shchi@snu.ac.kr

건설환경공학부 35동 304호

A Sea of Problems

- **Simple Problems: Worked in one's head**
  - Should I pay cash for an item or use my credit card?
  - Shall we replace a burned-out motor?
  - Do I take a bus or a subway?
- **Intermediate Problems: Organized and analyzed, Economic aspects are significant**
  - Shall I buy or lease my next car?
  - Which equipment should be selected for a new assembly line?
  - Which materials should be used as roofing, siding, and structural support for a new building?
  - Do I buy a semester parking pass or use the parking meters?
  - Which printing press should be purchased? A low cost press requiring three operators or a more expensive one needing only two operators?

A Sea of Problems

- **Complex Problems: Economic, political and humanistic**
  - The selection of a girlfriend or a boyfriend (who may later become a spouse): economic analysis can be of little or no help.
  - Manufacturing site: Texas or California

Texas	**California**
Permit time: 9-12 months	Permit time: 12-18 months
No seismic sensitivity	Seismic sensitive location
No dock Facilities (major market: Asia)	Coast with dock facilities
Lower labor/construction cost	Higher construction cost
Closer to raw materials	More environmental restrictions
Lower taxes	CEO' preference

Role of Engineering Economic Analysis

- **Suitable for Intermediate Problems & Economic Aspects of Complex Problems**
  - The decision is sufficiently important that serious thought and effort is required.
  - That careful analysis requires that the decision variables be carefully organized and the consequences be understood.
  - A significant component of the analysis leading to a decision are ECONOMIC ISSUES.
  - Engineering economic analysis focuses on: costs, revenues and benefits that occur at different times
  - When a civil engineer designs a road, a dam, or a building: construction costs occur in the near future and benefits to users only begin when construction is finished but then the benefits continue for a long time.

Decision Making Process

1. Recognize problem
2. Define the goal or objective
3. Assemble relevant data
4. Identify feasible alternatives
5. Select criteria to determine the best alternative
6. Construct a model
7. Predict each alternative's outcomes or consequences
8. Choose the best alternative
9. Audit the result

Example

- A machine part is manufactured at a unit cost of 40¢ for material and 15¢ for direct labor (other costs = 2.5 x direct labor cost). An investment of $500,000 in tooling is required. The order calls for 3,000,000 pieces. Half-way through the order, a new method of manufacture can be put into effect which will reduce the unit costs to 34¢ for material and 10¢ for direct labor, but it will require $100,000 for additional tooling. What, if anything, should be done?
- Alternative 1: Continue with present method
  - Direct cost: 1,500,000 pieces x 0.40 = $600,000
  - Direct labor cost: 1,500,000 pieces x 0.15 = $225,000 | Other costs = $562,500
  - Total = $1,387,500
- Alternative 2: Change the manufacturing method
  - Material cost: 1,500,000 pieces x 0.34 = $510,000
  - Direct labor cost: 1,500,000 pieces x 0.10 = $150,000 | Other costs = $375,000
  - Additional tooling cost: $100,000
  - Total = $1,135,000

Engineering Costs

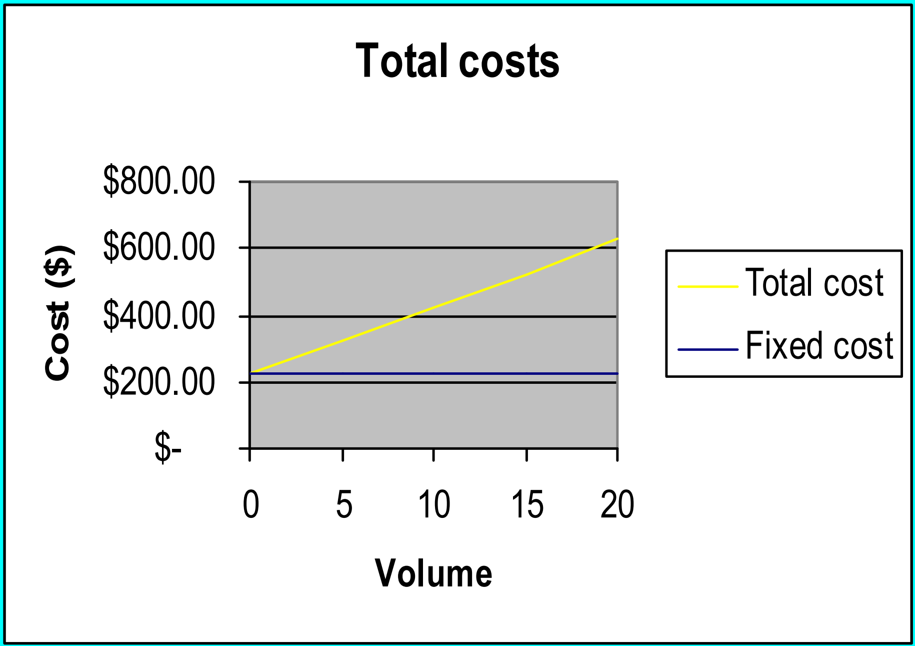
- **Classifications of Costs**
  - Fixed: constant , unchanging (e .g . “ crane ” costs)
  - Variable : depend on activity level (e .g . “ placing concrete ” cost depends on the quantity)
  - Marginal: variable cost for one more unit
  - Average : total cost /number of units

Engineering Costs

- An entrepreneur named YG was considering the money-making potential of chartering a bus to take people from is hometown to an event in a larger city. YG planned to provide transportation, tickets to the event, and refreshments on the bus for those who signed up. He gathered data and categorized these expenses as either fixed or variable.

Fixed Costs		Variable Costs	
Bus Rental	$ 80.00	Event Tickets	$ 12.50
Gas Expense	$ 75.00	Refreshments	$ 7.50
Other Fuels	$ 20.00		
Bus Driver	$ 50.00		
Total FC	$ 225.00	Total VC	$ 20.00

People	Fixed cost	Variable cost	Total cost
0	$ 225.00	$ -	$ 225.00
5	$ 225.00	$ 100.00	$ 325.00
10	$ 225.00	$ 200.00	$ 425.00
15	$ 225.00	$ 300.00	$ 525.00
20	$ 225.00	$ 400.00	$ 625.00

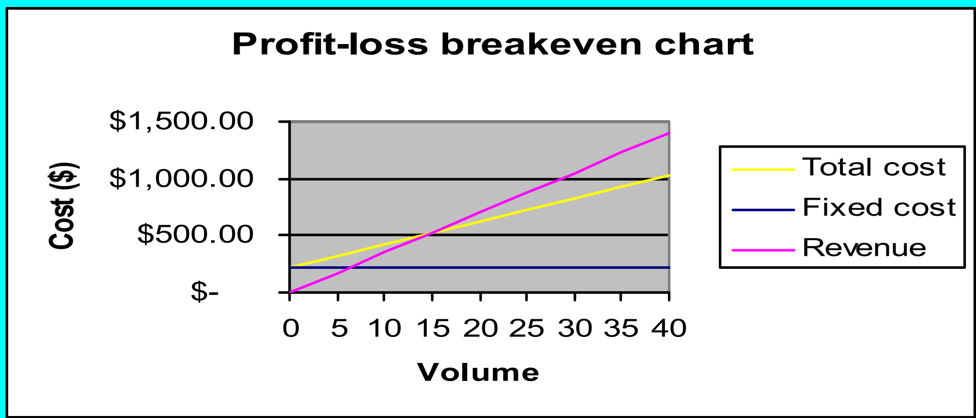


Engineering Costs

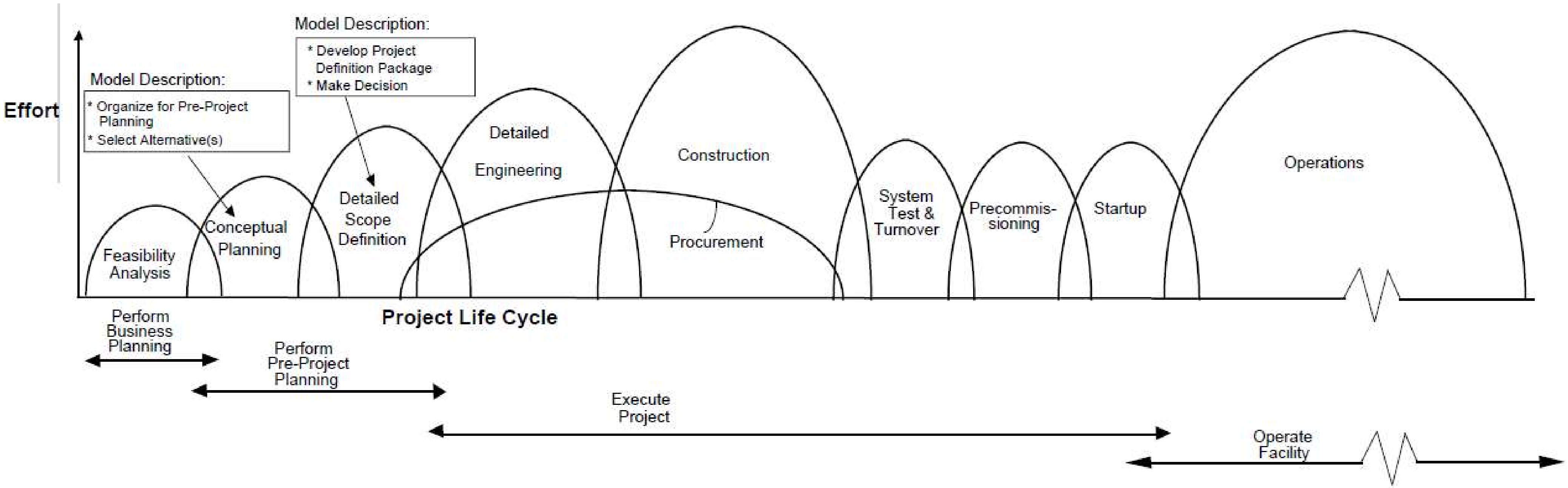
- ## Profit and Loss Terms

Fixed Costs		Variable Costs		Ticket price
Bus Rental	$ 80.00	Event Tickets	$ 12.50	$ 35.00
Gas Expense	$ 75.00	Refreshments	$ 7.50	
Other Fuels	$ 20.00			
Bus Driver	$ 50.00			
Total FC	$ 225.00	Total VC	$ 20.00	

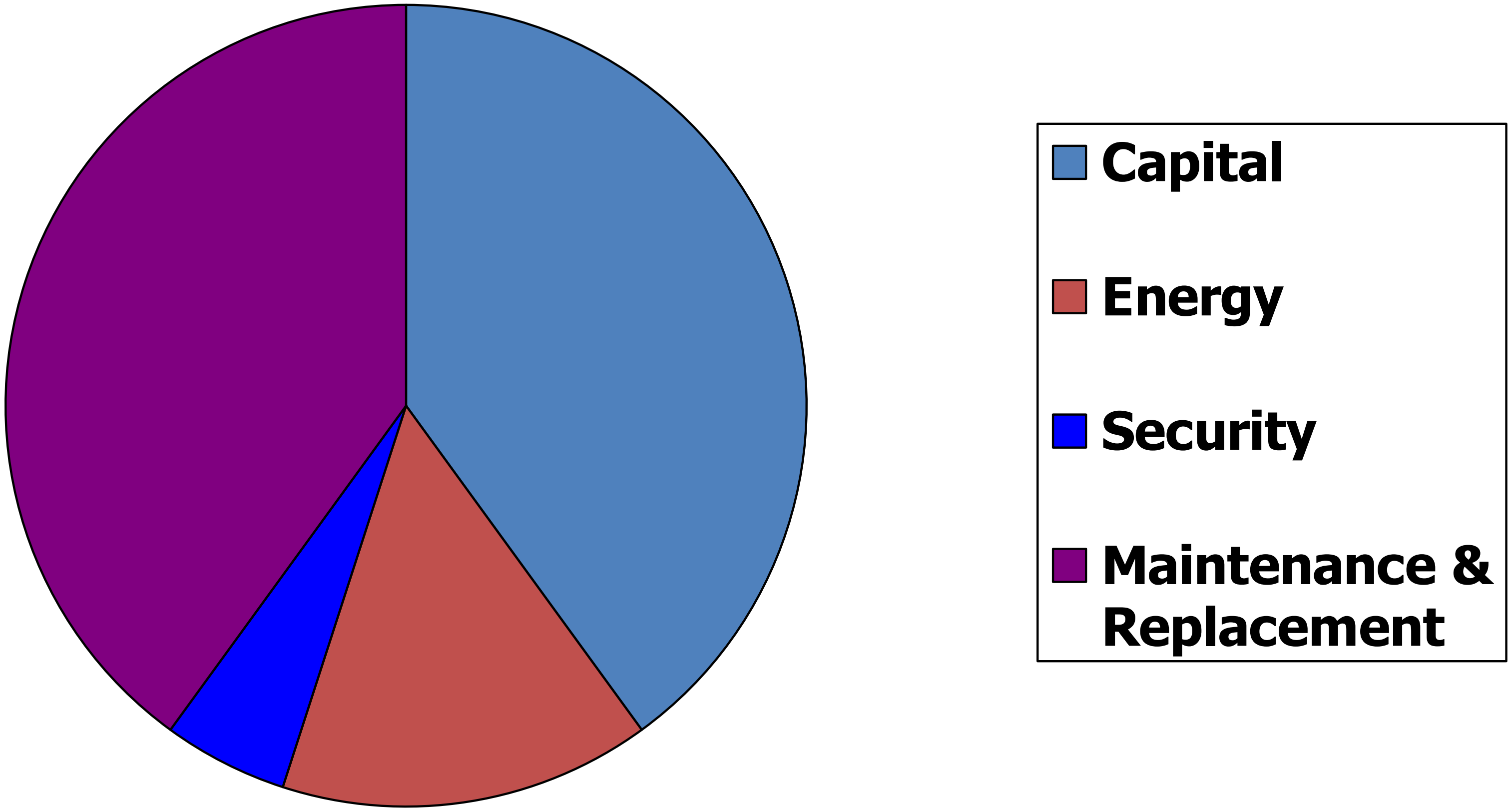
People	Fixed cost	Variable cost	Total cost	Revenue	Profit	Region
0	$ 225.00	$ -	$ 225.00	$ -	$ (225.00)	Loss
5	$ 225.00	$ 100.00	$ 325.00	$ 175.00	$ (150.00)	Loss
10	$ 225.00	$ 200.00	$ 425.00	$ 350.00	$ (75.00)	Loss
15	$ 225.00	$ 300.00	$ 525.00	$ 525.00	$ -	Breakeven
20	$ 225.00	$ 400.00	$ 625.00	$ 700.00	$ 75.00	Profit
25	$ 225.00	$ 500.00	$ 725.00	$ 875.00	$ 150.00	Profit
30	$ 225.00	$ 600.00	$ 825.00	$ 1,050.00	$ 225.00	Profit
35	$ 225.00	$ 700.00	$ 925.00	$ 1,225.00	$ 300.00	Profit
40	$ 225.00	$ 800.00	$ 1,025.00	$ 1,400.00	$ 375.00	Profit



