Exploring Economic Criteria for EOR Projects

A Capital Budgeting Workshop

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UNIVERSITY OF WYOMING

Enhanced Oil Recovery Institute
Exploring Economic Criteria for EOR Projects

A Capital Budgeting Workshop

This session will consist of a brief introduction to the key capital budgeting financial metrics used in evaluating projects, how those rules can be used to allocate scarce capital to the highest value projects, and a guided discussion with attendees on how these concepts apply to evaluating EOR projects.

Economics - Definition

The study of how individuals, firms, governments and nations deal with the production, distribution, and consumption of goods and services, and make choices about the use of scarce means to satisfy unlimited and competing wants and needs.

Capital Budgeting - Definition

The business process of determining which projects are worth pursuing in the context of financial capital constraints, and allocating funds.

+Include consideration of risk and other types of resources constraints impacting capabilities.
These types of stories are a good source for rough valuation multiples.

Note:
MEMP 10k says cost was $906.1 M

Memorial Production Buys Wyoming Oil Assets for $935M

By Claire Poole | 05/06/14 - 09:05 AM EDT

HOUSTON (The Deal) - Houston oil and gas explorer Memorial Production Partners (MEMP - Get Report) said Monday it agreed to buy oil producing properties in Wyoming from an unnamed seller for $935 million in cash.

Limited partner-owned Dallas oil and gas investor Merit Energy Co. owned the properties, MEMP said. Neither Merit nor Memorial Production Partners responded to requests for comment.

The partnership expects to close the purchase in the third quarter.

The properties consist of tertiary carbon dioxide floods in two fields in the Bairoil complex in Sweetwater and Carbon Counties. They are 100% operated, cover 6,800 net acres and include 140 producing wells and 166 injection wells. They have a projected average annual proved developed producing decline rate of 5% and estimated proved reserves of 83 million barrels, 59% of which are proved developed, and produce 5,900 barrels per day, 81% of which is oil and 19% of which is natural gas liquids.

May ’14 WTI = $102.18/bbl
July ’14 WTI = $103.59/bbl
July ’15 WTI < $60/bbl

$906.1 M for initial production of 5,900 bpd initial production.
~$153k-159k/boe
The Financial Function

Finance focuses on these two decisions:

- **Investment Decision**: How much to invest and in what?  
  **Capital Budgeting**

- **Financing Decision**: Where are $ going to come from?  
  **Capital Structure**

**Cost of Capital**

Source: Adapted from Professor Tim Thompson, Kellog School of Management

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Oil & Gas Industry Complexity

Depletable Resource in High Demand Everywhere and with Multiple End Uses

- Exploration for Oil & Natural Gas
- Production of Natural Gas
- Production of Crude Oil
- Upstream Processing
- Midstream Transportation
- Transportation
- Refining
- Downstream Marketing
- Marketing
- Petrochemical Industry
- End Users

Source: Adapted from David Wood Associates

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Reservoir Management Process

Working with an integrated team & setting project objective(s)
- Develop optimal plan for play
- Characterize and make realistic model of play
- Enhance production, new technology
- Engineering solutions to reservoir and well problems
- Conduct economic evaluations for properties and projects

Collecting, analyzing, validating, and managing data related to the project
- Reservoir engineering group
- Reservoir simulation group

Evaluate project economics & obtain management approval
- Forecast performance
- Use deterministic and probabilistic scenario analysis
- Address major risks

Implement, monitor, and evaluate project performance

Source: Adapted from Satter et al, Practical Enhanced Reservoir Engineering (2008)
Technically Feasible
Satisfying the physical and technical requirements for a given process or mechanism.

Economically Feasible
Satisfying the economic performance requirements, such as return thresholds, time to payback, and risk.
Characteristics of O&G Projects

High Upfront Capital Costs
No Revenue in Early Years
Increasing Revenues During Production Startup
A Peak Production
Declining Production and Revenues
Abandonment at the Economic Limit
Terminal Costs after Plugging
## Example WY Oil Revenue & Cost Breakdown

(WTI = $55/bbl, Royalty = 18.75%)

<table>
<thead>
<tr>
<th></th>
<th>WY Discount ~$10/bbl</th>
<th>WY Discount ~$10/bbl</th>
<th>WY Discount ~$10/bbl</th>
<th>WY Discount ~$10/bbl</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WY Oil Price</strong></td>
<td>~$45/bbl</td>
<td>~$45/bbl</td>
<td>~$45/bbl</td>
<td>~$45/bbl</td>
</tr>
<tr>
<td><strong>Revenues for Operation</strong></td>
<td>~$11.37/bbl</td>
<td>~$11.37/bbl</td>
<td>~$11.37/bbl</td>
<td>~$11.37/bbl</td>
</tr>
<tr>
<td><strong>Profit Oil</strong></td>
<td>~$16.31/bbl</td>
<td>~$16.31/bbl</td>
<td>~$16.31/bbl</td>
<td>~$16.31/bbl</td>
</tr>
<tr>
<td><strong>Basic OPEX</strong></td>
<td>~$19.79/bbl</td>
<td>~$19.79/bbl</td>
<td>~$19.79/bbl</td>
<td>~$19.79/bbl</td>
</tr>
<tr>
<td><strong>Taxes &amp; Royalties</strong></td>
<td>~$13.84/bbl</td>
<td>~$13.84/bbl</td>
<td>~$13.84/bbl</td>
<td>~$13.84/bbl</td>
</tr>
</tbody>
</table>

### Now think about incremental costs from EOR techniques:

\[ 6-10 \text{ Mcf CO}_2 = \frac{6-10}{\text{Bbl}} @ \$55 \text{ oil} + \text{Recycling & CAPEX} \]

