Petroleum Asset Development

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Written by: Mario A. Salazar, IWFS LLC

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Main Topics

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2. E&P Life Cycle of a Petroleum Asset
3. Revenue during the life cycle of a PA
4. Early Planning adds Value to Asset
5. Field Development Planning
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10. Construction of Production Facilities
11. Production Operations
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1.0 Introduction
This document presents an structured overview of the set of the basic preliminary steps to road map the main activities required to develop a potentially commercial petroleum asset.

2.0 The E&P Life Cycle of a Petroleum Asset
The E&P cycle of a field encompasses six (6) major phases as shown in Graph 1 below:

Graph 1. Major Phases in the Life Cycle of a Petroleum Asset
The E&P Cycle of the life span of a petroleum asset covers from the initial Acquisition of the property to the final Abandonment of the field including the following activities:

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>PHASE</th>
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<tbody>
<tr>
<td>Land Procurement</td>
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<td>Land Contracting</td>
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<td>Exploratory Basin Analysis</td>
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<td>Exploratory/Wildcat Drilling</td>
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<td>Appraisal Drilling</td>
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<td>Field Development Plan</td>
<td>Development</td>
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<td>Economic Analysis</td>
<td>Development</td>
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<td>Subsurface &amp; Surface Facility Construction</td>
<td>Development</td>
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<td>Production Operations</td>
<td>Production</td>
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<td>Reservoir Management</td>
<td>Production</td>
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<tr>
<td>Optimization</td>
<td>Production</td>
</tr>
<tr>
<td>Abandonment</td>
<td>Abandonment</td>
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</tbody>
</table>

Table 1. E&P Life Span Cycle Activities

2.1 ACQUISITION

The activities of the acquisition phase of the project must focus on finding the land where preliminary public or private data indicates the possibility of securing a promising block/area that qualifies as legal, safe and potentially viable for oil exploration.

Promising means the land is located in a basin with seismic and geological conditions that indicate hydrocarbons are most likely to be trapped or where commercial petroleum deposits in the subsurface have already been found in the past.

A promising block/area must also be free of any critical social, political or security risks and/or environmental restrictions that might jeopardize or disable the possibility of successful development.
Graph 2. Acquisition of land for oil exploration

Procurement to secure the land thru a concession/contractual system must represent the main efforts of the professional land team. The *signing of a land contract* to acquire the acreage must be the milestone to accomplish in this phase of the project.

2.2 EXPLORATION

Once the acreage is available for exploration activities, an aggressive plan needs to be put forward to identify subsurface oil and gas deposits.

Depending on the scope and comprehensiveness of the plan, the exploration effort might include the acquisition of detailed geographical data, airborne magnetic surveys, geochemical surveys, field geology, petroleum geology studies and many acres of 2D or 3D seismic data acquisition, processing and interpretation.
Graph 3. Field Geology

Graph 4. A group of advanced petroleum geology students in the field
Graph 5. Airborne magnetic survey mapping

Graph 6. Seismic data acquisition
Graph 7. Seismic data interpretation

In the *exploration phase*, a team of geophysicists, geologists and reservoir engineers must work together to set up, organize and analyze the information producing the mapping and interpretation, the expected volumes and the statistical analysis calculations as well as the evaluation of economics required to identify a subsurface geological formation likely to produce hydrocarbon fluids or putting in simple terms: *an oil or gas prospect*.

Graph 8. Structure map (top) and cross section of a prospect
Justification for drilling a prospect is made by assembling geoscience and engineering evidence of the existence of an active petroleum system with a reasonable probability of encountering quality-reservoir rock, a trap of sufficient size, adequate sealing rock and appropriate conditions for generation and migration of hydrocarbons to fill the trap.

Further planning and drilling execution of a exploratory well or wildcat may lead to the successful discovery of oil or gas.

Graph 9. Wildcat (exploratory) drilling

The discovery well will provide the opportunity to run a set of tests to collect very important reservoir engineering data including: initial production rates, reservoir tops, depths, pressures, temperatures, well logs, mud logs as well as fluids and rock properties.