Project Lifecycle



Life Cycle Cost (LCC)



Adapted from *Life Cycle Assessment – A Primer*, Paladino Consulting LCC, July 2000, Seattle, WA, www.palcon.com

LCC Practice

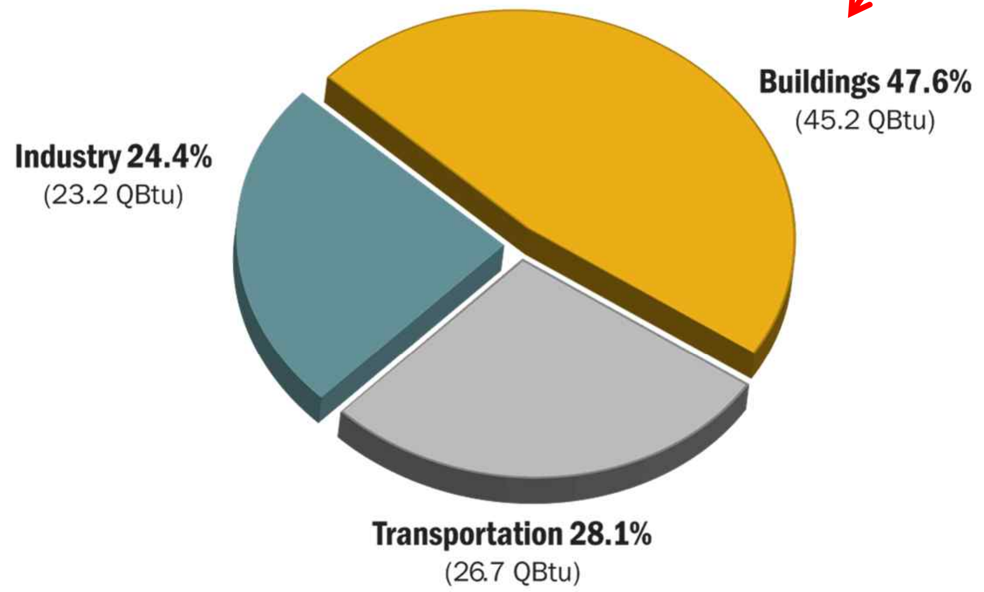
- **LCC methodology encompasses:**
  - Capital costs
  - O&M costs
    - Energy in particular
  - Salvage costs

- Economic analysis is future based.
- Costs and benefits in the future require estimating.
- Estimated costs are not known with certainty: Power Sizing(Segmenting + Interests), Cost Indexes, Learning Curve, etc.
- The more accurate the estimate, the more reliable the decision.

Energy Consumption

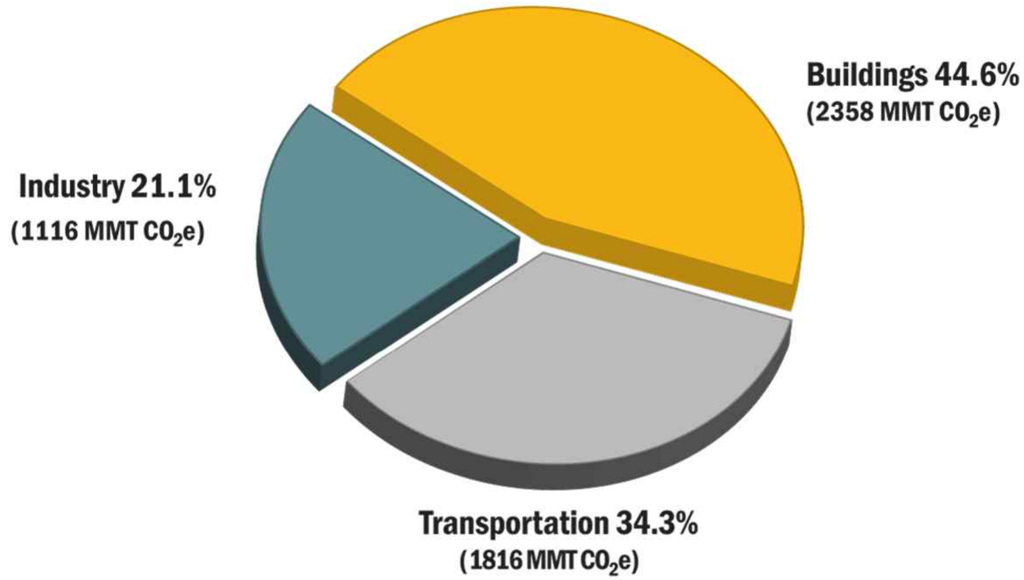
- **Buildings = Biggest polluters + Biggest Energy Consumption**

Building Operation 41.7%
Building Construction and Materials 5.9%



U.S. Energy Consumption by Sector

Data Source: U.S. Energy Information Administration (2012).

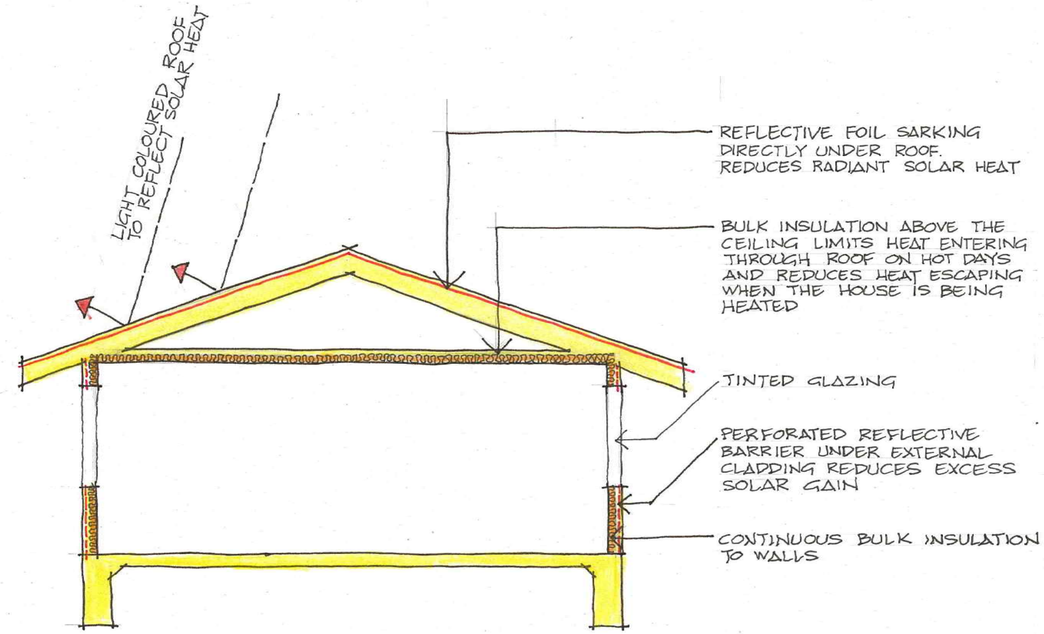


U.S. CO_2 Emissions by Sector

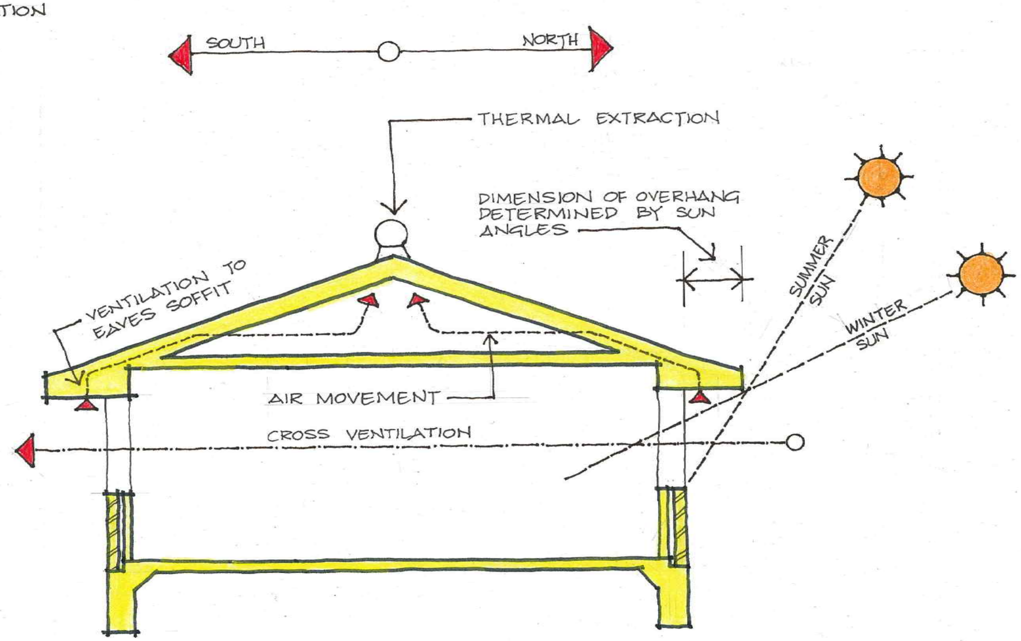
Data Source: U.S. Energy Information Administration (2012).

Green Building

- **Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction.**
- **Green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by:**
  - Efficiently using energy, water, and other resources
  - Protecting occupant health and improving employee productivity
  - Reducing waste, pollution and environmental degradation



ROOF AND WALL INSULATION

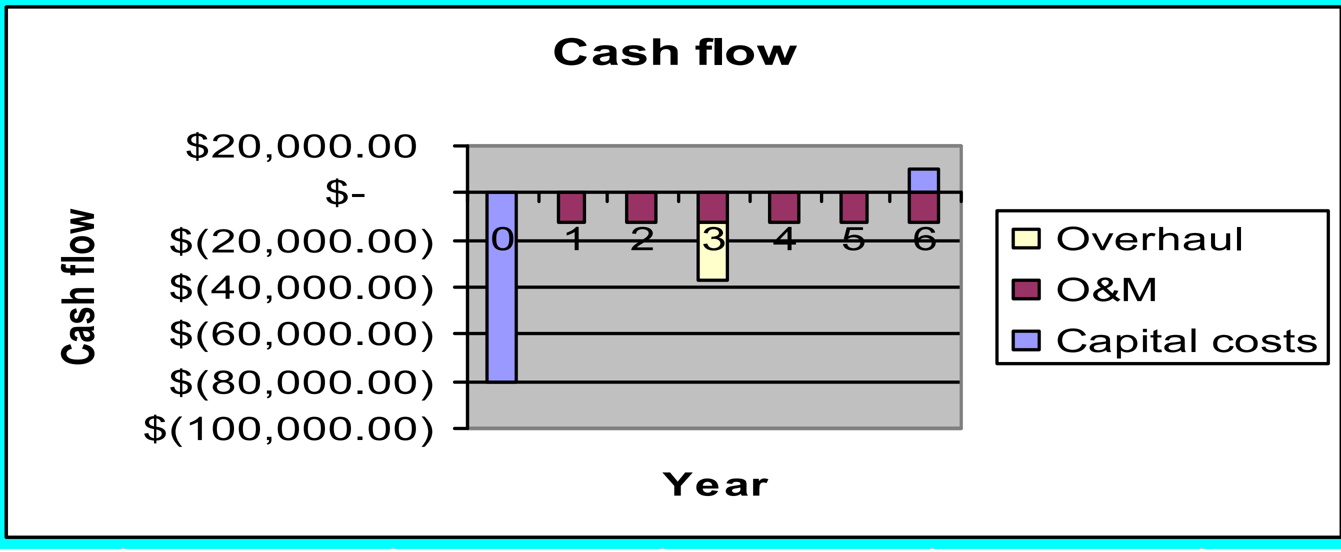


AIR MOVEMENT / SHADING

Cash Flow Diagrams

- Summarizes the flow of money overtime
- Can be represented using a spreadsheet

Year	Capital costs	O&M	Overhaul	Total
0	$ (80,000.00)			$ (80,000.00)
1		$ (12,000.00)		$ (12,000.00)
2		$ (12,000.00)		$ (12,000.00)
3		$ (12,000.00)	$ (25,000.00)	$ (37,000.00)
4		$ (12,000.00)		$ (12,000.00)
5		$ (12,000.00)		$ (12,000.00)
6	$ 10,000.00	$ (12,000.00)		$ (2,000.00)



*Overhaul: 기계시스템 정비

Net Present Value (NPV) Analysis

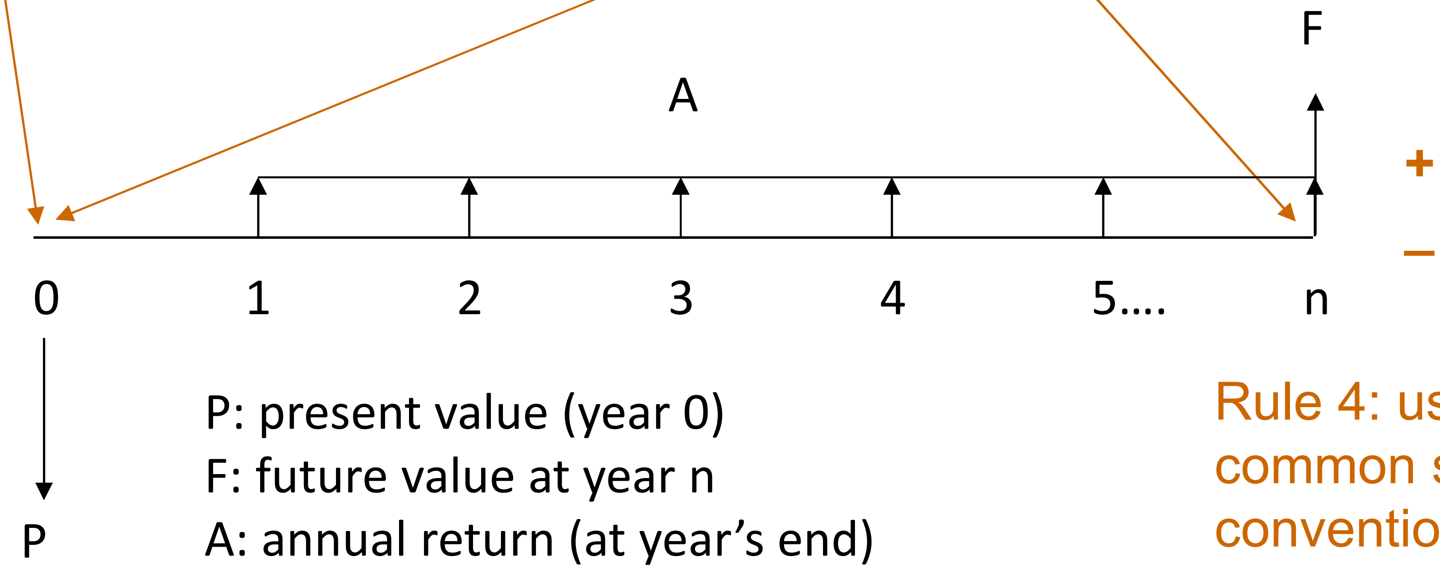
- **Today's $100 OR Tomorrow's $100?**
- **Discounting: $ tomorrow is worth less than $ today**
  - Why?
    - Risk. You might not get paid tomorrow.
    - Opportunity. You could invest the dollar today to make money.
    - Risk. Prices in the future might go up.
    - Risk. You might not be around tomorrow.
    - Value. Why delay gratification when you could have something now?