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Primary recovery
- Natural flow
- Artificial lift

Secondary recovery
- Waterflooding
- Pressure maintenance

Tertiary recovery
- Thermal
  - Steam
  - Hot water
  - Combustion
- Gas injection
  - CO₂
  - Hydrocarbon
  - Nitrogen/Flue gas
- Chemical & other
  - Alkaline
  - Polymer
  - Microbial

Enhanced oil recovery (EOR)

Source: SLB SBC,
Enhanced Oil Recovery Institute

Source: Haliburton.com
Figure 5–6. Enhanced oil recovery and investment

- **Enhanced Oil Recovery (EOR)**
  - Tertiary Recovery
    - Thermal recovery
    - Chemical flooding
    - Gas injection, CO₂
    - Microbial treatment
  - Secondary Recovery
    - Gas injection
    - Waterflooding
  - Primary Recovery
    - Natural reservoir pressure

Percentage of Oil-in-Place (OIP) Recovery vs. Expense & Investment
Characteristics of O&G Projects (2)

E&P Basin or Profit Centre Life Cycle

- Explore
- Appraise
- Develop
- Cashflow
- Recover Investment
- Production
- Harvets
- Divest?
- Enhance Recovery / Efficiency
- Decommission

Not to Scale

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EOR Decision Process (CO$_2$)

1. Physical Screening for Suitable Reservoir Properties
2. Preliminary Economic Scoping for Profitability
3. Business-As-Usual or Different EOR Technology
4. CO$_2$ Available and/or Planned
5. Detailed Reservoir Modeling and Simulation
6. Development Plan and Detailed Economic Analysis
7. Final Contracting and Implementation

Outcomes:
- YES: Proceed with EOR project
- NO: Delay...
The Capital Budgeting Process

1. Generate ideas and identify potential investments.
2. Reviewing, analyzing, and selecting from proposals that have been generated.
3. Analyzing fit of projects with company strategy.
4. Implementing and monitoring proposals that have been selected.

Managers should separate investment and financing decisions (i.e. “as-if” 100% equity).
Capital Budgeting Process Should...

- Be easy to apply and explain
- Focus on cash flows (incremental)
- Account for the time value of money (timing of cash flows matters)
- Account for project risk
- Lead to investment decisions that maximize shareholders’ wealth
Main Investment Decision Metrics

- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Modified Internal Rate of Return (MIRR)
- Payback Period
- Discounted Payback Period
- Average Accounting Rate of Return (AAR)
- Profitability Index (PI)
What CFOs Actually Use

<table>
<thead>
<tr>
<th>Technique</th>
<th>Percent of CFOs Routinely Using Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal rate of return</td>
<td>76%</td>
</tr>
<tr>
<td>Net present value</td>
<td>75%</td>
</tr>
<tr>
<td>Payback</td>
<td>57%</td>
</tr>
<tr>
<td>Discounted payback</td>
<td>29%</td>
</tr>
<tr>
<td>Accounting rate of return</td>
<td>20%</td>
</tr>
<tr>
<td>Profitability index</td>
<td>12%</td>
</tr>
</tbody>
</table>

Source: “Corporate Finance”, Graham, Smart, Megginson 3rd Ed.
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**Advantages**
- Properly adjusts for TVM
- Uses cash flows rather than earnings
- Accounts for all cash flows
- Project IRR is intuitive

**Key Problems with IRR**
- Lending versus borrowing?
- Multiple IRRs
- No real solutions
- IRR and NPV rankings don't always agree

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**Capital Allocation Factors**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Percentage of CFOs</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV Rank</td>
<td>70%</td>
</tr>
<tr>
<td>Manager Reputation</td>
<td>70%</td>
</tr>
<tr>
<td>Manager Confidence</td>
<td>50%</td>
</tr>
<tr>
<td>Cash Flow Timing</td>
<td>50%</td>
</tr>
<tr>
<td>Market Share</td>
<td>40%</td>
</tr>
<tr>
<td>Previous Return</td>
<td>30%</td>
</tr>
<tr>
<td>Gut Feel</td>
<td>20%</td>
</tr>
<tr>
<td>Internal vs. External Funds</td>
<td>20%</td>
</tr>
<tr>
<td>Corporate Politics</td>
<td>10%</td>
</tr>
<tr>
<td>Balanced Allocation</td>
<td>0%</td>
</tr>
</tbody>
</table>

Decision Rules

**Independent Projects**

1. NPV > 0  
   ACCEPT PROJECT
2. IRR/MIRR > Cost of Capital  
   ACCEPT PROJECT
3. Payback Period < Required Time  
   ACCEPT PROJECT
4. AAR > Required Return  
   ACCEPT PROJECT
5. Profitability Index > 1  
   ACCEPT PROJECT

**Capital Rationing/Mutually Exclusive Projects**

- Invest in the combination of projects that maximizes the expected NPV and real option value within the total capital constraints.
Independent or Mutually Exclusive

• **Independent Projects**
  – Accepting or rejection one project has no impact on the accept/reject decision for the other project.

• **Mutually Exclusive Projects**
  – Accepting one project implies rejecting another.
  – When ranking mutually exclusive projects, ration capital to highest combination of NPV.
Sequencing & Real Options

- **Sequencing**
  - Capital projects may occur in sequence with interdependencies.

