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Enhanced Biomass-to-Liquids – Project Development and Modeling

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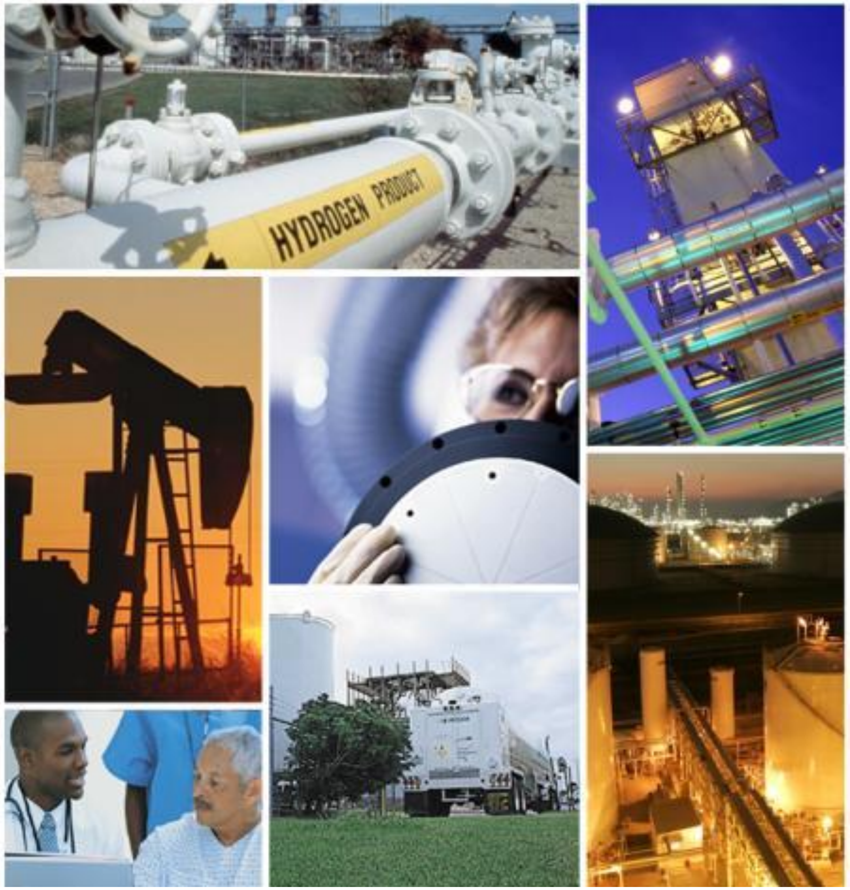

Outline

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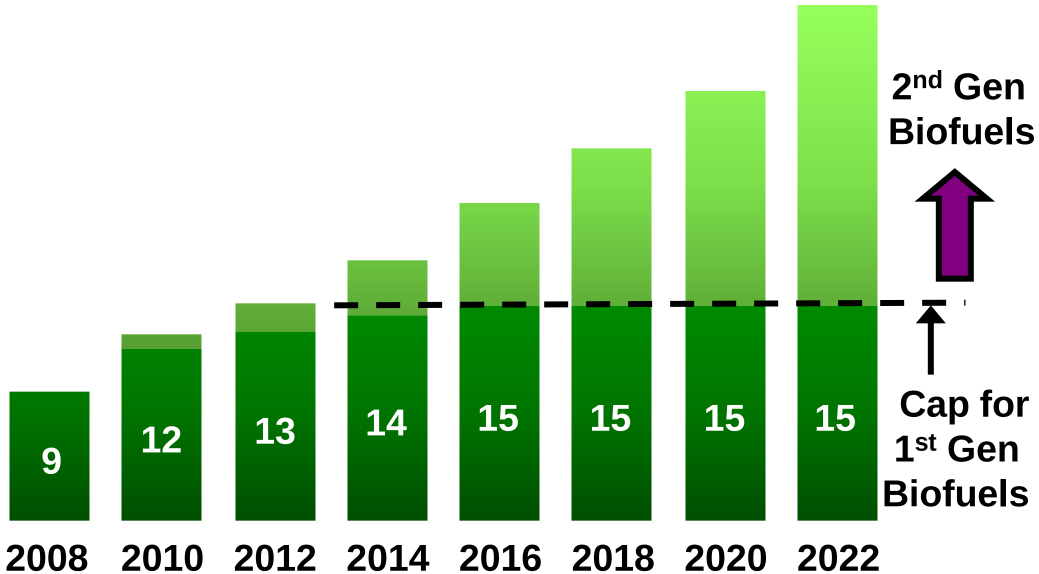
- Biomass-to-Liquids
- Modeling Approach for Project Development
- Key Modeling Issues
- Practical Considerations in Project Development
- Vision of Better Modeling Tools