Cash Flow Mapping

Rule 1: Always start at year 0!
(present time or start of study period)

Rule 3: always compare alternatives using the same study period

Rule 2:
Ignore expenses before study period (sunk costs).



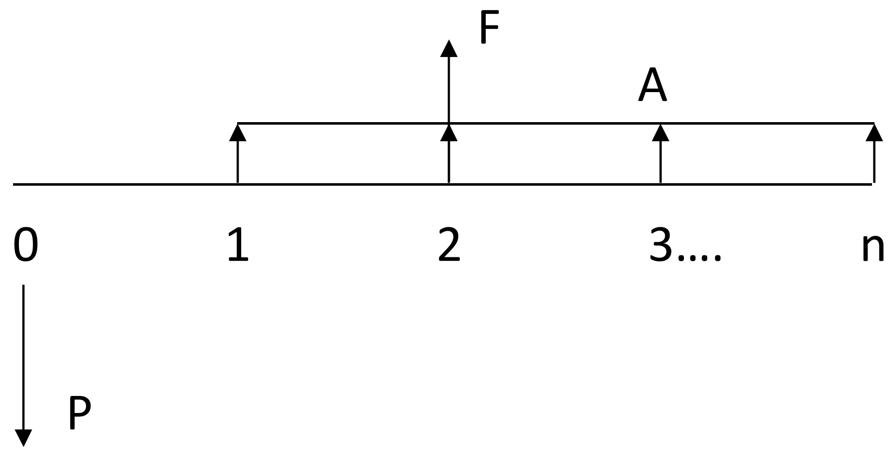
P: present value (year 0)
F: future value at year n
A: annual return (at year's end)
i: interest rate per period
n: number of years/periods

Rule 4: use a common sign convention

If you can get the cash flow diagram straight, you have the problem mostly solved!

Discounting or NPV Formulas

NPV = Net Present Value



F|P (P to F) $F = P(1+i)^n$

P|F $P = 1/(F|P)$

F|A (A to F) $F = A[((1+i)^n)-1)/i]$

A|F $A = 1/(F|A)$

P|A (A to P) $P = A\ [((1+i)^n)-1)/(i(1+i)^n)]$

A|P $A = 1/(P|A)$

NPV Example

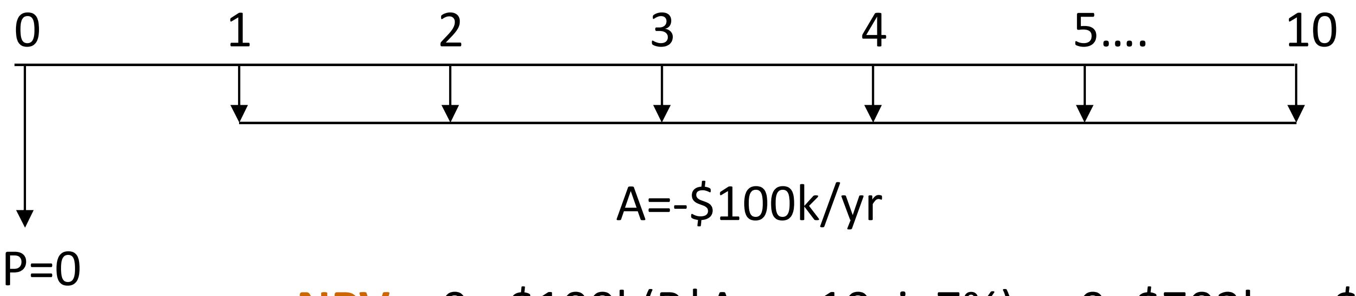
- **Repair vs Replace HVAC system**
  - If ***repair*** current HVAC,
    - no upfront costs (P=0), but O&M costs are \$100k/yr
  - If ***replace*** with new HVAC,
    - upfront costs are \$300k and O&M costs are \$50k/yr
  - Assume 10 year lifespan, $i = 7\%$

"\$100k(P|A, n=10, i=7%)"

NPV Example (Cont'd)

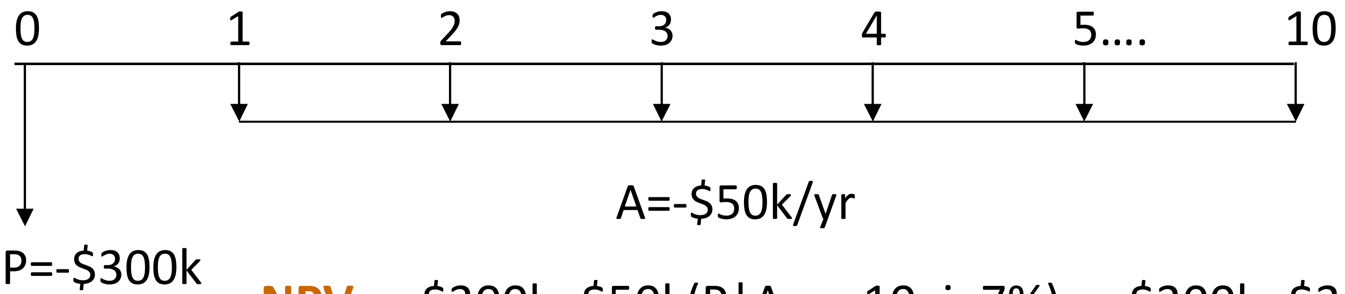
$P|A = A\ [((1+i)^{n})-1)/(i(1+i)^{n})]$

- **Repair**



NPV = 0 - $100k(P|A, n=10, i=7%) = 0 -$702k = -$702k

- **Replace**



NPV = -$300k -$50k(P|A, n=10, i=7%) = -$300k -$351k = **-$651k**

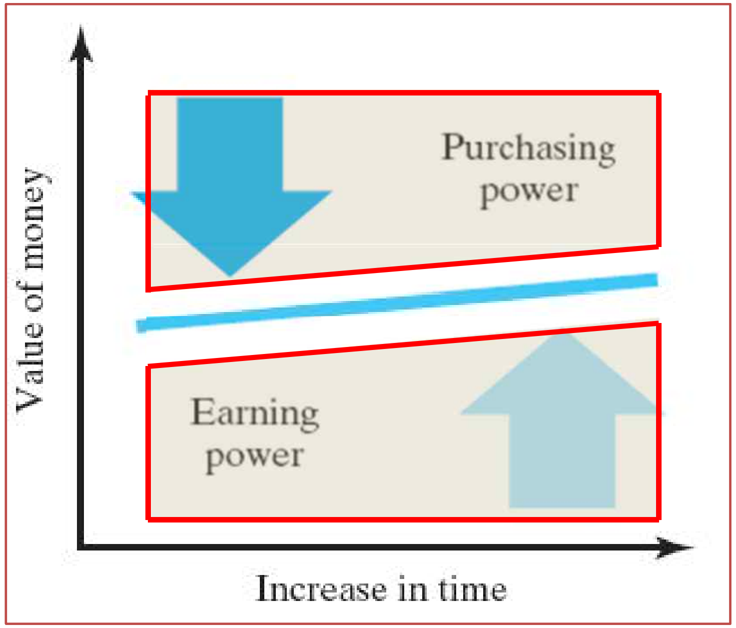
Makes sense to invest in the new system!

4% Compound Interest Factors 4%

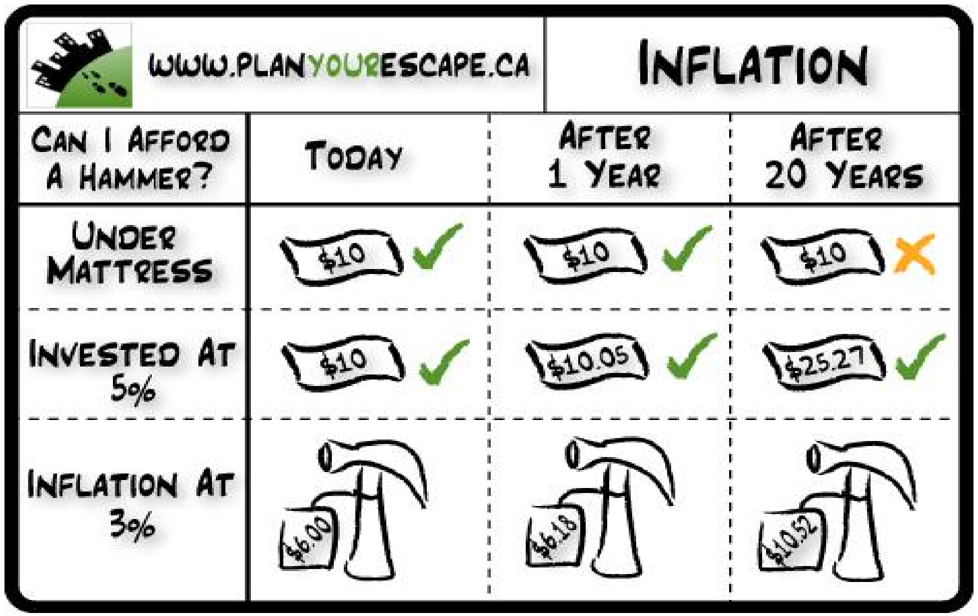
	Single Payment		Uniform Payment Series				Arithmetic Gradient		
	Compound Amount Factor	Present Worth Factor	Sinking Fund Factor	Capital Recovery Factor	Compound Amount Factor	Present Worth Factor	Gradient Uniform Series	Gradient Present Worth	
	Find F Given P F/P	Find P Given F P/F	Find A Given F A/F	Find A Given P A/P	Find F Given A F/A	Find P Given A P/A	Find A Given G A/G	Find P Given G P/G	
n									n
1	1.040	.9615	1.0000	1.0400	1.000	0.962	0	0	1
2	1.082	.9246	.4902	.5302	2.040	1.886	0.490	0.925	2
3	1.125	.8890	.3203	.3603	3.122	2.775	0.974	2.702	3
4	1.170	.8548	.2355	.2755	4.246	3.630	1.451	5.267	4
5	1.217	.8219	.1846	.2246	5.416	4.452	1.922	8.555	5
6	1.265	.7903	.1508	.1908	6.633	5.242	2.386	12.506	6
7	1.316	.7599	.1266	.1666	7.898	6.002	2.843	17.066	7
8	1.369	.7307	.1085	.1485	9.214	6.733	3.294	22.180	8
9	1.423	.7026	.0945	.1345	10.583	7.435	3.739	27.801	9
10	1.480	.6756	.0833	.1233	12.006	8.111	4.177	33.881	10
11	1.539	.6496	.0741	.1141	13.486	8.760	4.609	40.377	11
12	1.601	.6246	.0666	.1066	15.026	9.385	5.034	47.248	12
13	1.665	.6006	.0601	.1001	16.627	9.986	5.453	54.454	13
14	1.732	.5775	.0547	.0947	18.292	10.563	5.866	61.962	14
15	1.801	.5553	.0499	.0899	20.024	11.118	6.272	69.735	15
16	1.873	.5339	.0458	.0858	21.825	11.652	6.672	77.744	16
17	1.948	.5134	.0422	.0822	23.697	12.166	7.066	85.958	17
18	2.026	.4936	.0390	.0790	25.645	12.659	7.453	94.350	18
19	2.107	.4746	.0361	.0761	27.671	13.134	7.834	102.893	19
20	2.191	.4564	.0336	.0736	29.778	13.590	8.209	111.564	20
21	2.279	.4388	.0313	.0713	31.969	14.029	8.578	120.341	21
22	2.370	.4220	.0292	.0692	34.248	14.451	8.941	129.202	22
23	2.465	.4057	.0273	.0673	36.618	14.857	9.297	138.128	23
24	2.563	.3901	.0256	.0656	39.083	15.247	9.648	147.101	24
25	2.666	.3751	.0240	.0640	41.646	15.622	9.993	156.104	25
26	2.772	.3607	.0226	.0626	44.312	15.983	10.331	165.121	26
27	2.883	.3468	.0212	.0612	47.084	16.330	10.664	174.138	27
28	2.999	.3335	.0200	.0600	49.968	16.663	10.991	183.142	28
29	3.119	.3207	.0189	.0589	52.966	16.984	11.312	192.120	29
30	3.243	.3083	.0178	.0578	56.085	17.292	11.627	201.062	30
31	3.373	.2965	.0169	.0569	59.328	17.588	11.937	209.955	31
32	3.508	.2851	.0159	.0559	62.701	17.874	12.241	218.792	32
33	3.648	.2741	.0151	.0551	66.209	18.148	12.540	227.563	33
34	3.794	.2636	.0143	.0543	69.858	18.411	12.832	236.260	34
35	3.946	.2534	.0136	.0536	73.652	18.665	13.120	244.876	35
40	4.801	.2083	.0105	.0505	95.025	19.793	14.476	286.530	40
45	5.841	.1712	.00826	.0483	121.029	20.720	15.705	325.402	45
50	7.107	.1407	.00655	.0466	152.667	21.482	16.812	361.163	50
55	8.646	.1157	.00523	.0452	191.159	22.109	17.807	393.689	55
60	10.520	.0951	.00420	.0442	237.990	22.623	18.697	422.996	60
65	12.799	.0781	.00339	.0434	294.968	23.047	19.491	449.201	65
70	15.572	.0642	.00275	.0427	364.290	23.395	20.196	472.479	70
75	18.945	.0528	.00223	.0422	448.630	23.680	20.821	493.041	75
80	23.050	.0434	.00181	.0418	551.244	23.915	21.372	511.116	80
85	28.044	.0357	.00148	.0415	676.089	24.109	21.857	526.938	85
90	34.119	.0293	.00121	.0412	827.981	24.267	22.283	540.737	90
95	41.511	.0241	.00099	.0410	1 012.8	24.398	22.655	552.730	95
100	50.505	.0198	.00081	.0408	1 237.6	24.505	22.980	563.125	100