- **Real Options**
  - Most projects have “Real Options”
  - NPV can undervalue projects with options
    - Timing – delay for more information
    - Staging – phased project development
    - Expansion – expand the project
    - Exit – abandon project to avoid negative cash flow
    - Operating – operating choices influence results
    - Flexibility – multiple use, repurpose, oversize
    - Growth – project itself is poor, but stepping stone to big profits
# Elements of Project Evaluation

<table>
<thead>
<tr>
<th>Economic</th>
<th>Complications</th>
<th>Constraints</th>
<th>Other</th>
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<tbody>
<tr>
<td>Capital Investment</td>
<td>Ranking Projects</td>
<td>Technical Skill/Resources</td>
<td>Source of Funds</td>
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<tr>
<td>Future Cash Flows</td>
<td>Existing Commitments</td>
<td>Human Capital</td>
<td>Strategy</td>
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<tr>
<td>Tax Liabilities</td>
<td>Sources of Funds</td>
<td>Time/Timing</td>
<td>Fiscal Systems</td>
</tr>
<tr>
<td>Royalty Interests</td>
<td>I.D. Risks &amp; Opportunities</td>
<td>Financial Resources</td>
<td>Regulations</td>
</tr>
<tr>
<td>Chance for Success</td>
<td>Accounting for Uncertainty</td>
<td></td>
<td>Infrastructure</td>
</tr>
<tr>
<td></td>
<td>Market Conditions/Prices</td>
<td></td>
<td>Politics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Competitors</td>
</tr>
</tbody>
</table>
Key Elements of Cash Flow Models

Building an EOR financial model will require

1. Incremental Production Forecast
2. A Set of Price Forecasts for that Production
3. Incremental Capital Costs (CAPEX) Schedule
4. Incremental Operating Costs (OPEX)
5. Some Allowance for Taxes & Royalties
6. Time (over what period)
7. Weighted Average Cost of Capital (WACC) or other Discount Rate
## Typical Post-tax Oil & Gas Cash Flow Components

### Add Revenues
- Production \( \times (1 - \text{Royalty}) \times \text{Product Price} \)
- Tariff revenues (paid by third-parties for services or access to infrastructure)

### Less Expenditures
- **Transportation & Tariff Costs**: Transportation & Tariffs (T&T) costs, truck or train costs plus storage.
- **Operating Costs**: Fixed component $/month and Variable component $/bbl or mcf.
- **G&G costs (exploration)**: Geological and geophysical costs on areas not yet developed.
- **Overheads**: Business-related costs and investments plus finance costs.
- **Capital Investments**: Investments can include some ongoing operating costs (e.g. work-overs).

### Less Payments to Government
- **Licence Fees & Bonuses**: Rental payment to land-owner (an operating cost) may also be to Government.
- **Local Taxes**: Vary from % of Revenues to % of property values or both.
- **Fixed Foreign exchange**: In some countries an artificially high exchange rate is imposed by Government.
- **GST, VAT & Duties**: Goods, services, value-added taxes and import duties (exemptions & refunds).
- **Special Petroleum Taxes**: Range of fiscal structures depending upon country.
- **Corporate Taxes**: Allowances vary significantly and are frequently modified.
- **Withholding Taxes**: Taxes on funds remitted overseas.
- **(Royalties)**: Not technical part of company cash flow.

*David Wood & Associates*

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Note: Composition of Total Costs, NOT Magnitude

Source: SLB SBC,
Forecast Incremental Production

**Lost Soldier - Tensleep (Sweetwater County)**

**Monthly Oil & Pre-CO2 Decline Path**

- **Black Line**: Monthly Oil Production
- **Red Dash Line**: Pre-CO2 Decline Path
- **Purple Dotted Line**: CO2/Gas Inj (Since ’91)

**Legend**

- **Incremental Oil**
  - 2010 = 534,054
  - 2011 = 575,308
  - 2012 = 505,270

**Timeline**

- **Begin CO2 Flooding**: 1989
- **Oil Production (1,000 Bbls)**
- **CO2 Gas Injection (MMcf)**

**Month-Year**

- Jan-85 to Jan-13

- **Y-Axis**: 0-350 (Oil Production)
- **X-Axis**: 1,000-6,000 (CO2 Gas Injection)

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Dimensionless (HCPV) Analog Library

Incremental Oil (HCPV)
Water+CO2 Injection (HCPV)

17.5%
15.3%
13.3%
12.4%
11.1%
7.8%
8.9%
Little Buffalo Basin - Tensleep
Monthly Oil Production
Jan. 1994 - Dec. 2044

Monthly Production (bbls/mo)

Exp. Decline
Hyperbolic
Harmonic
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The Nature of Model Building

• Deterministic versus Probabilistic
  – Deterministic models yield a single snapshot based on the input assumptions and model structure.
  – Probabilistic (or stochastic) models employ probability distributions rather than point estimates.

• Two Modeling Adages:
  – “Garbage In – Garbage Out”
  – “Remember that all models are wrong; the practical question is how wrong do they have to be to not be useful...Essentially, all model are wrong, but some are useful.” –George E.P. Box
Payback Methods

The **payback period** is the amount of time required for the firm to recover its initial investment.

- If the project’s payback period is less than the max acceptable payback period, accept the project.
- Otherwise reject the project.

Management determines the maximum acceptable payback period.
Example – Submersible Pump

An ESP just failed, should I replace it or shut-in the well?

- The production engineer quickly evaluates the production levels of the failed well.
- Current prices and production costs reveal that the $200k ESP replacement cost will be recovered in roughly 16 months.
- Past experience with this particular field has been that ESPs fail on average every 36 months.

