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Real Options in Energy: The Gas-to-Liquid Technology with Flexible Input

Real Options Valuation in the Modern Economy
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Introduction and Presentation Outline

- **The current "*high oil prices*" and the growing *environmental constrain* have motivate investment in alternative clean fuels.**
  - **One important alternative is GTL (gas-to-liquid) also known as XTL (X-to-liquid, where X can be gas, liquid or solid inputs) that generates high-quality hydrocarbon liquids: *ultra-clean diesel*, *ultra-low smoke-point kero-jet fuel*, *high-yield naphtha*, *high-quality lubricant*, etc.**
- **Petrobras Research Center is developing two real options projects with Brazilian universities related with GTL valuation:**
  - **PUC-Rio (started in 2006): real options valuation of GTL/XTL projects considering input and output flexibilities.**
    - **Three M. Sc. dissertations in March 2007, but project is still running including two doctoral students. First software version/partial results.**
  - **UFMG (started in 2007): real options valuation of R&D portfolio with focus on GTL & Gasification different technology routes.**
    - **There are many specific R&D projects: alternative GTL equipments, iron and cobalt catalysts, flexible gasification, biomass gasification, etc.**
  - **This presentation describes the GTL flexibilities & PUC-Rio project.**

Fischer-Tropsch Technology

- Gas-to-Liquid (GTL) process is based on the Fischer-Tropsch (FT) chemistry technology, which dates back to the early 1920s.
- This process can be divided into three sub-processes:

Synthesis gas formation: $CH_n + O_2 \xrightarrow{\text{Catalyst}} \frac{1}{2} n\,H_2 + CO$

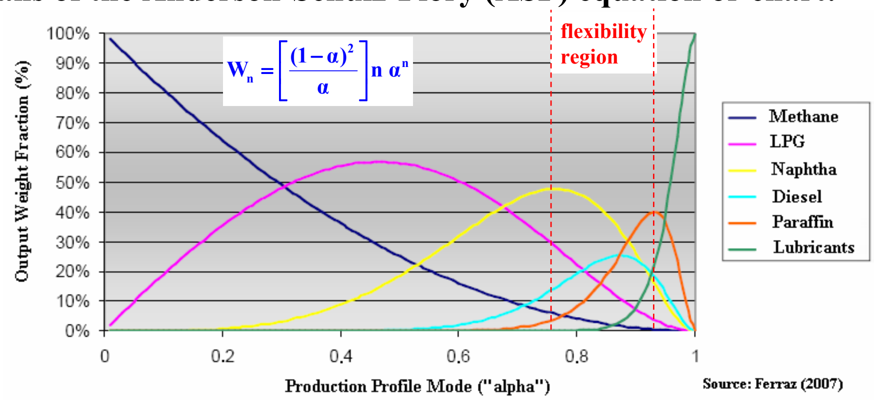
Fischer-Tropsch reaction: $2\,H_2 + CO \xrightarrow{\text{Catalyst}} -CH_2- + H_2O$

Refining process: $-CH_2- \xrightarrow{\text{Catalyst}}$ diesel, jet-fuel, lubricants, etc.

- In short, a *gasification unit* converts some input to synthesis gas; the *FT unit* + *hydrocracking (refining) unit* convert synthesis gas to ultra-clean liquid hydrocarbons such as diesel and jet-fuel.
- The product spectrum depends on *temperature*, *catalyst*, *pressure*, etc. So, we have some *output flexibility* by changing catalyst, etc.
  - Ex.: "Gasification News" (April 2006) about Qatar GTL Plant: "*Shell … manager Ralph Cherillo explained that GTL diesel output could vary between 40-70% 'depending upon how markets develop'*".