Time Value of Money

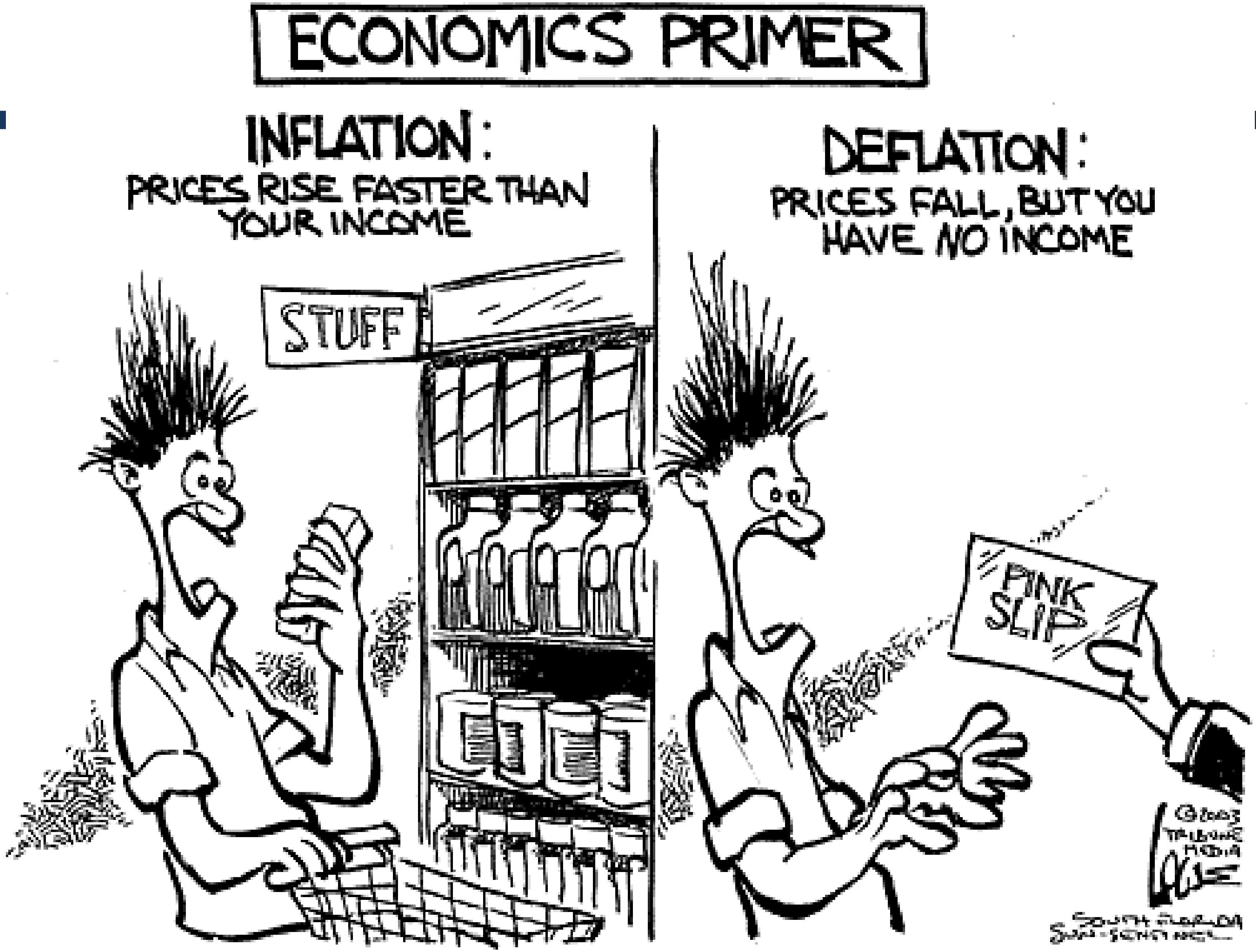
- Money has a time value because it can earn more money over time. (interest: earning power)
- Money has a time value because its purchasing power change over time. (inflation)



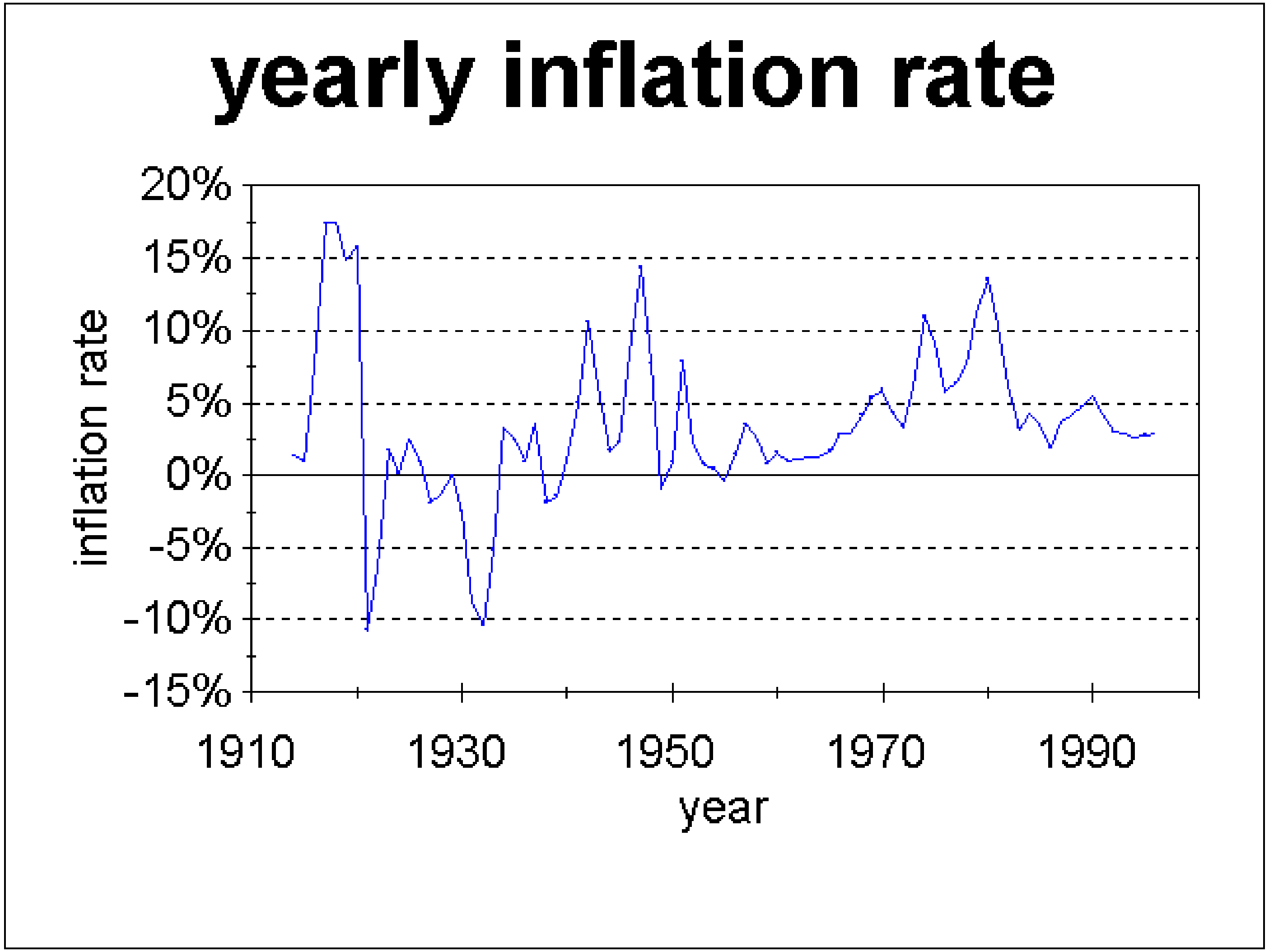
Contemporary Engineering Economics, 5th edition © 2010



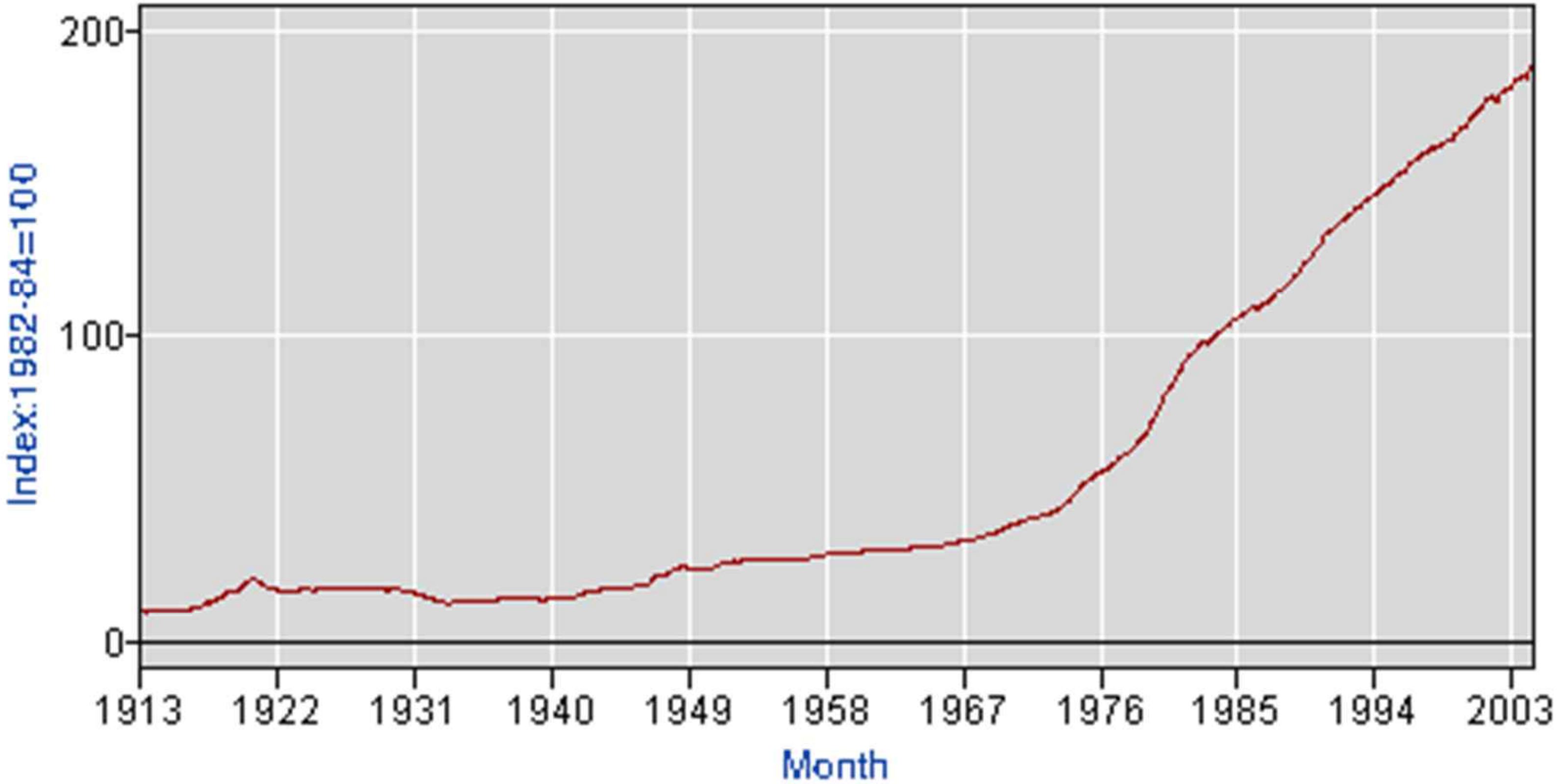
http://www.planyourescape.ca/understanding-inflation-24


ECONOMICS PRIMER
INFLATION:
PRICES RISE FASTER THAN YOUR INCOME
STUFF
DEFLATION:
PRICES FALL, BUT YOU HAVE NO INCOME
PINK SLIP
©2003 TRIBUNE MEDIA
SOUTH FLORIDA SUN-SENTINEL

Inflation Happens



…and it adds up



CPI (Consumer Price Index)
All items/Urban: 1913-2004

Source: US Dept of Labor
Bureau of Labor Statistics
www.bls.gov

The Corrosive Effect of Inflation

- **Suppose 3% inflation for 30 years**
  - $1 purchasing power today →
    F|P, 3%, 30 yrs → Need $2.43 tomorrow

- **Suppose 4% inflation for 30 years**
  - $1 today → Need $3.24 tomorrow

What does this do to your estimate for retirement savings?

Discount Rates and Inflation

- **Discount rate accounts for time value o f money**

– Nominal interest: Rate inclusive o f inflation

– Real interest: Rate after inflation

– Real ≈ Nominal - Inflation rate (approximate)

- **Cash flows**
  - – Constant dollars: No inflation . Thinking from present . Dollars expected to be same as base date

    e.g., \$100 O&M costs: In 2030, actually pay \$100+α
  - – Current dollars: Account for inflation in each periode .g ., \$ 1 ,000 home mortgage: In 2030 , actually still pay \$1 ,000

Discount Rates and Inflation

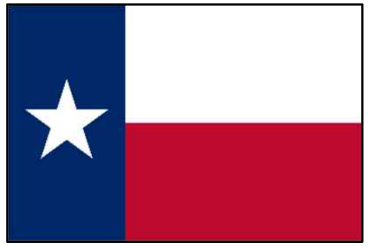
- **Use**
  - Real interest rate with constant dollars
  - Nominal interest rate with current dollars

- **Normally, you can ignore inflation!**
  - Make estimates in constant dollars
  - Everything is scaled to today's prices
  - Is more accurate: inflation varies, but real returns more stable

    *Real return: Real interest provides increase in money in the future after taking account of inflation increase

    e.g., $100 O&M costs: In 2030, actually pay $100+α

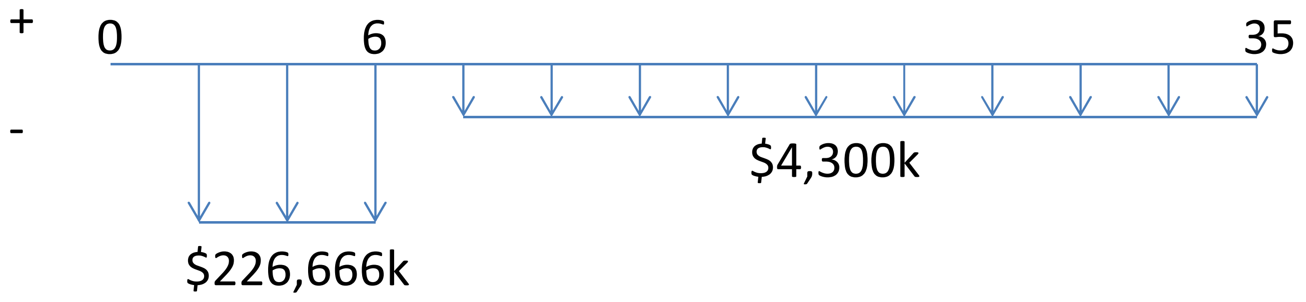
Exercise (1)



The SH 230 highway project east of Austin was awarded based on a life cycle cost analysis. Proposals were made by two consortiums; Lonestar and Four Rivers. **Lonestar** proposed to build the four lane divided highway east of Austin using **continuously reinforced concrete pavement** for a ***construction cost of $226,666,000/year for six years***, and for ***a maintenance cost of $4,300,000/year for the following 29 years***. **Four Rivers** proposed to build the highway using **asphalt concrete pavement for *$262,000,000/year for five years*** and for ***a maintenance cost of $10,600,000/year for the following 30 years***. TxDOT added ***a cost of $1,733,000/year in the last 15 years*** onto the **Four Rivers** proposal for a more realistic estimate that included milling and overlay expenses. At a **6% interest**, which proposal should TxDOT have chosen? Use NPV analysis and a **35 year analysis period**.