Market

Renewable Fuels Standard Requirements
(Billion Gallon Ethanol Equivalents)



Source: Energy Independence and Security Act of 2007

- *1st Gen – Corn ethanol*
- *2nd Gen – Ethanol, diesel from non-food sources*

- **Drivers**
  - **Domestic energy independence**
  - **Lower CO_2 footprint**
- **Tax credits**
- **Significant project development activity**

Next Generation Biofuels: Different Pathways Bring Different Opportunities

Today

Vegetable oils, Animal fats, Algal lipids (N_2) → Hydroprocessing (H_2) → Hydrocarbons, Renewable Diesel

Issue: Limited feedstock supply

Near term

Sugars, Energy crops, Agricultural residue (N_2), Woody biomass, MSW

- Biochemical → Fermentation or Digestion (H_2) → Alcohols, Organic Acids, & Hydrocarbons
- Thermochemical → (O_2) Pyrolysis and/or Gasification (H_2) → Alcohols, Organic Acids, & Hydrocarbons

Long term

Algae (CO_2 for algae growth) → Oil Extraction & Hydroprocessing (H_2) → Renewable Diesel

Gasification offers better potential for near-term commercialization

Biomass to Liquids – Baseline

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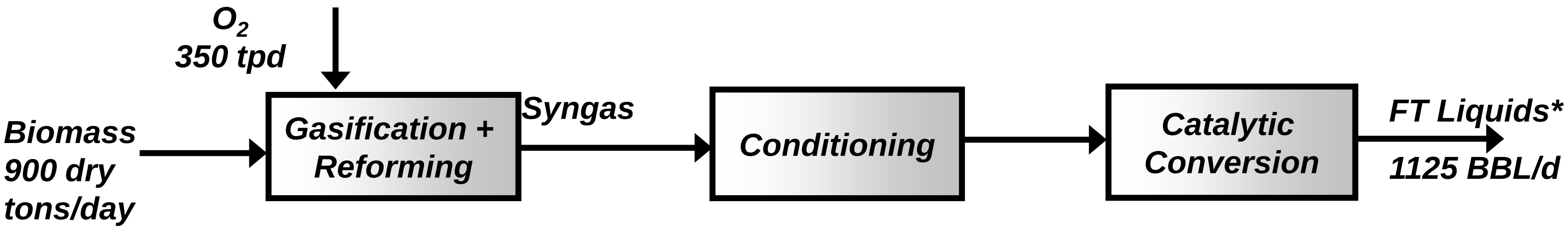
Gasification, Catalytic Methanol/MTG / Fischer-Tropsch liquids
Commercial Technologies



** 75% diesel, 25% naphtha*

Non-gasification approaches are also under development.
Technical /Economic Viability Uncertain
Needs demonstration on commercial scale

Low biofuel yield significantly impacts economic viability

** Adapted from "Wood to Wheels –The Challenges of Large Scale Forest Biomass to Liquids Conversion", R. Holford, International Biomass Conference, St. Louis, May 3rd 2011.*