Output Flexibility & Anderson Schulz Flory

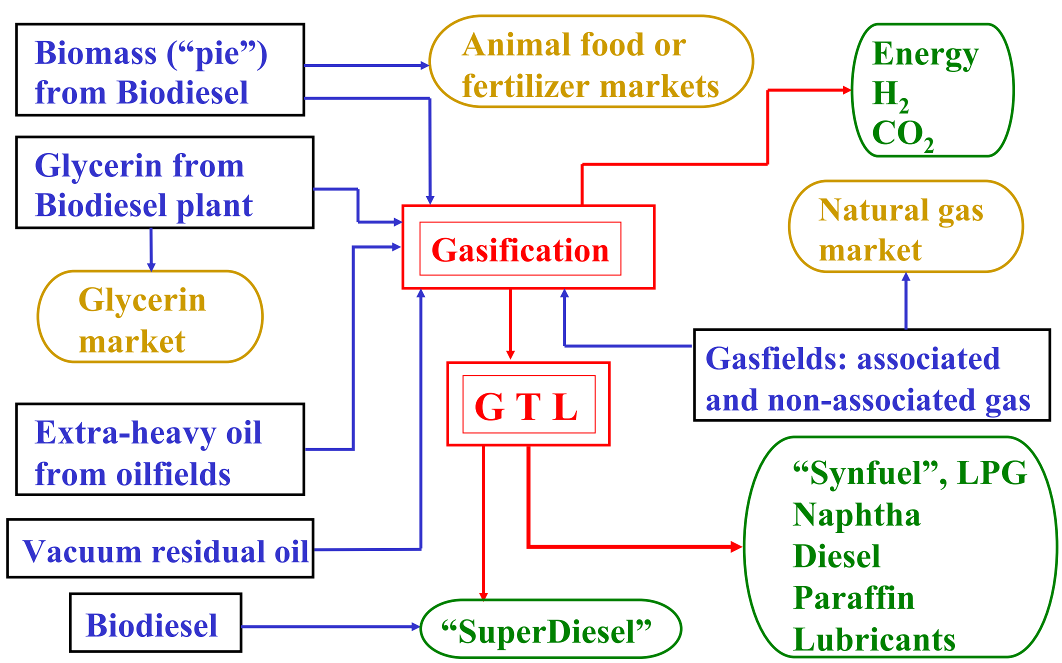
- There are output flexibilities in both FT unit and refining unit.
  - Refining unit: HCC (*hydrocracking*), for more diesel production; and HIDW (*hydrodewaxing*), for more lubricants and paraffin.
- The FT reaction generates a chain-lenghts of products, from methane (C1) to waxes (> C33). There is a flexibility region.
  - The (theoretical) chain length distribution can be described by means of the Anderson-Schulz-Flory (ASF) equation or chart:



Inputs Used in GTL Plants & Flexibility

- **There are many different inputs being used in existent or planned GTL plants. This suggest R&D for input flexibility.**
  - **The first industrial units in Germany and South Africa used *coal* as input to generate synthesis gas. It's also named *coal-to-liquid*.**
  - **Nowadays, *natural gas* has been the main input for new units, in order to leverage the value of remote gas fields (*stranded* gas).**
  - ***Extra-heavy oils* and *shale oil* are other input options for GTL plants, which are under development (e.g., oil sands in Canada).**
  - ***Biomass* is another input option, very important for countries like Brazil, but biomass-to-liquid technology needs a lot of R&D.**
  - **Even better could be a *flexible input technology*, at least partially.**
- **At Petrobras, we are considering many different inputs and plants with input flexibility at some cost. See next slide.**
  - **Gasification unit represents 50% or more from the total investment. So, the cost of flexibility is very high.**
    - **Is flexibility value enough to face this high cost (high exercise price)?**

Gasification + GTL: Input & Output Options



Leveraging Business with Input Options

- **The GTL project with input flexibility is more valuable for <u>integrated oil/energy firms</u> because leverage different business areas. For Petrobras, GTL leverage the business areas below:**
  - **Natural Gas: it creates an *interruptible market* for the natural gas, creating demand when thermo-generators are not operating.**
    - **For some oil companies, GTL represents a way to *monetize stranded gas fields*. In Brazil, we use mainly hydro-energy, with gas-fired thermo-generators used seasonally. So, we need interruptible market.**
  - **Biodiesel: it creates a *new market for co-products* from biodiesel units. The co-products are *crushed-grains biomass* (biodiesel pie) and *glycerin*. These products have limited alternative markets.**
  - **E&P (exploration & production): creates an economic alternative for *oilfields with extra-heavy oil*. Traditional refining needs blend with lighter oil and produce heavier derivatives like heating oil.**
  - **Refining: creates an economic alternative for *vacuum residual oil* from vacuum distillation units. Nowadays it has very low value.**

Payoff Function and Input Efficiencies

- **Every period (quarterly) we decide the *optimal operational mode* (*input-output combination*) to maximize the period profit.**
- **Let π_t be the *payoff function* at quarter t. This payoff is the operational revenue net of operational costs and taxes.**
- **This payoff function depends on the input efficiencies:**
  - **The FT average efficiency in converting synthesis gas into ultra-clean hydrocarbon liquids is ~ 700 Nm^3 syngas/bbl of liquid.**
  - **The synthesis gas average efficiencies in converting different inputs into synthesis gas is displayed in the table below:**