Exercise (1)

- **Lonestar**



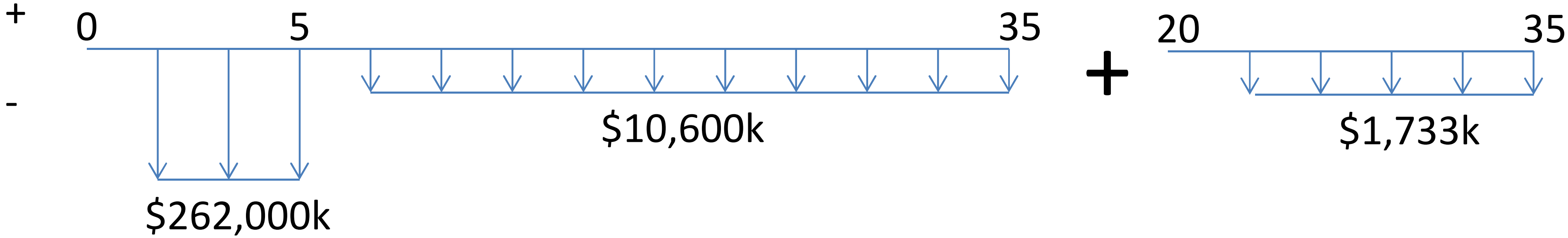
  - NPV = -\$226,666k × (P|A, n=6, i=6%)

    -\$4,300k × (P|A, n=29, i=6%) × (P|F, n=6, i=6%)

    = **-\$1,155,718k**

Exercise (1)

- **Four River**



– NPV = -\$262,000k × (P|A, n=5, i=6%)

-\$10,600k × (P|A, n=30, i=6%) × (P|F, n=5, i=6%)

-\$1,733k × (P|A, n=15, i=6%) × (P|F, n=20, i=6%)

= **<u>-\$1,271,830k</u>**

Thus, Choose LONESTAR (-\$1,156M) < Four River (-\$1,272M)

Exercise (2)

Apartment HVAC System Renovation?

Current Window-based System VS New Centralized System

System LCC = Initial Cost + Maintenance Cost + Replacement Cost

+ Residual Values + Energy Cost

Cost	Window-Unit Systems	Centralized Systems
Initial cost	-	$22,771
Maintenance cost	$90 per year	$90 per year
Window unit replacement cost	$1,300	-
Baseboard heater replacement cost	$130	-
Residual values	$138	-
Energy cost	$859 per year	$531 per year

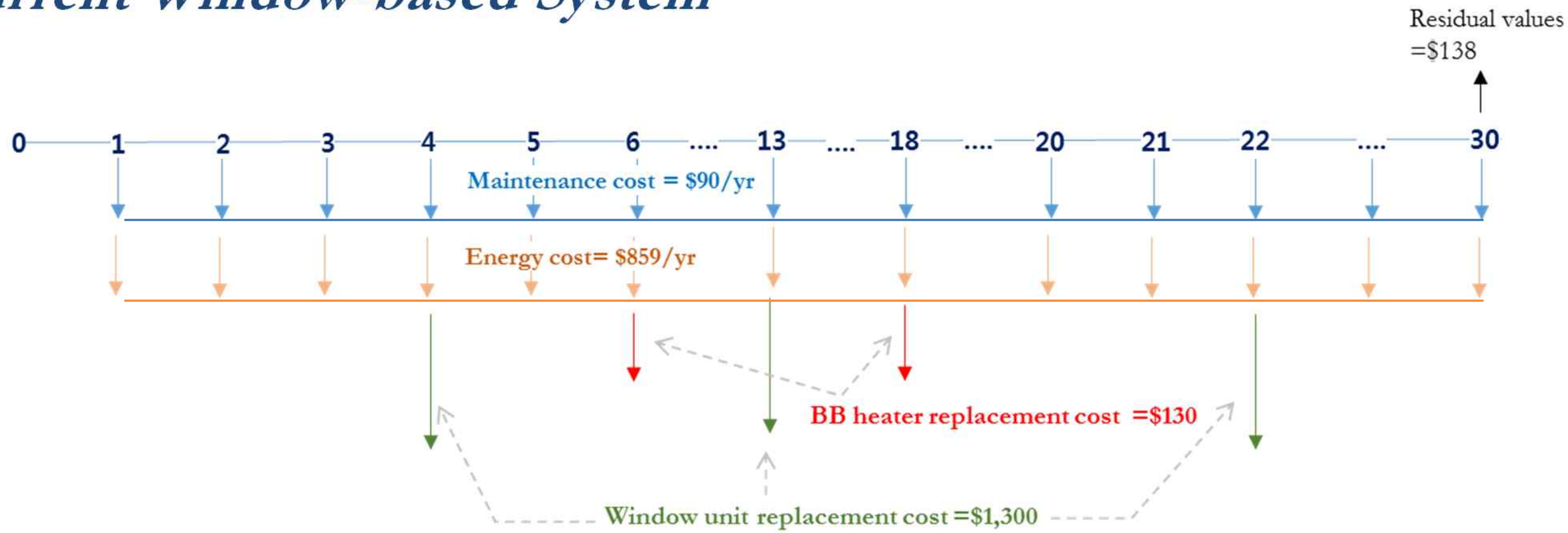
***Analysis period: 30 years | Constant value analysis | Discount rate: 4%**

Window unit replacement: 4th, 13th, 22nd year

Based board heater replacement: 6th, 18th year

Exercise (2)

Current Window-based System



※ NPV = **-$ 18,975**

Initial cost : 0

Maintenance cost : $90 × (P|A, n=30, i=4%)

Window unit replacement cost : $1,300 × ((P|F, n=4, i=4%)+ (P|F, n=13, i=4%)+ (P|F, n=22, i=4%))

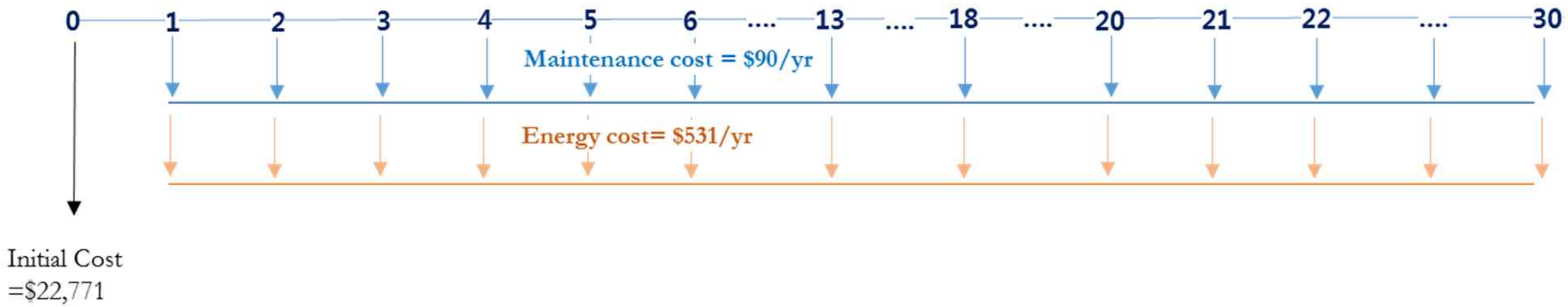
BB heater replacement cost : $130 × ((P|F, n=6, i=4%)+ (P|F, n=18, i=4%))

Residual values : $138 × (P|F, n=30, i=4%)

Energy cost : $859× (P|A, n=30, i=4%)

Exercise (2)

New Centralized System



※ NPV = **<u>-$ 33,509</u>**

Initial cost : $22,771

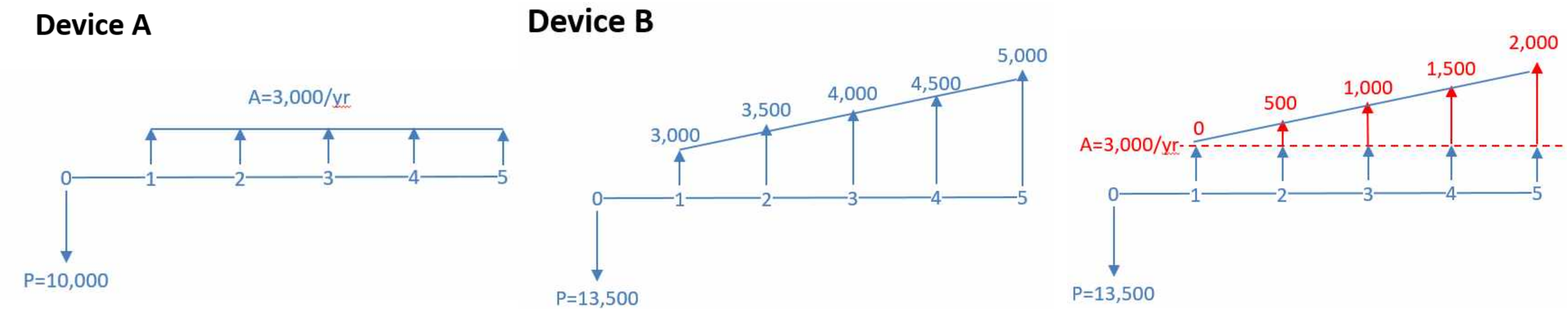
Maintenance cost : $90 × (P|A, n=30, i=4%)

Energy cost : $531× (P|A, n=30, i=4%)

Thus, Choose Current System (-$18,975) > New System(-$33,509)

Example (3)

A firm will install one of two mechanical devices to reduce costs. Both devices have useful lives of 5 years and no salvage value. Device A costs \$10,000 and can be expected to result in \$3,000 savings annually. Device B costs \$13,500 and will provide cost savings of \$3,000 the first year but savings will increase \$500 annually. With interest at 7%, which device should the firm purchase?



PV_A = – 10,000 + 3,000(P/A, n=5, i=7%) = – 10,000 + 3,000 (4.1) = **\$2,301**

PV_B = – 13,500 + 3,000(P/A, n=5, i=7%) + 500(P/G, n=5, i=7%)

= – 13,500 + 3,000(4.1) + 500(7.647) = **\$2,624**

Device B has the larger Present Value and is the preferred alternative.

Example (4)

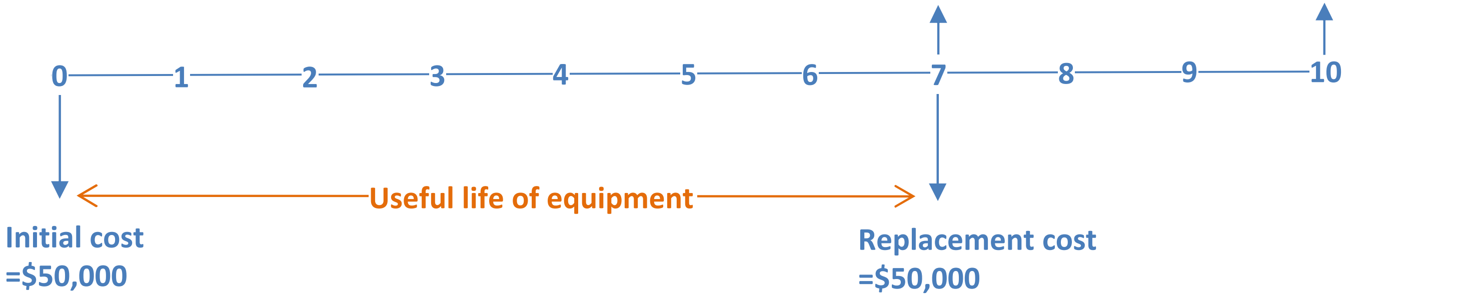
A diesel manufacturer is considering the two alternative production machine cashflows and specific data are as follows. The manufacturer uses as interest rate 8% and wants to use the NPV method to compare these alternatives over an analysis period of 10years.

	Alt.1	Alt.2
Initial Cost	$50,000	$75,000
Estimated salvage value at end of useful life	$10,000	$12,000
Useful life of equipment, in years	7	13
Estimated market value, end of 10-year analysis period	$20,000	$15,000

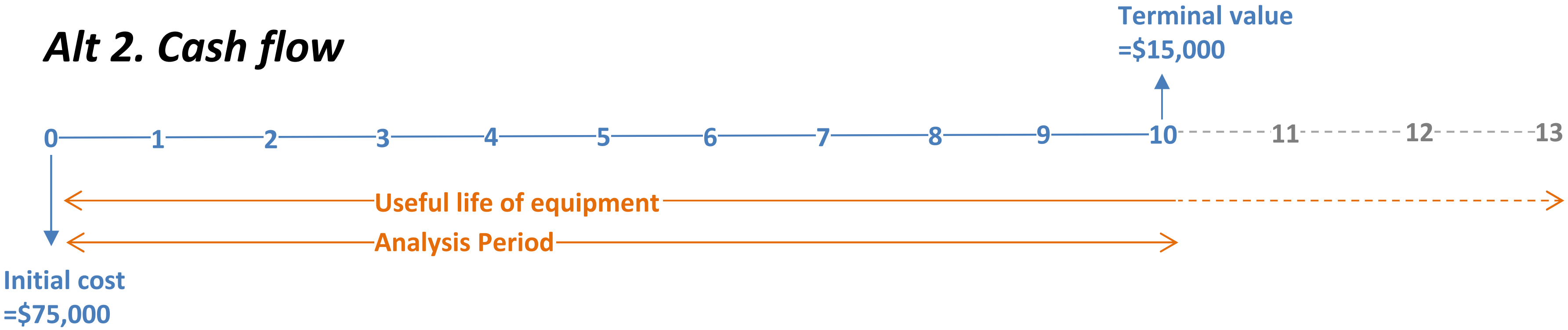
Example (4)

	Alt.1	Alt.2
Initial Cost	\$50,000	\$75,000
Estimated salvage value at end of useful life	\$10,000	\$12,000
Useful life of equipment, in years	7	13
Estimated market value, end of 10-year analysis period	\$20,000	\$15,000

Alt 1. Cash flow



Alt 2. Cash flow



$$PV_{At.1} = -50{,}000 + (10{,}000-50{,}000)(P/F, n=7, i=8\%)+20{,}000(P/F, n=10, i=8\%)$$

$$= -50{,}000 - 40{,}000\,(0.5835)+20{,}000(0.4632) = -\$64{,}076$$

$$PV_{At.2} = -75{,}000 + 15{,}000(P/F, n=10, i=8\%)$$

$$= -75{,}000 + 15{,}000(0.4632) = -\$68{,}052$$

To minimize PV of costs the diesel manufacturer should select Alt.1.

Example (5)

You have 4 choices:

Alt.1 Do nothing

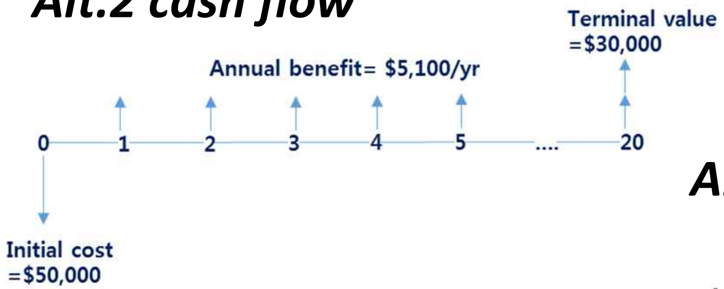
Alt.2 Build a market for $50,000. It will earn $5,100 per yr. and will sell for $30,000 in 20 yrs.