Enhanced Biomass-to-Liquids*

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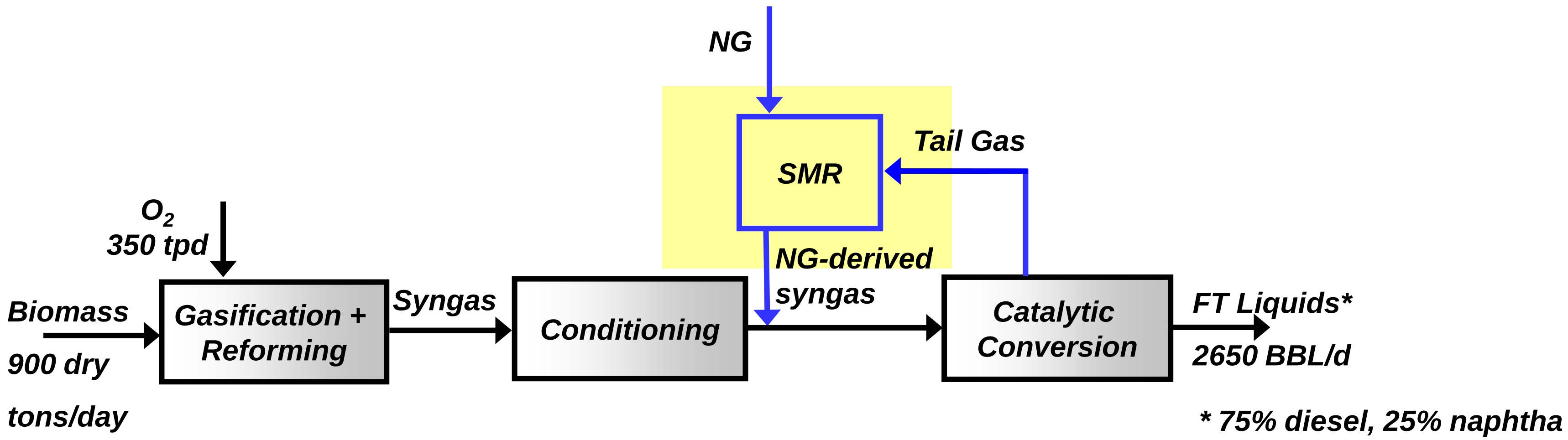
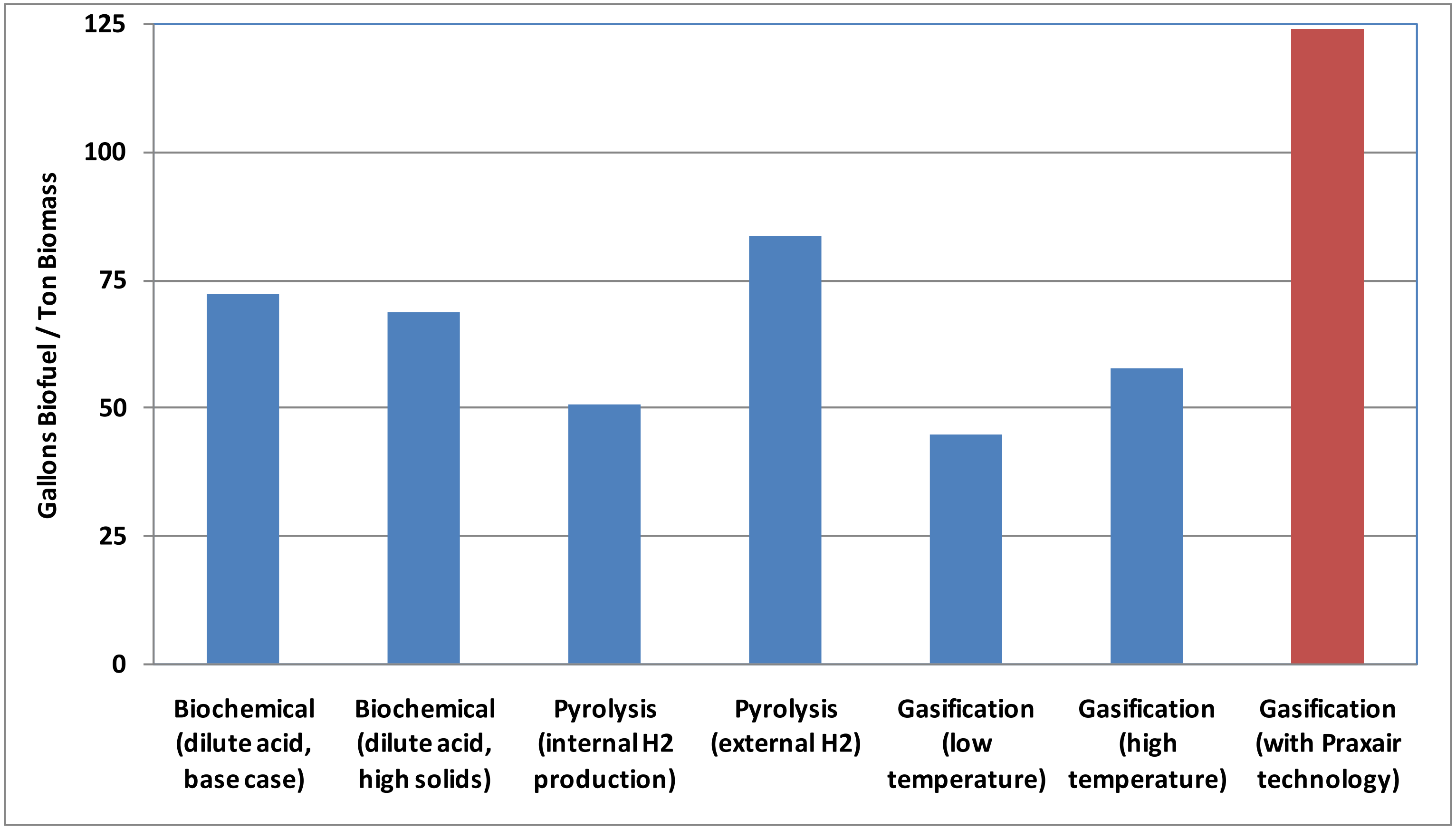