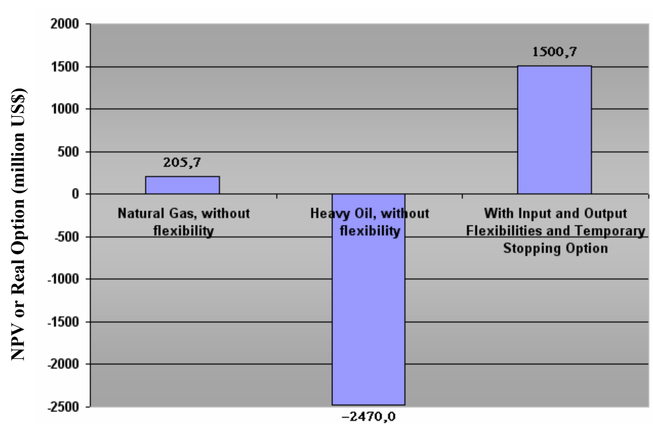
Input	Efficiency: metric tons to generate 1 Nm^3 of syngas
Natural Gas	3,450
Extra-Heavy Oil	2,600
Biomass (castor bean)	1,570
Vacuum residual oil	2,590

Flexible GTL Valuation with Real Options

- **The GTL flexibility is modeled as a *sequence of European call options on maximum of several risky assets*:**
  - **At each period t_i (quarter) the GTL plant choose the *input-output combination* (*operation mode*) that maximizes the profit at t_i.**
    - **At each quarter, we have an expiring (European) new option: if we don't exercise any input-output mode, GTL *temporally stops operation*.**
    - **These input-output assets follow specific and correlated stochastic processes. We are using GBM with reflecting barriers, mean-reversion and mean-reversion with jumps.**
  - **The *payoff function* is a very complex issue, because we need detailed information from very different areas and because there are a very large number of possible operation modes.**
- **We have performed *Monte Carlo simulations for the risk-neutral stochastic processes* of all possible input and output prices.**
    - **Problems: difficulties to estimate *many stochastic process parameters* (lack of data) and even more difficulties *to estimate dependence* between these many inputs and outputs. *Correlations are very unstable*.**

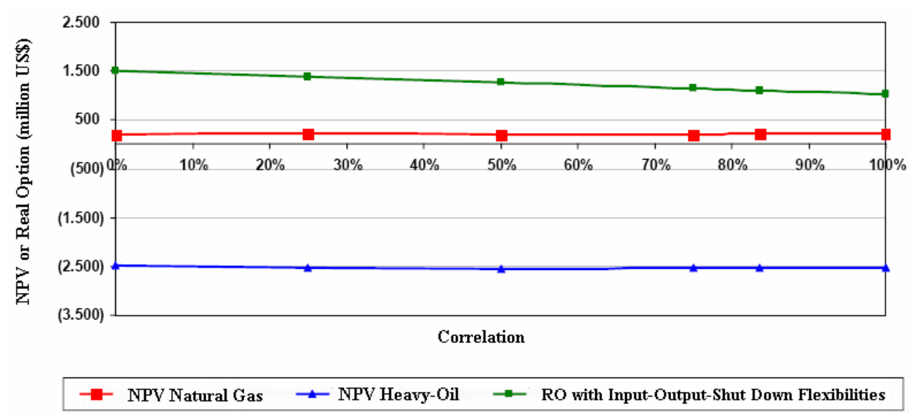
Preliminary Result: Partial Flexibility

- **We analyze first a GTL plant of 35,000 barrels per day (bpd).**
  - **Partial input flexibility: only natural gas x heavy oil inputs**
  - **Partial output flexibility: only on "alpha" ranging from 0.78 to 0.96 with 4 outputs (naphtha, diesel, paraffin, and lubricant).**
  - **Considered the temporary stopping option.**



Correlation Effect on Partial Flexibility Case

- **The case presented before was without correlation.**
- **With positive correlations, the input & output flexibility values decrease. In this case the option of temporary stopping becomes more important. The figure illustrates this correlation effect.**