This data is critical to evaluate the reservoir and provide critical information in the further definition of the Appraisal and Development phases of the project.
2.3 APPRAISAL

Right after a wildcat well has been drilled successfully and a potentially commercial petroleum discovery has been made, the team of geoscientists and reservoir engineers has to start the planning of *appraisal phase* activities leading to a better estimation of the size and the extension of the volumes in the reservoir and its characteristic (shape, potential and limits) in more detail.

Graph 10. Discovery and proposed appraisal well

The appraisal phase might require the drilling of one or more wells to complete the initial definition of the reservoir. Graph 10 depicts a discovery (continuous vertical line) and a proposed appraisal well (broken vertical line).

2.4 DEVELOPMENT

The initial definition of the size and extension of the reservoir signals the completion of the appraisal phase, a better definition of the field and the initiation of the development phase.
This phase requires the definition of a field development plan (FDP) to analyze and consider a set of development options from which the most technically effective, safest and economical should be selected to deplete the reservoir generating optimum return of the investment (ROI).

The preparation of a field development plan (FDP) needs the coordinated efforts of a multidisciplinary team of land professionals, geoscientists and reservoir, production, facilities, drilling and completion engineers whose primary responsibility is the layout and implementation of the plan whose backbone is the definition of the placement and design of the wells, the drilling and completion of the wells and the construction of surface facilities.

In this phase, capital expenditures (CAPEX) are going to be high as result of the cost of the number of wells to drill and complete in the campaign and the surface facilities to build.

2.5 PRODUCTION

The production phase focuses on the extraction, pre-processing (dehydration, degasification) and transportation of crude oil and gas. This phase is characterized for the positive cash flow it is expected to generate as result of the sale of the produced volumes of oil and gas as per pre-established contracts.

In the production phase, oil and gas production rates are expected to ramp up to a maximum, remain reasonable steady at the top for a short time and finally decline constantly to an economic limit at which, the field must be abandoned.

Graph 11. Oil Field Production

Graph 12. Oil Field Production Curve
If declining production rates are not arrested thru additional (infill) drilling campaigns, recompletions or enhanced oil recovery (EOR) projects, the decline will continue until production rates reach the economic limit of the field as shown in Graph 12.

Infill drilling campaigns drill a number of additional wells in strategic proved developed locations nearby existing producing wells to increase field production rates.

Well recompletion programs also provide a way to increase field oil production rates by modifying wells (perforating other zones of the well) to produce and commingle production with existing producing zones.

EOR or Enhanced Oil Recovery programs are designed and applied to increase oil production rates of a field by systematic injection of gas, chemicals, steam or carbon dioxide (CO2) in the reservoir thru injection wells drilled or adapted for that purpose.

The energy and fluids injected, force hydrocarbons out by facilitating its ability to flow to the producing wells from the reservoir rock.

Graph 13. Production ramp up, peak, decline and recovery in the life of a field.
A multidisciplinary team of reservoir, production and completion engineers must focus in the efforts to keep field production up and optimizing it by maximizing production volumes and minimizing failures and downtime.

Economically, the production phase is the best in terms of positive cash flow and profitable return of the investment.

2.6 ABANDONMENT

Once the field reaches its economic limit, executive management has to designate an specialized multidisciplinary team of engineers, regulatory and HSE specialists to stop production and prepare a plan to close operations and abandon field. The well abandonment operation is commonly known in the industry as P&A or plug & abandon.

Graph 14. Plugged off and abandoned well

To minimize damage to the environment, wells have to be plugged off permanently to prevent them from leaking above ground or contaminate subsurface fresh water aquifers, surface facilities (well equipment and tanks) have to be removed and land reclamation regulations have to be followed to restore as much as possible the outlook of the field and associated ecosystems.
The long-term objective of final reclamation is to set the course for eventual ecosystem restoration, including the restoration of the natural vegetation community, hydrology, and wildlife habitats.

The abandonment conditions mentioned above, generate a final negative cash flow as result of the high costs involved in most of the operations required to decommissioning wells and facilities and restore the environment.