- Maximizes yield with addition of H_2-rich syngas
  - Yield increase limited by lifecycle GHG emission constraint
- Increases overall system availability
- Enables start-up with SMR versus gasifier
- No need for a startup boiler
- Improves economies of scale for syngas to liquids section

~2.5X Yield versus straight Biomass to FT Liquids

** US Patent Application 2011/0218254 A1*

Comparison of Biofuel Production Pathways*



Praxair's technology significantly increases yield of gasification pathway

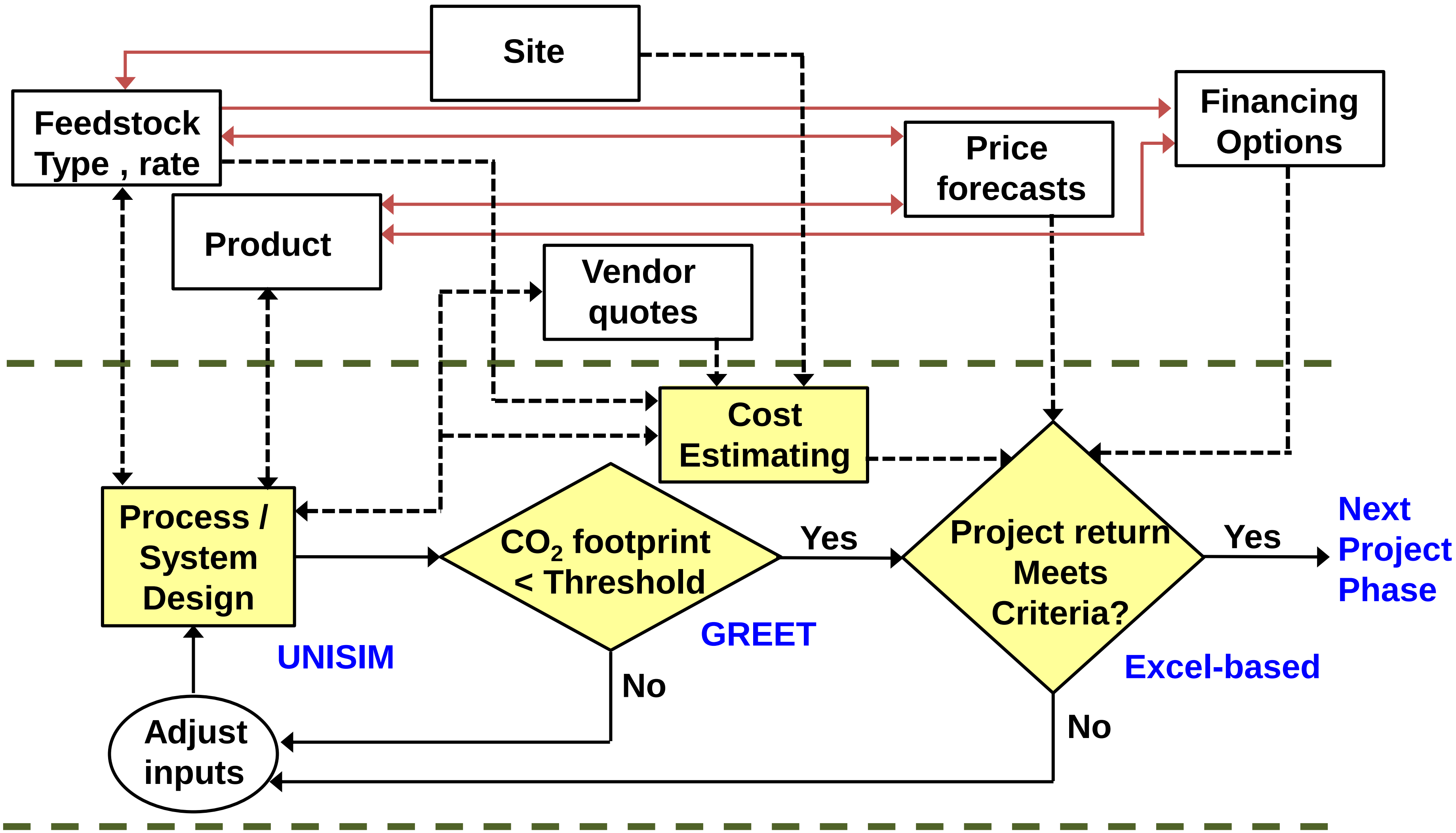
**Adapted from "Techno-economic comparison of biomass-to-transportation fuels via pyrolysis, gasification and biochemical pathways", Anex RP et al., Fuel (2010)*