16 month Payback < 36 month Replacement
Example WY Oil Revenue & Cost Breakdown

(WTI = $55/bbl, Royalty = 18.75%)

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</tr>
<tr>
<td>Revenues for Operation ~$31.16/bbl</td>
<td>Profit Oil ~$11.37/bbl</td>
<td>Basic OPEX ~$19.79/bbl</td>
<td>Basic OPEX ~$14.85/bbl</td>
</tr>
</tbody>
</table>

40 bbls oil 99% Watercut @ 5,500 feet

40 bbls oil 98.5% Watercut @ 5,500 feet

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Pros & Cons of Payback Method

**Advantages**
1. Simple to compute & understand
2. Provides some information on risk
3. Provides some measure of liquidity
4. Focus on cash flows

**Disadvantages**
1. Does not properly account for the time value of money (TVM)
2. Arbitrary cutoff values don’t indicate whether investment increases the value of the firm
3. Ignores cash flows beyond the payback period
4. Ignores the risk of future cash flows
5. Doesn’t capture managerial flexibility (option value)
Net Present Value

The net present value is the present value of all incremental cash flows, discounted to the present, less the initial costs.

\[ NPV = CF_0 + \frac{CF_1}{(1+r)} + \frac{CF_2}{(1+r)^2} + \frac{CF_3}{(1+r)^3} + \cdots + \frac{CF_N}{(1+r)^N} \]

- \( r \) is the minimum return the project must earn to satisfy investors, typically WACC
- \( r \) varies with the risk of the firm and/or project
Weighted Average Cost of Capital (WACC)

WACC is the simple weighted average of the required rates of return on debt and equity, where the weights equal the percentage of each type of financing in the firm’s capital structure.

\[
WACC = \left( \frac{D}{D+E} \right)(1 - T_c)r_D + \left( \frac{E}{D+E} \right)r_E
\]

- \(D\) = Total Debt
- \(T_c\) = Income Tax Rate
- \(r_D\) = Cost of Debt
- \(E\) = Total Equity
- \(r_E\) = Cost of Equity
The CAPM Model

The cost of equity in WACC is often estimated using the Capital Asset Pricing Model (CAPM), where Beta represents the relationship between the stock/asset and systematic risk of the broader market (S&P 500):

\[ E(R_i) = R_f + \beta_i (E(R_m) - R_f) \]

- \( E(R_i) \) = Expected return on the stock/asset equity
- \( R_f \) = Risk-free rate
- \( \beta_i \) = Beta of the stock/asset versus the market
- \( E(R_m) \) = Expected return of the overall market
- \( E(R_m) - R_f \) = Equity Risk Premium (ERP)
Linking the CAPM Model & WACC

In order to estimate discount rates for assets, we try to find “pure play” comparables and adjust the Beta for the Debt/Equity ratio.

\[ \beta_E = \beta_A \left[ 1 + (1 - T_c) \frac{D}{E} \right] \]

- Assumes Debt Beta = 0
- Holding the asset beta—the risk of the firm’s assets—constant, the more money the firm raises by issuing debt, the greater its financial leverage, and the higher its equity beta.
Finding the Right Discount Rate (1)

1. When an all-equity firm invests in an asset similar to its existing assets, the cost of equity is the appropriate discount rate to use in NPV calculations.

2. When a firm with both debt and equity invests in an asset similar to its existing assets, the WACC is the appropriate discount rate to use in NPV calculations.
Finding the Right Discount Rate (2)

3. In conglomerates, the WACC reflects the return that the firm must earn on average across all its assets to satisfy investors, but using the WACC to discount cash flows of a particular investment leads to mistakes.

4. When a firm invests in an asset that is different from its existing assets, it should look for pure-play firms to find the right discount rate.
Example – DNR as Pure-Play CO$_2$

Use Denbury as a Pure-Play in CO2 EOR to estimate Asset Beta

- Beta = 2.2  
  Debt/Equity = 0.64  
  Tax = 38%

$$\beta_A = \frac{2.2}{1 + (1 - 0.38)0.64} = 1.58$$

Now “Re-Lever” & Assume You Will Fund Your CO2 Project
with 65% Debt/35% Equity and a Tax Rate of 30%

$$\beta_E = 1.58 \left[ 1 + (1 - 0.30) \frac{0.65}{0.35} \right] = 3.634$$
Example – DNR as Pure-Play CO₂

Use the CAPM Model to Estimate the Equity Return
Beta = 2.2  Debt/Equity = 0.64  Tax = 38%

\[ E(R_i) = 3.25% + 3.634(9.25% - 3.25%) = 25\% \]

Finally, Recalculate the WACC
Assuming debt costs \( r_D = 10\% \)

\[ WACC = \left( \frac{65}{100} \right)(1 - 0.3)10\% + \left( \frac{35}{100} \right)25\% = 13.3\% \]

Sometimes Used as the Risk-Adjusted Discount Rate

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# Pros & Cons of NPV Method

<table>
<thead>
<tr>
<th><strong>Advantages</strong></th>
<th><strong>Disadvantages</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Focuses on all cash flows</td>
<td>1. Requires an estimate of cost of capital or risk adjusted discount rate</td>
</tr>
<tr>
<td>2. Considers time value of money (TVM)</td>
<td>2. Not as intuitive as Payback</td>
</tr>
<tr>
<td>3. Tell whether a project increases firm value</td>
<td>3. Doesn’t capture managerial flexibility (option value)</td>
</tr>
<tr>
<td>4. Can account for risk differences</td>
<td></td>
</tr>
</tbody>
</table>

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Internal Rate of Return

Internal rate of return (IRR) is the discount rate that results in a zero NPV for the project.

\[
NPV = CF_0 + \frac{CF_1}{(1 + r)^1} + \frac{CF_2}{(1 + r)^2} + \cdots + \frac{CF_{N-1}}{(1 + r)^{N-1}} + \frac{CF_N}{(1 + r)^N} = 0
\]

- **IRR usually found by computer or calculator.**
  - If the IRR is greater than the cost of capital, accept the project
  - If the IRR is less than the cost of capital, reject the project.
The **net present value profile** is the graphical illustration of the NPV of a project at different required rates of return.