The cost of plugging off a well depends on the depth (deeper wells are more expensive to plug) and the completion of the well. As an example, costs of plugging and abandoning wells in the state of Wyoming in 2015 ranged from $600 to $560,000.

Graph 15. Specialized oil field abandonment crew

3.0 Revenue during the life cycle of a field
Graph 16 displays the profile of the revenue versus time and the active main life cycle phases including Exploration, Appraisal, Development, Production and Abandonment.

As observed and expected, revenue decreases with Exploration, Appraisal, Development and Abandonment, and increases with Production until the abandonment production rate is reached and the field has to be decommissioned.
Graph 16. Revenue vs Time during life cycle phases

Graph 17. E & P lifecycle activities

Graph 17 shows an illustrated picture of the counterclockwise sequential relationship of the main E&P lifecycle activities that start with the acquisition of acreage where exploration activities have been or have to be started with analysis of the basin, the generation of a Prospect and the discovery of commercial hydrocarbons after a wildcat or exploratory well has been drilled.
The sequence continues with appraisal drilling, the design of a field development plan, the implementation of the development plan, the construction/installation of facilities, the onset of production operation and the management of the reservoir using financial, technological and human resources to minimize capital expenditure and operating expenses, in order to maximize economic recovery of oil or gas from the reservoir before the economic limit of the field is reached, and abandonment procedures have to be initiated.

4.0 Early planning & addition of value
Investing in early planning provides an excellent opportunity to add value to the project by developing a reservoir model, designing an optimized drilling program, minimizing well performance uncertainty and selecting the correct surface facilities to support production.

**Early Planning Creates the Greatest Value**

- The greatest value to a project is created in the Appraise and Select phases which involve:
  - Developing a robust reservoir model and depletion plan
  - Optimizing the drilling program (greatest recovery with fewest wells)
  - Minimizing well performance uncertainty
  - Selecting the right surface facility plan

- The spend in these phases is generally a small percentage of total development spend but provides substantial added value to the project

Graph 18. Early Planning and Value
5.0 Field Development Planning

Field development planning is the process of evaluating multiple development options for a field and selecting the best one based on assessing tradeoffs among factors including:

- NPV (Net Present Value)
- Oil and Gas Recovery Volumes
- Operational flexibility and scalability
- Capital vs Operating Cost Profiles
- Technical, operating and financial risks

Graph 19. Oil & Gas Field Development Planning
6.0 Field Development Planning Workflow

Graph 6 below shows a workflow of the main elements of the field development planning process.

A team of reservoir, production, completion, facilities and drilling engineers and geoscientists have to team up to resolve one of the most important steps in the development of the asset: lay out a development plan that should include and project the main elements required to generate optimum hydrocarbon recovery and the best return of the investment (ROI) until abandonment.
Development and Depletion Strategy

- The input of all disciplines, mutual understanding and inter-discipline communication is the key to developing a successful optimum plan.

- In order to come up with an economically viable development and depletion strategy, the team need to address the following main questions:

1. **Recovery scheme:**
   - natural depletion or
   - natural depletion augmented by fluid (water or gas) injections

2. **Well spacing** — number of wells, platforms, reserves, and economics

3. **Type of well:** vertical, slanted, horizontal, multi-lateral

Graph 20A. Field Development and Depletion Strategy

To be successful, a plan must include the input, feedback and collaboration from all disciplines involved in the development of the asset.

Strong communication exchange and synergy between the multidisciplinary groups must be exercised to come up with a good development and depletion plan that is technically and economically productive providing the flexibility to accept improving options in the future.
7.0 Data, Data Management and Analysis

The development of the field requires the acquisition and management of critical geoscience, reservoir and production data to enable the analysis and interpretation required to generate intelligent development decisions.

The data required to acquire and manage includes the following types:

1. Land
2. Geographic
3. Geoscience
4. Well logging
5. Mud logging
6. Well site geology
7. Drilling log
8. Rock properties
9. PVT/Fluid properties
10. Pressure transient
11. Production data
12. HSE (Health, Safety and Environment) data

Graph 21 captures elements of the performance monitoring and data management architecture of a relatively large oil company, this architecture can be used to promote E&P functional data integration, more efficient use of software technology and operations, collaboration between disciplines, advanced analytics, production surveillance, modelling and optimization.