Alt.3 Build a gas station for $95,000. It will earn $10,500 per yr, and will sell for $30,000 in 20 yrs.

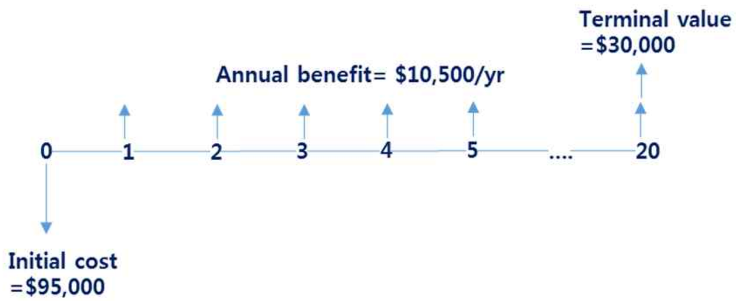
Alt.4 Build a motel for $350,000. It will earn $36,000 per yr, and will sell for $150,000 in 20 yrs.

Which alternative would you choose at 10% interest?

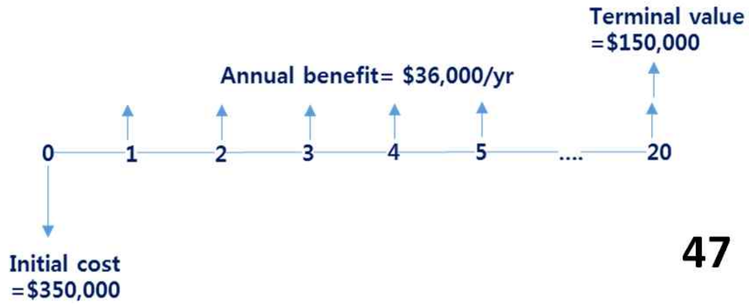
Alt.2 cash flow



Alt.3 cash flow



Alt.4 cash flow



Example (5)

$PV_{At.1}$ = 0

$PV_{At.2}$ = -50,000 + 5,100(P/A,n=20,i=10%) +30,000 (P/F,n=20,i=10%)

= - 50,000 + 5,100 (8.5146) + 30,000 (0.1486) = -\$2,122

$PV_{At.3}$ = -95,000 + 10,500(8.5146) + 30,000 (0.1486) = -\$1,148

$PV_{At.4}$ = -350,000 + 36,000 (8.5146) + 150,000 (0.1486) = -\$21,215

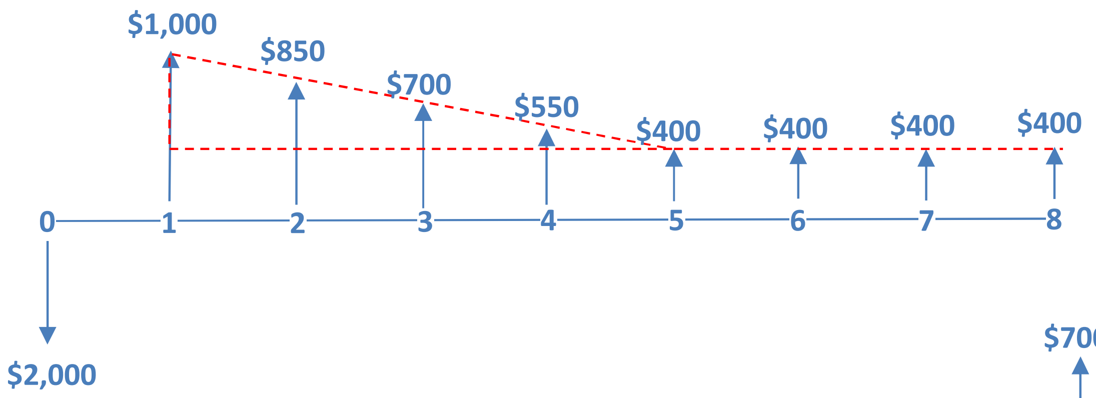
None of the alternatives have a positive present value.

Therefore it makes sense to choose the do nothing alternative.

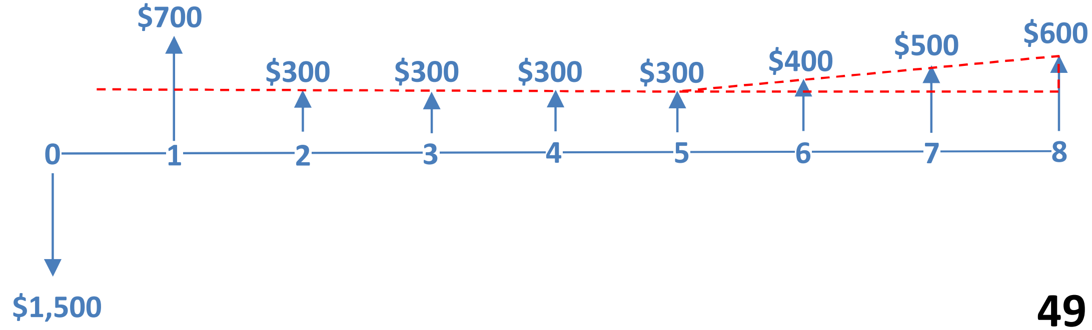
Example (6)

Machine A costs \$2,000, income starts at \$1000 in Year 1, declines \$150 per yr, and settles at \$400 per yr for Years 5-8.
Machine B costs \$1,500, income is \$700 in yr 1, then \$300 in Years 2-5, then grows by \$100 per yr to end at \$600 in Year 8.
Which is preferable at 8%?

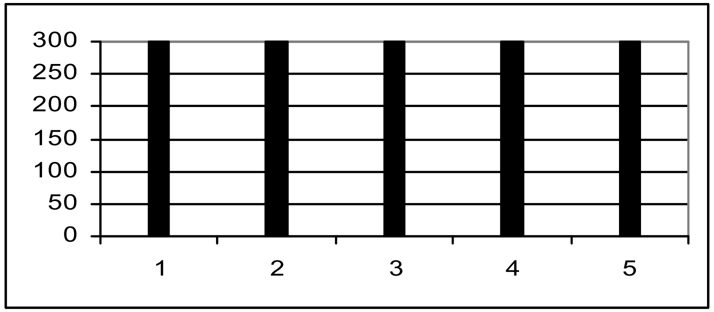
Machine A cash flow

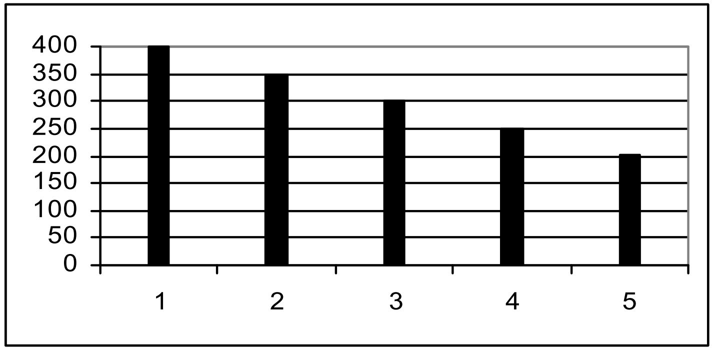


Machine B cash flow



Ex. 5.1: Consider 2 options costing \$1000 each, but savings from the first will be \$300 per year ending at 5 years, while the savings from the second start at \$400 and decline \$50 per year, ending at 5 years. At 7% interest, which would you recommend?





Analysis period: Assume 5 years

PW of A = -1000 + 300(P/A, n=5, i=7%)

= -1000 + 300 (4.100) = \$230

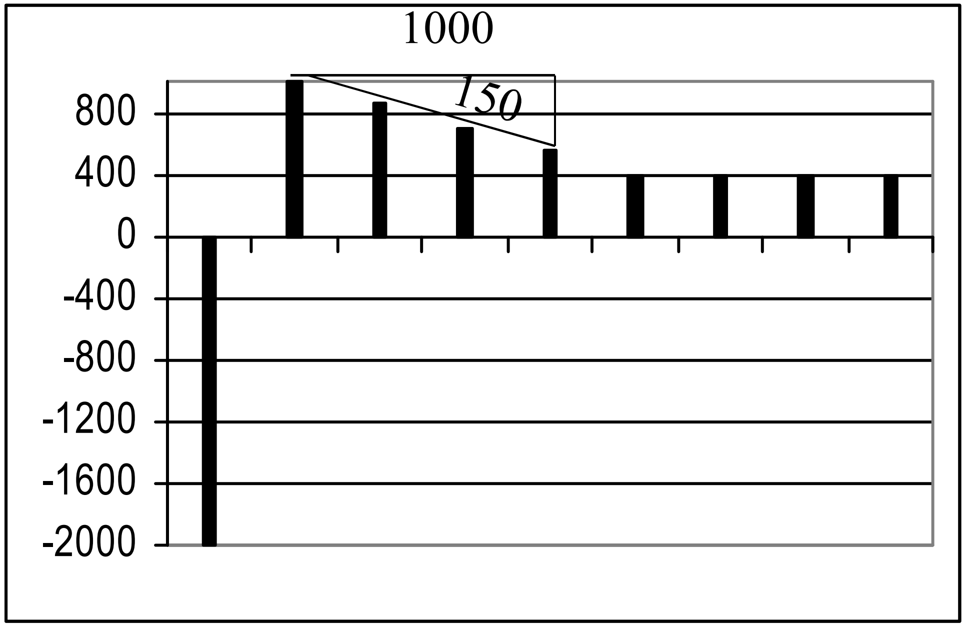
PW of B = -1000 + 400(P/A, n=5, i=7%) – 50(P/G, n=5, i=7%)

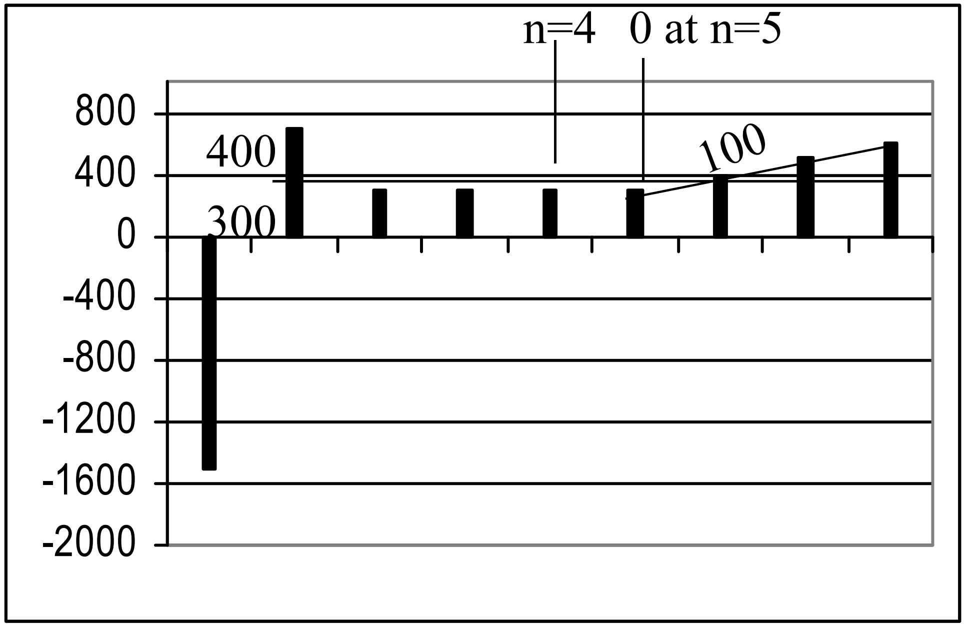
= -1000 + 400(4.100) – 50(7.647) = \$258

<u>Alternative B</u> has a higher Present Worth.

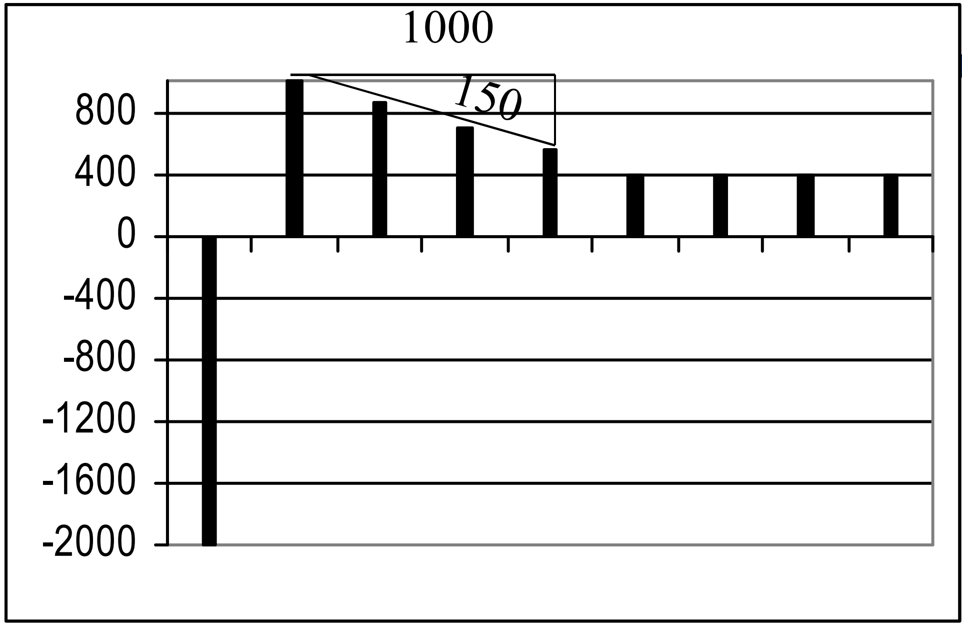
Alternatives with Complex Cash Flows

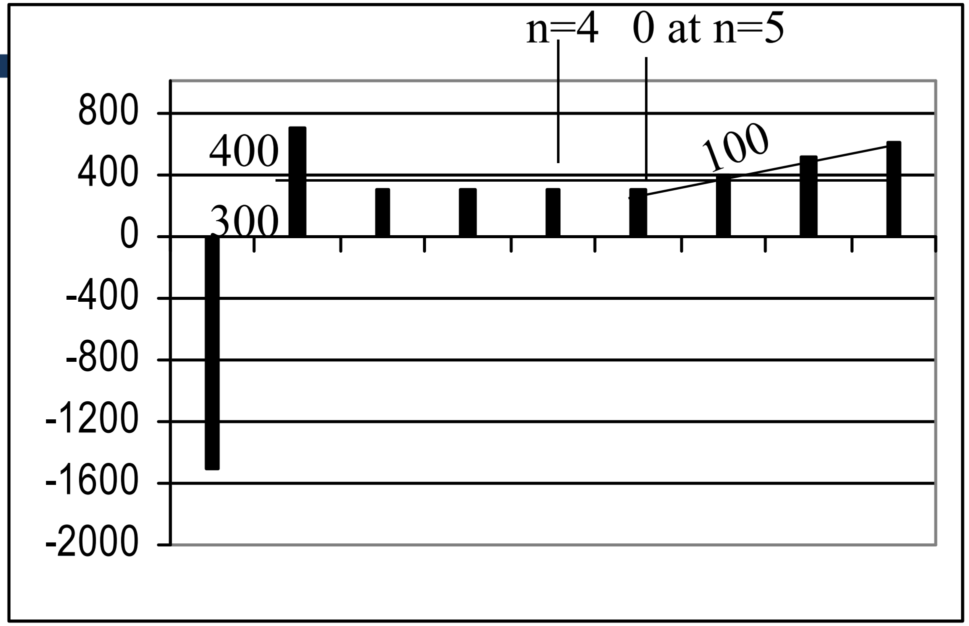
Ex. 5.10: Machine A costs $2000, income starts at $1000 in Year 1, declines $150 per yr, and settles at $400 per yr for Years 5-8. Machine B costs $1500, income is $700 in yr 1, then $300 in Years 2-5, then grows by $100 per yr to end at $600 in Year 8. Which is preferable at 8%?