The NPV profile intersects the vertical axis at the sum of the cash flows (i.e., 0% required rate).

The NPV profile crosses the horizontal axis at the project’s

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Source: CFA Institute 2013, Chapter 2, Corporate Finance
# IRR Examples for Calculators

For each of the projects shown in the following table, calculate the internal rate of return.

<table>
<thead>
<tr>
<th>Initial Cash Outflow (CF₀)</th>
<th>Project A</th>
<th>Project B</th>
<th>Project C</th>
<th>Project D</th>
</tr>
</thead>
<tbody>
<tr>
<td>$72,000</td>
<td>$440,000</td>
<td>$18,000</td>
<td>$215,000</td>
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</table>

<table>
<thead>
<tr>
<th>Year (t)</th>
<th>Cash Inflows (CFₜ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$16,000</td>
</tr>
<tr>
<td>2</td>
<td>20,000</td>
</tr>
<tr>
<td>3</td>
<td>24,000</td>
</tr>
<tr>
<td>4</td>
<td>28,000</td>
</tr>
<tr>
<td>5</td>
<td>32,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year (t)</th>
<th>Cash Inflows (CFₜ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$135,000</td>
</tr>
<tr>
<td>2</td>
<td>135,000</td>
</tr>
<tr>
<td>3</td>
<td>135,000</td>
</tr>
<tr>
<td>4</td>
<td>135,000</td>
</tr>
<tr>
<td>5</td>
<td>—</td>
</tr>
</tbody>
</table>

17.4%     8.7%     27.2%     21.4%
Recall – Infill Drilling Program

A field may benefit from greater well density, what is the NPV?

Your team is considering drilling a new set of infill wells for a total project cost of $10 million, with subsequent cash flows of $4MM, $3.5MM, $3.0MM, $2.5MM, $2.0MM, and $1.5MM.

<table>
<thead>
<tr>
<th>Period</th>
<th>Cash Flow ($MM)</th>
<th>Discount Factor [1/(1+r)^t]</th>
<th>Discounted Cash [CF*DF]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>($10.00)</td>
<td>1.0000</td>
<td>($10.00)</td>
</tr>
<tr>
<td>1</td>
<td>$4.00</td>
<td>0.8826</td>
<td>$3.53</td>
</tr>
<tr>
<td>2</td>
<td>$3.50</td>
<td>0.7790</td>
<td>$2.73</td>
</tr>
<tr>
<td>3</td>
<td>$3.00</td>
<td>0.6876</td>
<td>$2.06</td>
</tr>
<tr>
<td>4</td>
<td>$2.50</td>
<td>0.6068</td>
<td>$1.52</td>
</tr>
<tr>
<td>5</td>
<td>$2.00</td>
<td>0.5356</td>
<td>$1.07</td>
</tr>
<tr>
<td>6</td>
<td>$1.50</td>
<td>0.4727</td>
<td>$0.71</td>
</tr>
</tbody>
</table>

NPV $1.62

What is the NPV of the project of the WACC is 13.3%?

**IRR = 20.1%**
Pros & Cons of IRR Method

**Advantages**
1. Properly adjusts for TVM
2. Uses cash flows rather than earnings
3. Accounts for all cash flows
4. Project IRR is intuitive

**Disadvantages**
1. IRR and NPV rankings don’t always agree
2. Assumes positive cash flows are “re-invested” at the projects IRR
3. Can’t be used with multiple cash-flow sign changes...multiple IRRs
4. No real solutions
5. Scale and timing problems
6. Doesn’t capture managerial flexibility (option value)
When project cash flows have multiple sign changes, there can be multiple IRRs.
Multiple IRRs (1)

• If a project has more than one change in the sign of cash flows, there may be multiple IRRs.

• Though odd traditionally, can easily be observed in the energy industry and high-tech firms.

• NPV or Modified IRR still work for this type of project with sign changes.
Conflicts Between NPV & IRR (1)

• NPV and IRR do not always agree when ranking mutually exclusive projects

• **The scale problem:**
  – When choosing between mutually exclusive investments, we cannot conclude that the one offering the highest IRR necessarily provides the greatest wealth creation opportunity.
Scale Problem

Here again are the NPV and IRR figures for the two investment alternatives.

<table>
<thead>
<tr>
<th>Project</th>
<th>IRR</th>
<th>NPV (18%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Europe</td>
<td>27.8%</td>
<td>$75.3 million</td>
</tr>
<tr>
<td>Southeast U.S.</td>
<td>36.7%</td>
<td>$25.7 million</td>
</tr>
</tbody>
</table>
Conflicts Between NPV & IRR (2)

• The timing problem:
  – Managers can neglect long-term investments to meet short-term goals.
  – A naïve reliance on the IRR method can lead to investments that unduly favor short-term payoffs.
Conflicts Between NPV & IRR (3)

• **The reinvestment problem:**
  – The calculation of IRR assumes that positive cash flows are reinvested at that same rate of return for the project in question.
  – Can dramatically inflate IRR beyond what most would consider reasonable.
  – NPV doesn’t have this issue, and is a reason to use MIRR and assume a reinvestment rate.
Modified Internal Rate of Return (MIRR) assumes negative outlays are financed at one rate, and positive cash flows is reinvested at the another rate.

\[ MIRR = \left( \frac{FV(Positive CF, WACC)}{PV(Outlays, r_D)} \right)^{\frac{1}{n}} - 1 \]

- Analytical calculation with no problems with multiple or irrational solutions
- More conservative and realistic IRR
- Still has issues with the scale problem
Recall – Infill Drilling Program

A field may benefit from greater well density, what is the NPV?