Conclusions

- **We are seeing a "boom" in GTL projects due to the nowadays "*high oil prices*" and the growing *environmental constrain*.**
  - **The demand for *ultra-clean fuels* is growing everywhere and GTL is one of best alternatives. Many oil & energy companies has started investments at both industrial and R&D/prototype scales.**
  - However, the real options literature for GTLs projects practically is non-existent. There are many flexibilities that can leverage the project.
- **This GTL project with *input flexibility* is particularly valuable for integrated oil/energy companies, allowing synergistic gains**
  - Input flexibility leverages many business areas, from upstream (E&P) to downstream (refining), including biodiesel units.
- **We started two real options projects with universities.**
  - PUC project is considering many operational flexibilities, given one technology. UFMG is valuating R&D portfolio of GTL technologies.
  - But this project is very complex, mainly to estimate stochastic processes parameters and correlations or other dependence metric.
- **Thank you very much for your time!**

APPENDIX

SUPPORT SLIDES

Real x Risk-Neutral Stochastic Processes

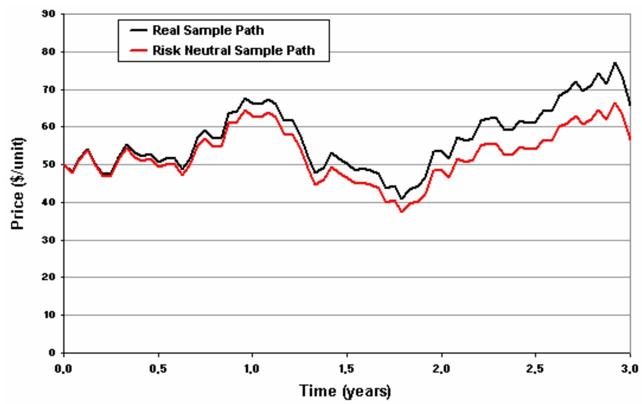
- **We can simulate either the real stochastic process or the risk-neutral stochastic process. The difference is a risk-premium π subtraction from the real drift α.**
  - **Risk-neutral simulation is used for derivatives pricing because we don´t know (or is hard) the derivative´s risk-adjusted discount rate.**
    - **So we penalize the drift and so the distribution (lower mean), a *martingale change of measure*, in order to use the risk-free discount rate for the derivative.**
  - **Real drift = α $\Rightarrow$ Risk-neutral drift = $\alpha - \pi$ = $r - \delta$**
- **For the geometric Brownian motion (GBM), used in Black-Scholes-Merton, the real and risk-neutral GBMs are:**

$$\frac{dP}{P} = \alpha \, dt + \sigma \, dz$$ ⇒ **Real GBM.**

$$\frac{dP}{P} = (r - \delta) \, dt + \sigma \, dz'$$ ⇒ **Risk-Neutral GBM.**

Real x Risk-Neutral Stochastic Processes

- A typical sample-paths for both real and risk-neutral GBMs (with the same stochastic shocks) is showed: the difference is π.



- While risk-neutral simulation is used to price derivatives, real simulation is useful for *planning purposes* (e.g., if wait and see is optimal, what is the probability of option exercise?) and for *risk-analysis* (e.g., value-at-risk estimation) & hedging.

Equations for Stochastic Process Simulation

- Some stochastic processes (not all) admit *exact discretization*, i.e., numerical precision independs of the time-step length.
  - This is particularly useful for real options, because we work with long time to expiration, e.g., we can use $\Delta t = 1$ year without losing precision.
- The exact discretization equations to simulate both the real and risk-neutral geometric Brownian motions are, respectively:

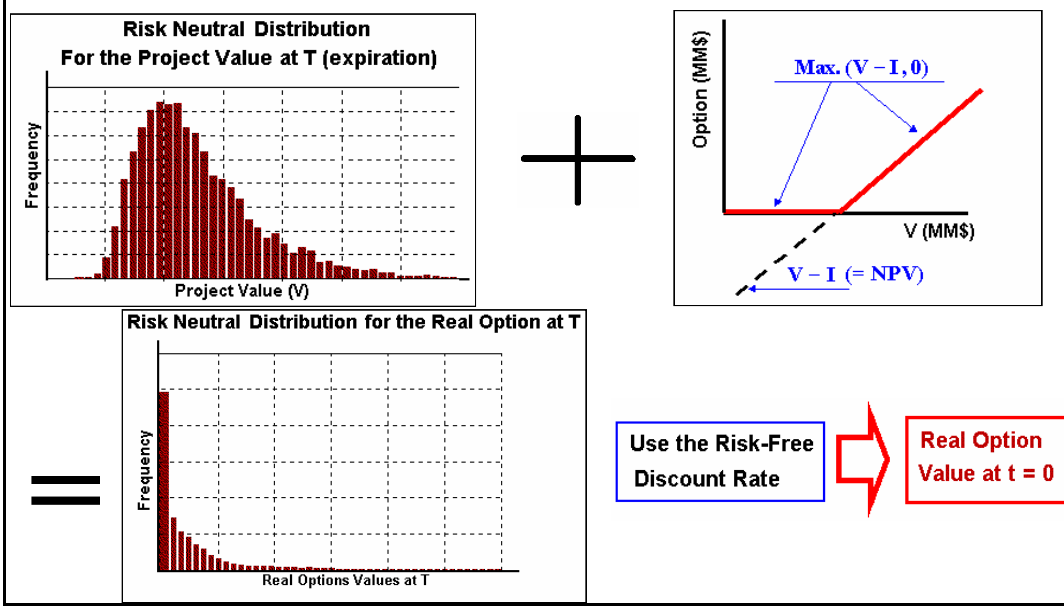
$$P_t = P_0 \exp\{(\alpha - 0.5\,\sigma^2)\,\Delta t + \sigma\, N(0, 1) \sqrt{\Delta t}\,\}$$