A similar architecture can be replicated at downscaled levels accordingly depending upon oil field and company size.
Graph 21. Data Management

8.0 Reservoir Model (s)

The construction and use of first, an analytical reservoir model and later in the development a numerical model, are standard and critical tools in field development to provide key information on volumes, production rates, wells architecture, well completions and solving a number of fluid flow problems involved in the recovery of hydrocarbons.

A reservoir model is a very important factor in the successful implementation of the FDP. Graph 22 displays the graphical representation of a reservoir model.
Reservoir Model a Standard Tool for FDP

- The success of oil and gas FDP is largely determined by the reservoir: its size, complexity, productivity and the type and quantity of fluid it contains. To optimize a FDP, the characteristics of the reservoir must be well defined. Unfortunately, in some cases, a level of information available is significantly less than that required for an accurate description of the reservoir and estimates of the real situation need to be made.

- Reservoir numerical model is a standard tool in petroleum engineering for solving a variety of fluid flow problems involved in recovery of oil and gas from the porous media of reservoirs.

- Typical application of reservoir simulation is to predict future performance of the reservoirs so that intelligent decisions can be made to optimize the economic recovery of hydrocarbons from the reservoir. Reservoir simulation can also be used to obtain insights into the dynamic behavior of a recovery process or mechanism.

Graph 22. Reservoir Model, an important FDP tool

Graph 23. Reservoir Model Grid (Geological & Numerical)
9.0 Drilling & Completion

Drilling & Completion operations are carried out in the *Exploration, Appraisal and Development* phases of the project to tap the reserves from the reservoir.

Graph 24. Drilling & Completion Operations

Geological studies and seismic surveys can point the way to a hydrocarbon prospect. But there is only one way to know if that prospect contains oil or gas, and that is to drill a well.

Drilling projects are team efforts. They involve a wide range of disciplines and job functions, from geology, geophysics and engineering to operations, support and logistics, safety and regulatory compliance, management and administration.

Drilling project teams are normally collaboration groups of companies that include:

- Operator company owner of the well
- A drilling contractor company that provides the rig and personnel to run it
- One or more service companies that provide specialized expertise and equipment. In offshore projects it may encompass 50 or more companies
The main objectives of drilling operations are:

- Drilling safety, in drilling operations, HSE considerations are the first priority
- The basis of design (BOD) of the well must be honored with all requirements to provide functionality and operational flexibility at any stage of the life cycle.
- Minimize the cost of the well thru drilling efficiency

10.0 Design and Construction of Production Facilities

Graph 25. Construction of Production Facilities

After a well is completed, the produced fluids are separated into gas, oil and water. Special technology has been developed for separating these fluids, for
overcoming associated problems such as corrosion, hydrates and emulsions, and for ensuring the quality of products piped to refineries and end-users.

Oil and gas production facilities are installed on a field in order to make the transportation of the main products possible. Stabilized oil is transported in oil pipelines or shuttle tankers, and dry gas in gas pipelines. The gas is in some cases treated to the requirements of the end user and distributed directly to gas distribution systems.

The design and construction of production facilities is critical to ensure efficient production operations that could support reliability, flexibility and scalability during the life cycle of the field as recommended by the field development plan.

11.0 Production Operations
Field operations involve activities in every stage of the production cycle and everywhere in the oil field from the inflow of hydrocarbons to the wellbore, thru the wellhead, production facilities to the final point of sale.

Graph 26. Production Monitoring
Graph 27. Artificial Lift Design

12.0 Production Optimization

Significant advances in the quality of last generation commercial software packages, well/reservoir modelling methods, database and communications technology, data analytics and petroleum engineering technology are enabling opportunities to optimize reservoir management, reservoir understanding and decisions that result in improved oil/gas recovery factors and minimum production losses.