Comparing Two Alternatives (cont'd)

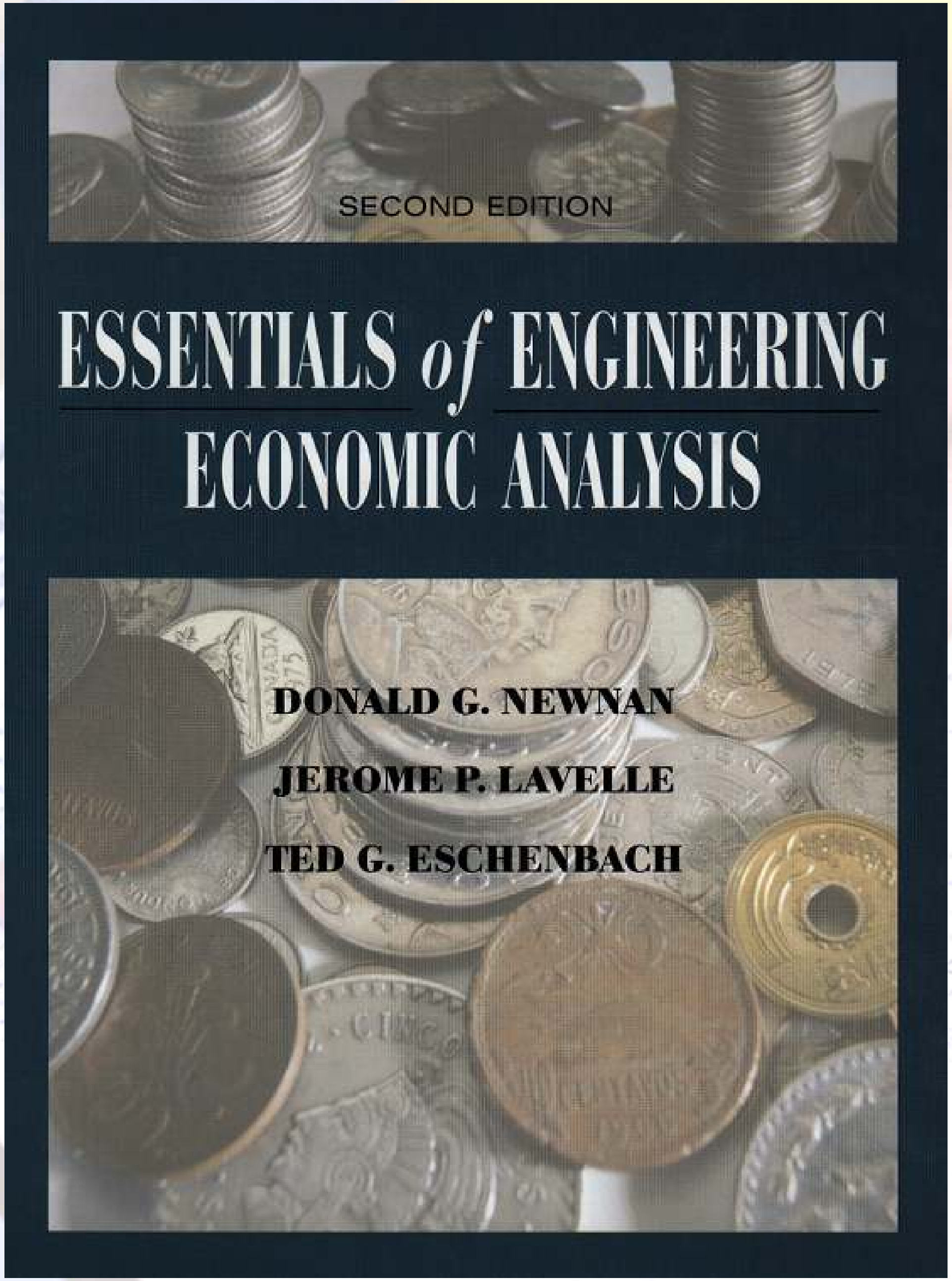




PW of A = - 2000 + 400(P/A, n=8, i=8%)
+ 600(P/A, n=4, i=8%) – 150 (P/G, n=4, i=8%)
= - 2000 + 400(5.747) + 600(3.312) – 150(4.650) = $1589

PW of B = - 1500 + 400(P/F, n=1, i=8%) + 300(P/A, n=8, i=8%)
+100(P/G, n=4, i=8%)(P/F, n=4, i=8%)
= - 1500 + 400(0.9259) + 300(5.747) + 100(4.650)(0.7350) = $936

Machine A has greater Present Worth.



Present worth analysis

Annual cash flow analysis

Rate of return analysis

Incremental analysis

Future worth analysis

Benefit-cost ratio analysis

Payback period

Sensitivity and breakeven analysis

…

Uncertainty Assessment

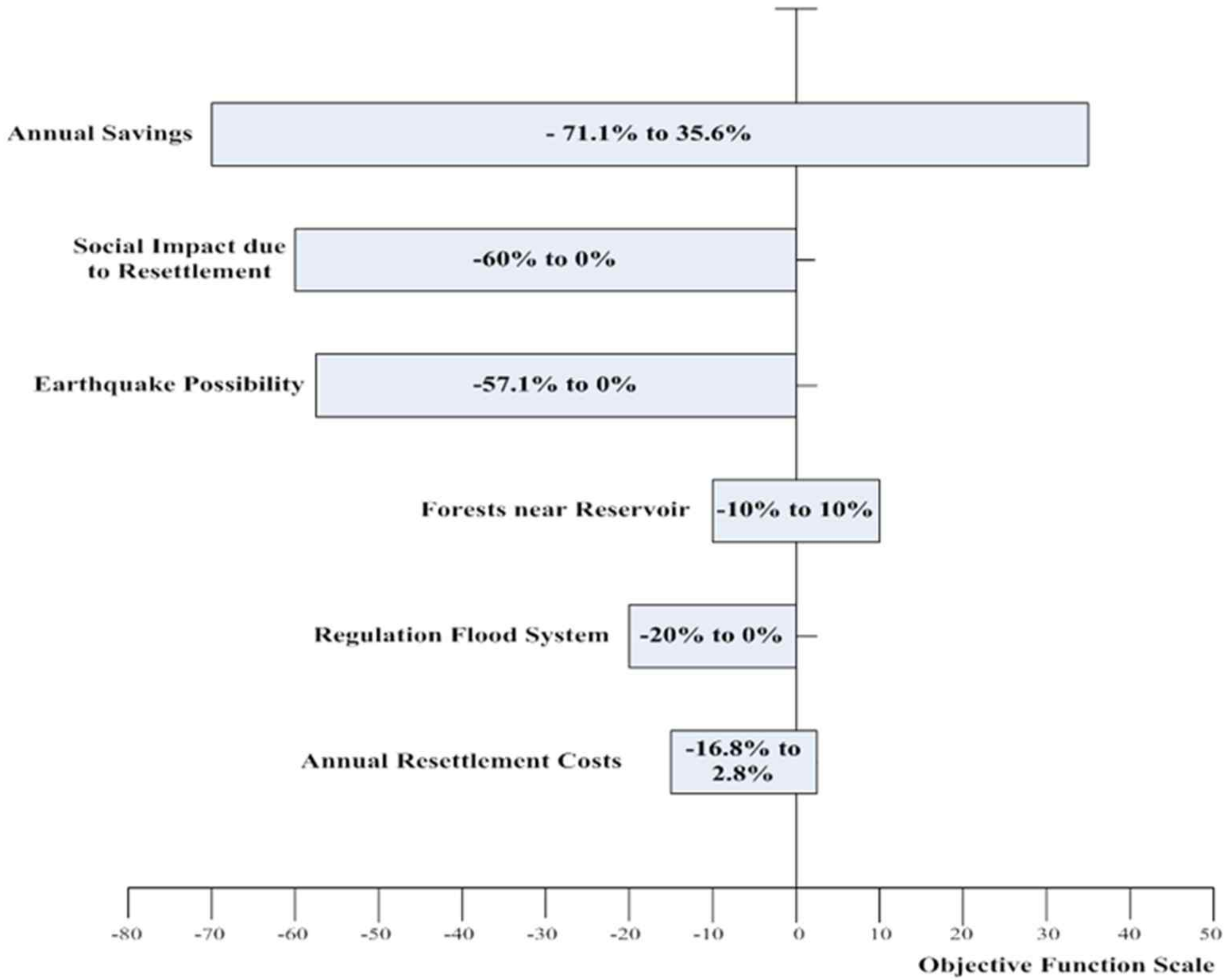
- **Future predictions are uncertain by nature**
  - Interest rates, costs, timing of replacements, etc.
- **Need to make an assessment of how variation in costs makes a difference to NPV**
  - In general, the further out in time, the less important something is (discounting at work)
  - Most important assessment is uncertainty in costs in near term and annual costs
  - Change in NPV due to variation in interest rates also important

Uncertainty Assessment

- **Sensitivity Analysis:**
  - Vary key costs, re-compute NPV
    - Generally "High-Expected-Low" is good to get a range
    - Vary costs one at a time to build picture of most influential
    - Cost that have great influence on NPV bear further study to increase certainty

Uncertainty Assessment

- **Sensitivity Analysis: Tornado Diagram**



Uncertainty Assessment

- **Breakeven analysis:**
  - Compute min/max values
    - Minimum value of a savings for project to breakeven
    - Maximum value of initial investment for project to breakeven
  - Useful to determine at what threshold value(s) project becomes uneconomic
    - Compare min/max to expectations about costs

Assess Non-Monetary Value

- **Some costs/benefits cannot easily be quantified**
  - Value of a quieter HVAC system
  - Value of north facing windows with a view
- **These should be identified and presented to decision makers along with cost assessment**
  - e.g., energy efficient HVAC has LCC savings of $235,000, but is significantly noisier (>3db)

Assess Non-Monetary Value

- Generally, multiple considerations attach to multiple alternatives

Ambient temp
Acoustic privacy
Lighting
View

Base (do nothing)
Alternative 1
Alternative 2

- Difficult to make a fair, collective comparison
- Several structured, matrix approaches exist to help rank, value non-monetary considerations
  - Attach benefit value and importance for each consideration to each alternative
  - Make a weighted comparison

Make Recommendations

SIR: Saving-Investment Ratio

- **Present**
  - Alternatives
  - LCC of each alternative with non-monetary benefits/costs
  - Ranking of independent projects (SIRs) (as needed by decision)
- **Make a recommendation**
  - Alternative 2 costs $10k more than Alternative 1 but saves $25k over the base (do-nothing) scenario. Alternative 2 provides a better working environment than Alternative 1 and the base scenario (non-monetary benefits), which we believe outweighs the $10k difference in cost.

Energy Prices

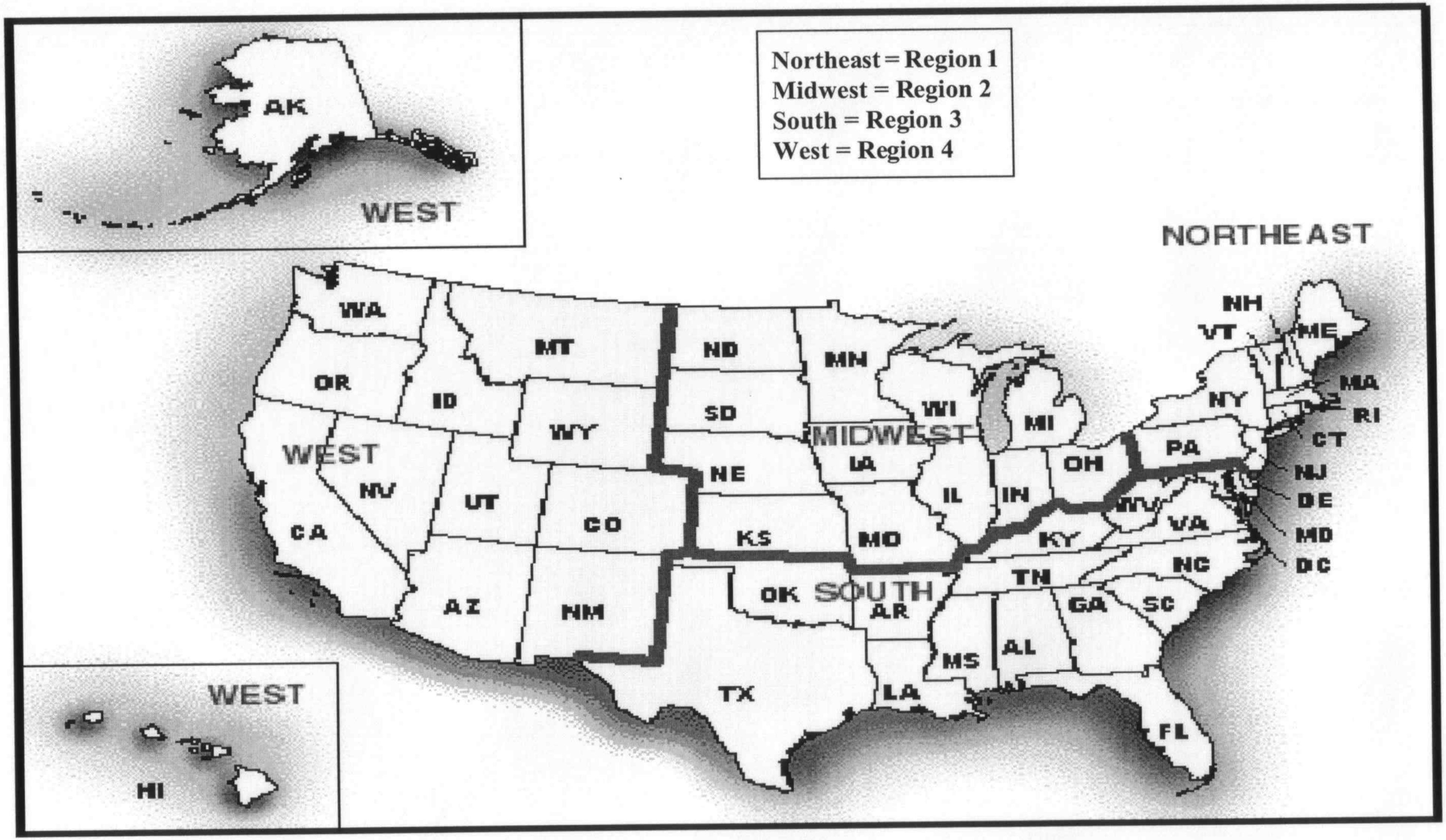
- **Energy savings are a key area of LCC practice**
  - Annual savings/expenditures
  - Energy costs can be large share of operating costs
    - 15% of total lifecycle cost, higher portion of operating costs
- **Lighting/electrical, HVAC, & water most common replacements and upgrades**
  - Direct users of energy (e.g., air handling units)
  - Indirect energy wasters (e.g., windows)

Energy Price Indices/Factors

- **Energy costs may have changes in real rates aside from inflation**
  - Contradicts constant dollar assumptions

- **US Government publishes energy price indices and discount factor tables**
  - NISTIR 85-3273 (DOE rates)
  - Lookup FEMP UPV* factor
    - Federal Energy Management Program Uniform Present Value Factor
  - Multiply FEMP UPV* by present annual expenditure rate to get discounted NPV (this NPV includes real price adjustments)
  - FEMP UPV* determined by:
    - Region, fuel type, rate type, discount rate, study period

DOE Energy Regions



FEMP UPV* Example

- **$20,000/yr annual energy cost**
  - Get costs from current data, utilities, manufacturers…
- **Data for analysis using Table**
  - Federal commercial office building
  - 20 year span
  - Natural gas
  - Connecticut building: Region=1
  - Discount: std DOE value
  - **FEMP UPV* = 17.09**
- **NPV = $20,000 × 17.09 = $341,800**

**Dist: Distillate Oil*
Resid: Residual Oil

FEMP UPV* Table

Table Ba-1. FEMP UPV* Discount Factors adjusted for fuel price escalation, by end-use sector and fuel type.