$$P_t = P_0 \exp\{\,(r - \delta - 0.5\,\sigma^2)\,\Delta t + \sigma\, N(0, 1) \sqrt{\Delta t}\,\}$$

  - The difference is the drift. Sampling N(0, 1) n times, we get n outputs P_t.
- Stochastic processes with exact discretizations include mean-reversion. See: www.puc-rio.br/marco.ind/sim_stoc_proc.html
- We can simulate the entire GBM path or only at the expiration (European options). The European options can be calculate by simulation and compared with the Black-Scholes analytic result.

European Call Valuation by Simulation

- If the underlying asset V is the operating project and I is the exercise price (investment), the visual equation for European real option is:



European Real Options by Simulation

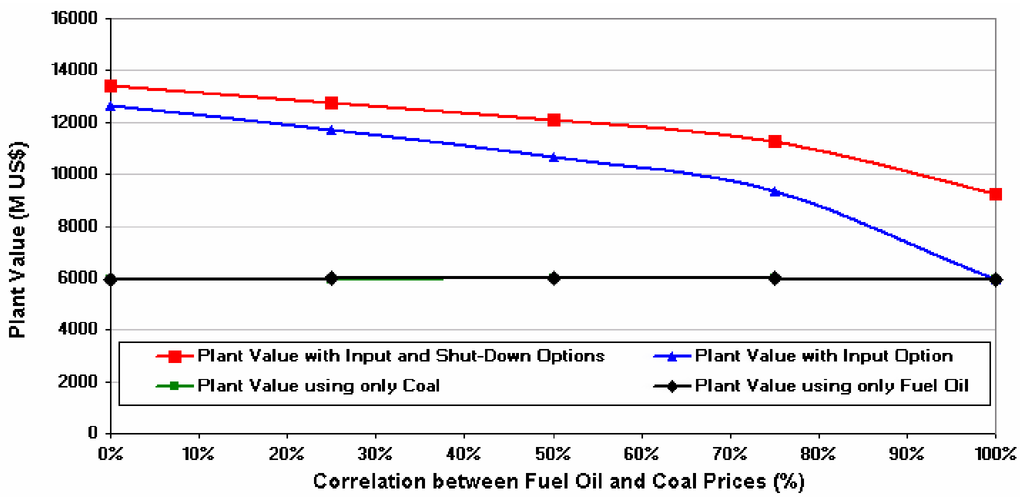
- There are many practical problems that we can apply the European option valuation by Monte Carlo simulation, mainly ***sequence of European real options*** (e.g., calls on a *basket* of assets).
  - This is best way to valuate projects with flexible inputs and/or flexible outputs, because at specific decision dates (ex.: every month) the firm has to decide the best mix of inputs and outputs for the next operational period (to maximize the payoff, e.g., for the next month).
  - We´ll see some real life cases. The idea is to simulate the risk-neutral stochastic processes for the inputs and outputs prices, which are not necessarily GBMs (e.g., could be mean-reversion with jumps).
  - In addition, the exercise payoff function can be very complex, with many real life details (e.g., one input is not available in the first year or in certain months; a minimum quantity of one input must be used due to a contract commitment, etc.).
  - MC simulation plugged into a spreadsheet is very flexible to handle multiple/complex stochastic processes and complex payoff functions.