Graph 28. Well production system characterization

Graph 29. Pressure transient analysis
Graph 30. Rate Transient Analysis

Graph 31. Enhanced Oil Recovery
Graph 32. Integrated Asset Modelling

Graph 33. Production Data Analytics
### 13.0 Keywords and Abbreviations

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<th>Keyword/Abbr.</th>
<th>Description</th>
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<tr>
<td>E&amp;P</td>
<td>Exploration and Producing</td>
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<td>O&amp;G</td>
<td>Oil and Gas</td>
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<tr>
<td>FDP</td>
<td>Field Development Planning</td>
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<tr>
<td>HSE</td>
<td>Health, Safety and Environment</td>
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<tr>
<td>Petroleum Asset</td>
<td>A land property that is going to or has been developed to produce oil/gas</td>
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<tr>
<td>Reservoir</td>
<td>Geological structure where hydrocarbons and/or water are trapped</td>
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<td>Reserves</td>
<td>The estimated amount of oil and/or gas contained in a reservoir</td>
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<td>Reservoir modelling</td>
<td>Construction of the computer model of a petroleum reservoir</td>
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<td>Reservoir surveillance</td>
<td>Methodical monitoring of the performance of a reservoir</td>
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<td>Upstream</td>
<td>The business of explore, appraise, develop and produce oil and gas</td>
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<tr>
<td>Midstream</td>
<td>The business of transporting oil and gas</td>
</tr>
<tr>
<td>Downstream</td>
<td>The business of refining and selling oil and gas products</td>
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<td>Seismic</td>
<td>O&amp;G exploration method of analysis of low frequency waves</td>
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<tr>
<td>Geology</td>
<td>Study of the earth, the materials composing it, and processes acting on it</td>
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<td>Wildcat</td>
<td>An exploratory well to be drilled to prove hydrocarbon reserves</td>
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<td>Petroleum Exploration</td>
<td>The scientific search to find hydrocarbon reservoirs in the subsurface</td>
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<td>Appraisal</td>
<td>Drilling activities to define the volume, shape and limits of the reservoir</td>
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<td>Drilling</td>
<td>Activities to build a borehole to connect to subsurface reservoir fluids</td>
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<td>Completion</td>
<td>Process to case, cement, perforate and configure a well for oil production</td>
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<td>Workover</td>
<td>Process of doing major maintenance or remedial treatment to a well</td>
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<td>Recompletion</td>
<td>Process of modifications to enhance the production capacity of a well</td>
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<tr>
<td>Artificial Lift</td>
<td>Technology to improve by artificial means the production of a well</td>
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<tr>
<td>Well logging</td>
<td>Technology to make a record of the subsurface rocks penetrated by well</td>
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<tr>
<td>Coring</td>
<td>Technology to sample the rocks of interest penetrated by the wellbore</td>
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<tr>
<td>PVT/Fluid Properties</td>
<td>Laboratory analysis of the fluid samples collected from the reservoir</td>
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<tr>
<td>Petrophysical</td>
<td>Related to the physical properties of the rocks (porosity,permeability)</td>
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<td>Mud logging</td>
<td>Real time analysis and monitoring of return fluids while drilling a well</td>
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<td>Pressure transient</td>
<td>Recording of pressures when a well is shut-in or is producing or injecting</td>
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<tr>
<td>Nodal Analysis</td>
<td>Analysis of production rate and pressures of a well at different depths</td>
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<tr>
<td>Well testing</td>
<td>Recordings of pressures as result of changes in production rates of a well</td>
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<td>EOR</td>
<td>Enhanced Oil Recovery or practices to enhance final recovery of a field</td>
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<td>Play</td>
<td>Group of oil fields or prospects in the same region under similar geology</td>
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<td>Lead</td>
<td>Geological anomaly that still does not qualify as a prospect</td>
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<tr>
<td>Prospect</td>
<td>Geological anomaly identified by team as likely to produce oil or gas</td>
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<tr>
<td>Oil field</td>
<td>Area from which vast amounts of oil/gas are extracted from subsurface</td>
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