Your team is considering drilling a new set of infill wells for a total project cost of $10 million, with subsequent cash flows of $4MM, $3.5MM, $3.0MM, $2.5MM, $2.0MM, and $1.5MM

<table>
<thead>
<tr>
<th>Period</th>
<th>Cash Flow ($MM)</th>
<th>Discount Factor [1/(1+r)^t]</th>
<th>Discounted Cash [CF*DF]</th>
</tr>
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<tbody>
<tr>
<td>0</td>
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<td>$1.50</td>
<td>0.4727</td>
<td>$0.71</td>
</tr>
</tbody>
</table>

NPV $1.62

What is the NPV of the project if the WACC is 13.3%?

IRR = 20.1%
MIRR = 16.2%
The Nature of Model Building

• Deterministic versus Probabilistic
  – Deterministic models yield a single snapshot based on the input assumptions and model structure.
  – Probabilistic (or stochastic) models employ probability distributions rather than point estimates.
Expected Monetary Value (EMV)

• ...basically the probability weighted NPV
  – Calculate the NPV under various scenarios.
  – Assign probabilities to those scenarios.
  – Calculate the probability weight NPV, or EMV

• Probabilities can be subjective, but...
  – “educated guesses” based on technical evidence and practical experience are USEFUL
  – Decision Trees can help organize scenarios, document and visualize options, and fully characterize EMV.
Simple Example

Decision Node

DRILL

DON’T DRILL

Event Node

EMV = $2.0

70%

15%

10%

5%

Dry Well

10 BCF

50 BCF

250 BCF

EMV = $15.0

EMV = $75.0

Probabilities Must Sum to 100%

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Probabilities Must Sum to 100%
Simple Example

EMV = $4.2

DRILL

EMV = $0.0

DON’T DRILL

Dry Well

70% ($2.0)

15% $2.0

10% $15.0

5% $75.0

10 BCF

50 BCF

250 BCF

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Monte Carlo Simulations

• **Assign probability distributions to variables**
  – Simulate hundreds or thousands of random draws from distributions of variables.
  – Summarize key metrics (NPV, MIRR) with frequency distributions to assess risk and ranges.
  – Use volatility of earnings from the Monte Carlo as the input for calculation of Real Option values using Binomial or Black-Scholes models.
Monte Carlo Simulations

NPV\(_{\text{WACC}}\) Distribution

Prob NPV > 0
88.0%
Questions & Feedback
EORI’s Economic Scoping Model

BENJAMIN R. COOK
EORI/MBA PROGRAM
UNIVERSITY OF WYOMING

Petroleum & Chemical Engineering Senior Design
October 13th, 2014 (PETE 4720)
Enhanced Oil Recovery Institute

Main Dashboard

Many Other Parameters
- Taxes & Royalties
- Oil Price & Cost Correlation
- Injection Rates

CAPEX
- Drilling & Workover Costs
- Recycling Plant Costs
- Pipeline Costs
- Power Infrastructure

OPEX
- Plant L&M + Electricity
- Lift & Other Well Costs
- CO₂ Purchasing

<table>
<thead>
<tr>
<th>Oil Reservoir/Development Data</th>
<th>Analysis Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Original Oil In Place (OOIP, bbls)</td>
<td>70,000,000</td>
</tr>
<tr>
<td>Cumulative Oil Production (bbls)</td>
<td>27,000,000</td>
</tr>
<tr>
<td>Last Monthly Oil Production (bbls/month)</td>
<td>300</td>
</tr>
<tr>
<td>Monthly Production Decline Rate (%/month)</td>
<td>1.20%</td>
</tr>
<tr>
<td>Monthly Water Production (bbls/prod. well-month)</td>
<td>40,000</td>
</tr>
<tr>
<td>Percent (%) Produced Water Injected</td>
<td>80.00%</td>
</tr>
<tr>
<td>* Oil Gravity (API)</td>
<td>37</td>
</tr>
<tr>
<td>Initial Formation Volume Factor (rb/stb)</td>
<td>1.35</td>
</tr>
<tr>
<td>Current Formation Volume Factor (rb/stb)</td>
<td>1.25</td>
</tr>
<tr>
<td>CO₂ Formation Volume Factor (rb/mcf)</td>
<td>0.36</td>
</tr>
<tr>
<td>Average Depth (feet)</td>
<td>7,000</td>
</tr>
<tr>
<td>Fracture Gradient (fraction)</td>
<td>0.65</td>
</tr>
<tr>
<td>Operating Pressure (psi)</td>
<td>2,000</td>
</tr>
<tr>
<td>Temperature (deg F)</td>
<td>137</td>
</tr>
<tr>
<td>Surface Area (acres)</td>
<td>720</td>
</tr>
<tr>
<td>Average Net Pay Thickness (feet)</td>
<td>40</td>
</tr>
<tr>
<td>Initial Oil Saturation (Soi)</td>
<td>93%</td>
</tr>
<tr>
<td>Porosity (md)</td>
<td>0.20</td>
</tr>
<tr>
<td>Permeability (md)</td>
<td>235.00</td>
</tr>
</tbody>
</table>

Existing Wells (non-plugged)

<table>
<thead>
<tr>
<th>Analysis Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Active Producing Wells (count)</td>
</tr>
<tr>
<td>* Active Injection Wells (count)</td>
</tr>
<tr>
<td>* Temporary Abandoned &amp; Shut-In Wells (count)</td>
</tr>
</tbody>
</table>

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Step One:

- Define the development area of your project, and collect the primary data for that area.
Step Two….

- Working top-to-bottom and left-to-right on the Dashboard, enter the primary data of your project and specify the other model assumptions.