Flex-Fuel Plant with & without Shut-Down Option

- **One firm is going to invest in a energy consuming plant. There are three energy technology alternatives:**
  - **Plant using only oil fuel; plant using only coal; and flex-fuel plant, i.e., plant with (costless) input flexibility (oil or coal).**
  - **We'll see also the flex-fuel plant with costless *shut-down option*.**
- **What are the plant values in each case considering that oil fuel and coal follow correlated mean-reversion processes?**
  - **The answer gives an idea of the maximum value that a firm is willing to pay for the (more expensive) flex-fuel technology.**
  - **Positive correlation decreases the option value, but it is necessary a (unlikely) very high correlation for the input option be negligible.**
- **What is the effect of the costless shut-down option?**
  - **This option can be very important. There are contract implications.**
- **<u>MC simulation answers easily these questions</u>.**
  - **This is a *sequence of European options* (choose the maximum payoff at each operational decision date). The next slide shows an example.**

Flex-Fuel Plant, Correlation & Flexibility Value

- **The chart shows a numerical example with mean-reversion for both oil fuel and coal, for different correlations.**
  - **The chart numerical values were obtained with MC simulation.**
  - **Plant values using only one input (without options) are ~ the same.**

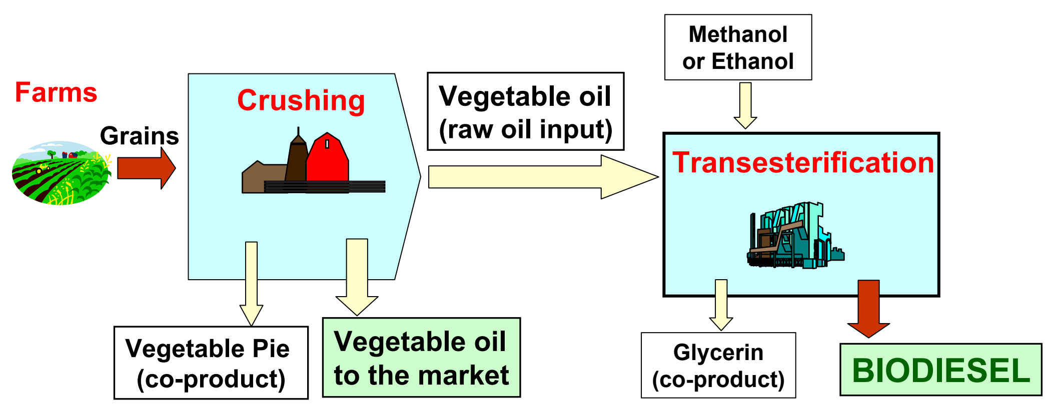


Real Life Application: Biodiesel Project

- Biodiesel fuel for diesel engines has low emission advantage and is produced from vegetable oil or animal fat by the chemical process of transesterification with alcohols.
  - Commercial biodiesel production in US started in late 1990's.
  - Biodiesel as fuel additive, will be obligatory in Brazil in 2008.
- We are considering only multi-vegetable biodiesel plants.
  - So, there is *input flexibility* to choose the vegetable that maximize the project value. Real options is the natural tool to evaluate this.
  - Some Braziliam vegetable considered were soybean, cotton, castorbean, pinion (jatropha curcas), uricury syagrus palm, etc.
  - In addition, there is input reagent flexibility: methanol or ethanol.
  - The vegetables price (and their oils) and the alcohols are commodities and oscillate in the market.
    - We use stochastic processes to model these uncertain prices.

Biodiesel Plant, Inputs and Outputs

- A biodiesel plant has two main units:
  - The *crushing* unit, the vegetable grain is crushed generating raw oil and residue (pie). Raw (vegetable) oil is the main revenue.
  - The *transesterification* unit, that uses raw vegetable oil (cost) and reagent (alcohol), generating biodiesel plus residuals .
  - The figure below shows the biodiesel plant and its inputs/outputs.



Biodiesel Project: The Value of Input Flexibility

- Petrobras biodiesel business format: owner of *both units*, (crushing and transesterification). Why crushing unit?
  - In order to guarantee the raw oil quality; and
  - In order to *capture the flexibility* (real option) *value* in choosing the vegetable grain input.
- This flexibility is modeled as a *sequence of European call options on maximum of several risky assets*:
  - At each period the biodiesel plant choose the vegetable(s) and reagent combination that maximizes the profit in that period.
  - We performed Monte Carlo simulations for the stochastic processes of the input prices (several grains, vegetable raw oils, methanol, ethanol) and the output prices (biodiesel = diesel, residues, and vegetable oils to the market).
    - Difficulties to estimate some stochastic process parameters (lack of data).
  - The flexibility (real options value) added a significant and decisive value for biodiesel project economic feasibility.