Discount rate = 3.0 % (DOE)

Census Region 1 (Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont)

	RESIDENTIAL				COMMERCIAL					INDUSTRIAL					TRANSPORT	
N	Elec	Dist	LPG	NtGas	Elec	Dist	Resid	NtGas	Coal	Elec	Dist	Resid	NtGas	Coal	Gasln	N
1	0.91	0.97	0.96	1.01	0.87	0.98	0.97	1.04	0.95	0.83	1.00	0.98	1.12	0.96	1.01	1
2	1.83	1.96	1.92	2.03	1.74	1.99	2.01	2.10	1.88	1.65	2.03	2.02	2.32	1.89	2.04	2
3	2.76	2.98	2.90	2.99	2.60	3.03	3.14	3.14	2.77	2.48	3.09	3.14	3.49	2.78	3.11	3
4	3.66	4.00	3.87	3.92	3.42	4.09	4.31	4.12	3.64	3.25	4.18	4.30	4.61	3.65	4.20	4
5	4.53	5.02	4.85	4.82	4.21	5.15	5.50	5.09	4.48	4.00	5.27	5.47	5.70	4.49	5.28	5
6	5.38	6.05	5.81	5.69	4.99	6.23	6.70	6.02	5.30	4.74	6.37	6.65	6.75	5.29	6.36	6
7	6.22	7.09	6.76	6.54	5.76	7.31	7.90	6.93	6.08	5.47	7.48	7.84	7.78	6.08	7.42	7
8	7.04	8.12	7.70	7.37	6.52	8.39	9.12	7.81	6.84	6.18	8.59	9.03	8.77	6.84	8.47	8
9	7.83	9.14	8.62	8.18	7.25	9.47	10.35	8.68	7.57	6.88	9.69	10.23	9.74	7.57	9.51	9
10	8.60	10.15	9.52	8.97	7.97	10.53	11.57	9.52	8.28	7.56	10.78	11.42	10.69	8.28	10.53	10
11	9.35	11.14	10.40	9.74	8.68	11.57	12.77	10.34	8.96	8.23	11.85	12.59	11.62	8.96	11.53	11
12	10.09	12.11	11.26	10.50	9.37	12.60	13.95	11.15	9.62	8.89	12.91	13.74	12.54	9.63	12.51	12
13	10.81	13.06	12.10	11.25	10.05	13.60	15.11	11.95	10.27	9.54	13.94	14.87	13.44	10.28	13.48	13
14	11.51	13.98	12.93	11.97	10.72	14.58	16.25	12.73	10.90	10.18	14.95	15.99	14.32	10.91	14.42	14
15	12.19	14.90	13.73	12.68	11.37	15.55	17.38	13.48	11.51	10.80	15.94	17.09	15.18	11.51	15.34	15
16	12.85	15.79	14.52	13.37	11.99	16.50	18.48	14.22	12.10	11.41	16.91	18.16	16.03	12.11	16.24	16
17	13.49	16.67	15.29	14.05	12.61	17.43	19.56	14.95	12.68	12.00	17.87	19.21	16.86	12.68	17.13	17
18	14.12	17.53	16.04	14.72	13.21	18.34	20.62	15.67	13.24	12.59	18.80	20.24	17.69	13.24	18.00	18
19	14.74	18.37	16.78	15.38	13.81	19.24	21.67	16.38	13.78	13.17	19.73	21.25	18.51	13.79	18.85	19
20	15.34	19.20	17.50	16.04	14.40	20.12	22.69	17.09	14.32	13.75	20.63	22.25	19.33	14.32	19.69	20
21	15.94	20.02	18.20	16.69	14.98	20.99	23.71	17.79	14.84	14.32	21.53	23.24	20.16	14.83	20.51	21
22	16.52	20.82	18.89	17.33	15.56	21.85	24.72	18.48	15.34	14.89	22.41	24.21	20.97	15.34	21.31	22
23	17.09	21.62	19.57	17.96	16.13	22.70	25.70	19.16	15.83	15.44	23.27	25.16	21.77	15.82	22.10	23
24	17.64	22.40	20.24	18.57	16.68	23.53	26.67	19.82	16.31	15.99	24.13	26.11	22.56	16.30	22.88	24
25	18.19	23.16	20.89	19.17	17.22	24.35	27.62	20.48	16.78	16.53	24.97	27.03	23.33	16.77	23.64	25
26	18.72	23.92	21.53	19.76	17.76	25.16	28.56	21.11	17.23	17.05	25.80	27.94	24.09	17.22	24.39	26
27	19.23	24.66	22.16	20.34	18.28	25.96	29.49	21.74	17.67	17.57	26.61	28.84	24.84	17.66	25.13	27
28	19.74	25.39	22.77	20.91	18.78	26.74	30.41	22.36	18.11	18.07	27.41	29.72	25.58	18.09	25.85	28
29	20.23	26.10	23.37	21.47	19.28	27.50	31.32	22.97	18.52	18.56	28.20	30.60	26.31	18.50	26.55	29
30	20.71	26.80	23.96	22.01	19.76	28.26	32.21	23.56	18.93	19.04	28.97	31.46	27.03	18.91	27.25	30

Optimal Efficiency Level

- **Definition: Most cost effective *Performance Level* for a facility**
  - Differs from other LCC analysis
    - Not LCC for alternative with potentially different performance
    - Rather, least costly parameter for a given level of performance
  - Performance examples (energy efficiency):
    - Level of insulation in roof and walls (R-values)
    - Efficiency of a furnace
    - Collector area for a solar heating system

**R-value: Measure of thermal resistance (insulation)*

Calculating Efficiency Level

- **General assumption: increasing efficiency increases initial investment**
  - If not, no tradeoffs
- **Steps:**
  - Define parameters and range of possible alternatives
  - Estimate energy usage (or relevant parameter) for each alternative
  - Calculate LCC for each alternative
  - Select lowest LCC
  - Interpolate as needed

Efficiency Example

- **Find R-Value on House Attic Insulation**
  - Service date: Jan 13
  - Life: 25 yrs
  - Replacement schedule: N/A
  - Residual value: None
  - Electricity price: $0.08/kWh
  - Location: Ohio (DOE Region 2)
  - Rate type: Residential
  - **FEMP UPV* = 17.57**

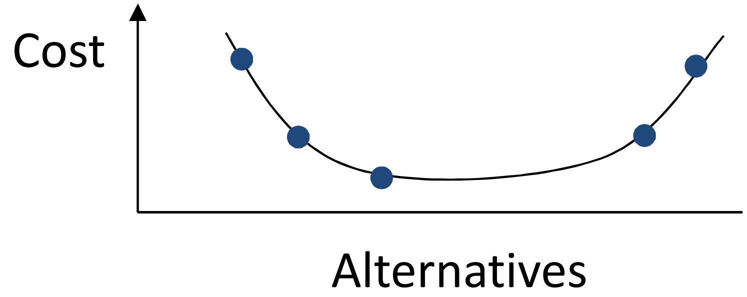
Efficiency Example

Table Ba-2. FEMP UPV* Discount Factors adjusted for fuel price escalation, by end-use sector and fuel type.

Discount Rate = 3.0 % (DOE)

Census Region 2 (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin)

	RESIDENTIAL				COMMERCIAL					INDUSTRIAL					TRANSPORT	
N	Elec	Dist	LPG	NtGas	Elec	Dist	Resid	NtGas	Coal	Elec	Dist	Resid	NtGas	Coal	Gasln	N
1	0.93	0.95	0.97	1.02	0.91	0.97	1.06	1.05	0.98	0.87	0.98	1.08	1.17	0.96	1.00	1
2	1.84	1.93	1.95	2.03	1.79	1.96	2.15	2.12	1.94	1.70	2.00	2.17	2.42	1.90	2.02	2
3	2.74	2.93	2.96	3.00	2.64	3.00	3.26	3.17	2.87	2.51	3.06	3.30	3.65	2.81	3.08	3
4	3.62	3.95	3.98	3.92	3.48	4.05	4.40	4.17	3.78	3.29	4.13	4.46	4.84	3.70	4.18	4
5	4.48	4.96	4.99	4.82	4.29	5.10	5.53	5.16	4.66	4.04	5.21	5.60	6.00	4.58	5.26	5
6	5.32	5.99	6.01	5.71	5.09	6.18	6.66	6.12	5.52	4.79	6.31	6.75	7.15	5.44	6.33	6
7	6.14	7.03	7.02	6.57	5.87	7.26	7.78	7.07	6.36	5.52	7.41	7.88	8.26	6.28	7.39	7
8	6.93	8.07	8.01	7.42	6.62	8.34	8.89	7.98	7.16	6.23	8.51	9.01	9.35	7.09	8.44	8
9	7.70	9.09	9.00	8.24	7.36	9.42	9.98	8.88	7.94	6.92	9.61	10.12	10.41	7.88	9.48	9
10	8.45	10.11	9.96	9.05	8.08	10.48	11.04	9.76	8.69	7.60	10.69	11.19	11.45	8.64	10.49	10
11	9.18	11.10	10.90	9.84	8.79	11.52	12.09	10.62	9.41	8.26	11.75	12.25	12.47	9.38	11.49	11
12	9.89	12.08	11.83	10.62	9.48	12.55	13.11	11.48	10.11	8.91	12.80	13.29	13.49	10.09	12.47	12
13	10.58	13.03	12.73	11.39	10.16	13.55	14.11	12.31	10.79	9.55	13.82	14.31	14.48	10.78	13.43	13
14	11.26	13.97	13.62	12.13	10.82	14.54	15.09	13.12	11.45	10.17	14.82	15.31	15.43	11.44	14.37	14
15	11.91	14.89	14.49	12.85	11.47	15.50	16.06	13.91	12.09	10.78	15.80	16.29	16.36	12.09	15.29	15
16	12.55	15.79	15.34	13.56	12.10	16.45	17.00	14.68	12.71	11.38	16.77	17.24	17.28	12.72	16.19	16
17	13.16	16.68	16.17	14.26	12.71	17.38	17.92	15.44	13.31	11.95	17.71	18.18	18.19	13.32	17.08	17
18	13.76	17.55	16.98	14.95	13.31	18.30	18.82	16.20	13.89	12.52	18.64	19.09	19.09	13.92	17.95	18
19	14.34	18.40	17.78	15.64	13.89	19.20	19.71	16.95	14.46	13.08	19.56	19.99	20.00	14.50	18.81	19
20	14.92	19.24	18.57	16.32	14.47	20.09	20.58	17.70	15.02	13.62	20.46	20.88	20.90	15.06	19.64	20
21	15.47	20.07	19.34	17.00	15.03	20.96	21.45	18.45	15.56	14.16	21.35	21.76	21.81	15.61	20.46	21
22	16.02	20.89	20.09	17.67	15.58	21.82	22.29	19.19	16.08	14.69	22.22	22.62	22.71	16.14	21.27	22
23	16.55	21.69	20.83	18.33	16.12	22.67	23.13	19.91	16.59	15.21	23.08	23.47	23.59	16.66	22.06	23
24	17.07	22.48	21.56	18.98	16.65	23.51	23.95	20.62	17.09	15.72	23.93	24.30	24.46	17.17	22.84	24
25	17.57	23.26	22.28	19.61	17.16	24.34	24.76	21.32	17.58	16.22	24.77	25.13	25.32	17.66	23.60	25
26	18.07	24.03	22.99	20.24	17.67	25.15	25.55	22.01	18.05	16.71	25.60	25.93	26.17	18.15	24.36	26
27	18.55	24.78	23.68	20.85	18.16	25.95	26.34	22.69	18.52	17.19	26.41	26.73	27.01	18.62	25.09	27
28	19.02	25.52	24.35	21.45	18.65	26.74	27.11	23.36	18.96	17.66	27.21	27.52	27.83	19.07	25.82	28
29	19.47	26.25	25.02	22.05	19.12	27.51	27.87	24.01	19.40	18.12	27.99	28.29	28.65	19.52	26.53	29
30	19.92	26.97	25.67	22.63	19.59	28.27	28.62	24.66	19.83	18.57	28.76	29.05	29.46	19.96	27.22	30



Efficiency Example

R-value	1 Initial Cost	2 Annual kWh	3 Annual Energy Cost	4 NPV Energy Cost	5 LCC	6 Net Savings
			(2)×$0.08/kWh	(3)×17.57	(1)+(4)	$13,497-x
R-0	$0	9,602	768	$13,497	$13,497	$0
R-11	300	7,455	596	10,479	10,779	2,718
R-19	450	7,055	564	9,917	10,367	3,130
R-30	650	6,804	544	9,564	10,214	3,283
R-38	800	6,703	536	9,422	10,222	3,275
R-49	1,000	6,628	530	9,316	10,316	3,181

R-30 is best option (lowest LCC-using positive number convention)

Project Financing

- **Many projects are financed**
- **Need to include NPV of financing in LCC**
- **Why is this tricky?**
  - Value of annual payments in CURRENT, not constant dollars
  - EX: Mortgage payment of $12,000/yr, 30yr period. The payment does not grow with inflation!!!

Financing Example

- **Project Financing Data**
  - Annual O&M costs \$2,000/yr
  - Loan payment: \$12,000/yr
  - 30 years
  - Nominal rate: 7%
  - Real rate: 4%
- O&M NPV = \$2,000 × (P|A, n=30, i=4%) = \$34,584
- Mortgage NPV = \$12,000 × (P|A, n=30, i=7%)
  = \$148,909

Thus, LCC = \$34,584 + \$148,909 = <u>\$183,493</u>