**Important**
- Start with primary data, well counts, and injection rate.
- After that, you can continue with the included economics, or copy the oil and CO₂ flows into your own model.
**Main Dashboard**

**Oil & CO2 Price Paths for Scoping Analysis**

- WTI Oil Price (left axis)
- Regional Oil Price (left axis)
- CO2 Price (right axis)

**Summary CO2-EOR Scoping Results**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Analysis Value</th>
<th>Default/Calc Override</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the Oil Unit Miscible?</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Is CO2-EOR Economic?</td>
<td>Profitable, but IRR &lt; 20%</td>
<td></td>
</tr>
<tr>
<td>Inj. Rate (HCPV/year) &amp; Duration (years)</td>
<td>4.88% for 50.25 years</td>
<td></td>
</tr>
<tr>
<td>Incr. Oil (mmbbls) &amp; CO2 Purchased (bcf)</td>
<td>8.99 mmbbls &amp; 63 bcf</td>
<td></td>
</tr>
<tr>
<td>Calculated Pretax 30-Year IRR (%)</td>
<td>18.42%</td>
<td></td>
</tr>
<tr>
<td>Incremental Nominal Oil Revenues</td>
<td>$1,201.75</td>
<td></td>
</tr>
<tr>
<td>Capital Cost/Investment</td>
<td>($63.45)</td>
<td></td>
</tr>
<tr>
<td>Royalty, Severance &amp; Property Tax</td>
<td>($298.05)</td>
<td></td>
</tr>
<tr>
<td>Incremental Operating Costs</td>
<td>($327.29)</td>
<td></td>
</tr>
<tr>
<td>Cumulative Pre-Tax Profits</td>
<td>$512.95</td>
<td></td>
</tr>
</tbody>
</table>

**Oil Pricing Assumptions**

- *Oil Price Path (1=Constant, 2=Trend, 3=Random)*: 3
- *Constant/Starting WTI Oil Price ($/bbl, pre-discount)*: $100.00
- Oil Price Trend Years (years<=75, if selected): --
- Oil Price at End of Time Trend ($/bbl, if selected): --
- * Adjust Oil for "Regional" Discount (0=NO, 1=YES): 1
  - "Regional" Discount per Barrel ($/bbl): $25.00
  - Adjusted (post-discount) Oil Prices = Starting Oil Price=$75

**CO2 Price Assumptions**

- Fixed CO2 Charge($/mcf): $0.50
- Addt'l CO2 Cost as Share of Oil Price (%): 1.50%
Enhanced Oil Recovery Institute
<table>
<thead>
<tr>
<th>Misc Project Metrics</th>
<th>Metric Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchased CO2 Utilization (mcf/bbl)</td>
<td>6.3</td>
</tr>
<tr>
<td>Total Injected CO2 Utilization (mcf/bbl)</td>
<td>22.71</td>
</tr>
<tr>
<td>Payback Period (years)</td>
<td>3.56</td>
</tr>
<tr>
<td>Avg. OPEX per Barrel (excl tax/royalty)</td>
<td>($16.79)</td>
</tr>
<tr>
<td>Avg Net Pre-Tax Profit per Barrel</td>
<td>$55.86</td>
</tr>
<tr>
<td>NPV @ 20% Discount Rate ($MM)</td>
<td>$491.31</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IRRs: Starting Oil Prices &amp; Analog Library</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Library Codes</td>
<td></td>
</tr>
<tr>
<td>33.65%</td>
<td></td>
</tr>
<tr>
<td>$70</td>
<td></td>
</tr>
<tr>
<td>14.7%</td>
<td>18.7%</td>
</tr>
<tr>
<td>$80</td>
<td></td>
</tr>
<tr>
<td>18.1%</td>
<td>22.4%</td>
</tr>
<tr>
<td>$90</td>
<td></td>
</tr>
<tr>
<td>18.2%</td>
<td>22.4%</td>
</tr>
<tr>
<td>$100</td>
<td></td>
</tr>
<tr>
<td>19.9%</td>
<td>25.0%</td>
</tr>
<tr>
<td>$110</td>
<td></td>
</tr>
<tr>
<td>20.0%</td>
<td>25.1%</td>
</tr>
<tr>
<td>$120</td>
<td></td>
</tr>
<tr>
<td>9.7%</td>
<td>15.4%</td>
</tr>
<tr>
<td>$130</td>
<td></td>
</tr>
<tr>
<td>7.7%</td>
<td>13.4%</td>
</tr>
<tr>
<td>$140</td>
<td></td>
</tr>
<tr>
<td>21.6%</td>
<td>27.2%</td>
</tr>
</tbody>
</table>
## CAPEX Calculations

### Summary CO₂-EOR Scoping Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Unit Miscible?</td>
<td>Yes</td>
</tr>
<tr>
<td>Is CO₂-EOR Economic?</td>
<td>Yes</td>
</tr>
<tr>
<td>Oil Project &gt; 20%</td>
<td>Yes</td>
</tr>
<tr>
<td>Initial Rate (HCPV/year) &amp; Duration (years)</td>
<td>9.9%</td>
</tr>
<tr>
<td>Incremental Oil (mbbls) &amp; CO₂ Purchased (bcf)</td>
<td>20.4%</td>
</tr>
<tr>
<td>Incremental Operating Costs</td>
<td>$202.36</td>
</tr>
<tr>
<td>Cumulative Pre-Tax Profit</td>
<td>$85,306.68</td>
</tr>
<tr>
<td>Incremental Oil Revenues</td>
<td>$5,077.19</td>
</tr>
<tr>
<td>Capital Cost/Investment</td>
<td>$702,96</td>
</tr>
<tr>
<td>Royalty, Severance &amp; Property Tax</td>
<td>$1,418.42</td>
</tr>
<tr>
<td>Incremental Operating Costs</td>
<td>$100,000.00</td>
</tr>
<tr>
<td>Total Capital Cost of New Well Drilling (SMM)</td>
<td>$53,28</td>
</tr>
</tbody>
</table>

### Capital Cost Calculations

<table>
<thead>
<tr>
<th>Component</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Production Wells (SMM)</td>
<td>$14,90</td>
</tr>
<tr>
<td>All Other Production Wells (SMM)</td>
<td>$0</td>
</tr>
<tr>
<td>Injection Wells (SMM)</td>
<td>$27,53</td>
</tr>
<tr>
<td>Production Lines/Misc (SMM)</td>
<td>$7,40</td>
</tr>
<tr>
<td>Total Capital Cost of New Well Drilling (SMM)</td>
<td>$53,28</td>
</tr>
<tr>
<td>Total Well Related Costs (SMM)</td>
<td></td>
</tr>
</tbody>
</table>

### Pipeline Costs

<table>
<thead>
<tr>
<th>Component</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major CO₂ Delivery Trunk Pipeline Costs (SMM)</td>
<td>$0</td>
</tr>
<tr>
<td>Project’s Share of Trunk Pipeline (%)</td>
<td>0.0%</td>
</tr>
<tr>
<td>Total CO₂ Pipeline Cost (SMM)</td>
<td>$11,17</td>
</tr>
<tr>
<td>Total CO₂ Pipeline and Meter Cost (SMM)</td>
<td>$11,69</td>
</tr>
</tbody>
</table>

### Electricity Infrastructure Costs

<table>
<thead>
<tr>
<th>Component</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of New Terminal Bays</td>
<td>$0</td>
</tr>
<tr>
<td>Cost of New Substation (SMM)</td>
<td>$0</td>
</tr>
<tr>
<td>Total Electricity Infrastructure Costs (SMM)</td>
<td>$0</td>
</tr>
</tbody>
</table>

### Recycling Facility Costs

<table>
<thead>
<tr>
<th>Component</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge for Compression Horsepower (SMM)</td>
<td>$53,30</td>
</tr>
<tr>
<td>Total Ext. Cost of Recycling Plant (SMM)</td>
<td>$137,45</td>
</tr>
</tbody>
</table>

### Oil Property Acquisition Costs (SMM)

<table>
<thead>
<tr>
<th>Component</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Capital Cost Estimate (SMM)</td>
<td>$202.36</td>
</tr>
</tbody>
</table>

### Miscellaneous Calculations & Values

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Volumetric Pore Volume (brcp, ft³)</td>
<td>1,312,883</td>
</tr>
<tr>
<td>HCPV per Injection Well (brcp)</td>
<td>6,903,772</td>
</tr>
<tr>
<td>Pre-CO₂ Injection Rate (brcp/year)</td>
<td>8.24%</td>
</tr>
<tr>
<td>Injection Adjustment Factor (Fraction)</td>
<td>1.00</td>
</tr>
<tr>
<td>Adjusted Injection Rate (brcp/year)</td>
<td>8.24%</td>
</tr>
<tr>
<td>Estimated Spur Pipe Diameter (inches)</td>
<td>10</td>
</tr>
<tr>
<td>Current Daily Oil Production (bbls/day)</td>
<td>1075.5</td>
</tr>
<tr>
<td>Current Daily Water Production (bbls/day)</td>
<td>1,571</td>
</tr>
<tr>
<td>Annual Decline Rate of Oil Fraction/year</td>
<td>8.38%</td>
</tr>
</tbody>
</table>

### CO₂-EOR Capital Costs

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Costs vs Pre-Tax Income</td>
<td></td>
</tr>
<tr>
<td>Total Estimated Cost</td>
<td>$202.36</td>
</tr>
<tr>
<td>Total Oil &amp; Gas Royalties</td>
<td>$51,428</td>
</tr>
<tr>
<td>Total CO₂ Purchases</td>
<td>$7,474</td>
</tr>
<tr>
<td>Total Other Operating Costs</td>
<td>$14,428</td>
</tr>
<tr>
<td>Total Cumulative Pre-Tax Income</td>
<td>$85,306.68</td>
</tr>
</tbody>
</table>
Other Modules

Annual Cash Flows

Quarterly Breakdown
- Breakdown of all model of results on a quarterly basis out to 75 years.

Custom Oil Price Path

Analog Library
- Dimensionless data
- Slot for user’s own analog

Analog Builder
- Tool to enter raw data and convert to analog.
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**Analog Builder**

- Original Oil in Place (OOIP)
- Initial & Current Oil Volume Factors
- CO2 Volume Factor
- CO2 & Water Injection Volumes
- Oil Production
- CO2 & Water Production Volumes

**User’s Analog Project Injection & Production Data (up to 20 years of weekly observations)**

<table>
<thead>
<tr>
<th>Date</th>
<th>CO2 Injection</th>
<th>Water Injection</th>
<th>Oil Production</th>
<th>CO2 Produced</th>
<th>Water Produced</th>
<th>Inj Rate Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1/1989</td>
<td>4,868</td>
<td>8,746,877</td>
<td>64,043</td>
<td>11,412</td>
<td>3,268,765</td>
<td>1,239</td>
</tr>
<tr>
<td>3/1/1989</td>
<td>0</td>
<td>1,075,789</td>
<td>88,126</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/1/1989</td>
<td>98,954</td>
<td>1,555,987</td>
<td>89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/1/1989</td>
<td>1,622,769</td>
<td>2,216,474</td>
<td>91</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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**CO2scope Formatting of User’s Analog**

- CO2 Injection
- Water Injection
- Oil Production
- CO2 Produced
- Water Produced
- Inj Rate Variation

**Percentage of BLAMO!**

- Dimensionless Analog