Project Development / Analysis

- Site selection
- Biomass feedstock definition
- Product slate definition
- Process/system design
  - Heat and material balance
  - Utility and emissions
- Estimation of lifecycle GHG emissions
- Vendor quotes for sub-systems
- Cost estimation
- Feedstock and product pricing forecasts
- Project Economics
- Business Planning
- Project risk assessment
- EPC contractor interfacing

Modeled each item independently and iterated as required to optimize project

Current Modeling Approach



Key Modeling Issues

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- No common platform
- Manual interfaces between platforms
- Variety of inputs – process, financial, regulatory
- Complexity drives use of less rigorous shortcut methods
- Rigor also limited by availability of sub-system models, e.g.
  - Gasifier
  - FT Liquids and Liquids Upgrading
- Capital cost estimation
  - Always a challenge for first-of-a-kind plants
  - Mechanism for using vendor quotes not available
  - Interpretation of level of accuracy and adjustment for contingency requires a tool like the RAND analysis*
  - Limited database for costing software

Need for a unified modeling tool to assist with project development on a case-by-case basis

** Understanding cost growth and performance shortfalls in pioneer process plants. E. Merrow, K. Phillips and C. Myers, RAND Corp.; 1981. Report No.: RAND/R-2569-DOE.*

Site

- **Selection Criteria**
  - **Site area**
  - **Proximity to market**
  - **Regional construction productivity**
  - **Feedstock availability and pricing**
  - **Transportation of feedstock to site**
  - **Availability of utilities**
    - Electrical power
    - Water / wastewater treatment
    - Natural gas
  - **Potential site synergies**
- **Selected existing industrial facility in Southeastern US**

Key factors – Feedstock availability and site synergies

Biomass Feedstock Definition

- **Candidates**
  - **Agricultural residue, e.g. corn stover**
  - **High energy crops, e.g. switchgrass**
  - **Woody biomass, e.g. forest residue, wood chips, wood logs**
  - **Municipal Solid Waste**
- **Selection criteria**
  - **Cost of feedstock delivered to site**
  - **Continuous and abundant supply / no seasonal disruptions**
  - **Minimum variability**
  - **Infrastructure for collection and transportation**
- **Selected wood chips – 900 tons/day @ $ 60 - $ 80 per bone dry ton**

Feedstock rate constrained by delivered price

Product Slate Definition

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- **Candidates**
  - **Methanol / Methanol-to-Gasoline**
  - **Ethanol**
  - **FT Liquids – Diesel, naphtha, waxes**
- **Selection criteria**
  - **Product value**
  - **Complexity of product synthesis**
  - **Fungibility with existing fuel infrastructure**
  - **Forecasted demand and pricing**
- **Selected FT Liquids (diesel, naphtha) – 2650 BBL/d production rate**

Production rate limited by lifecycle CO_2 emission constraint

Process/System Design

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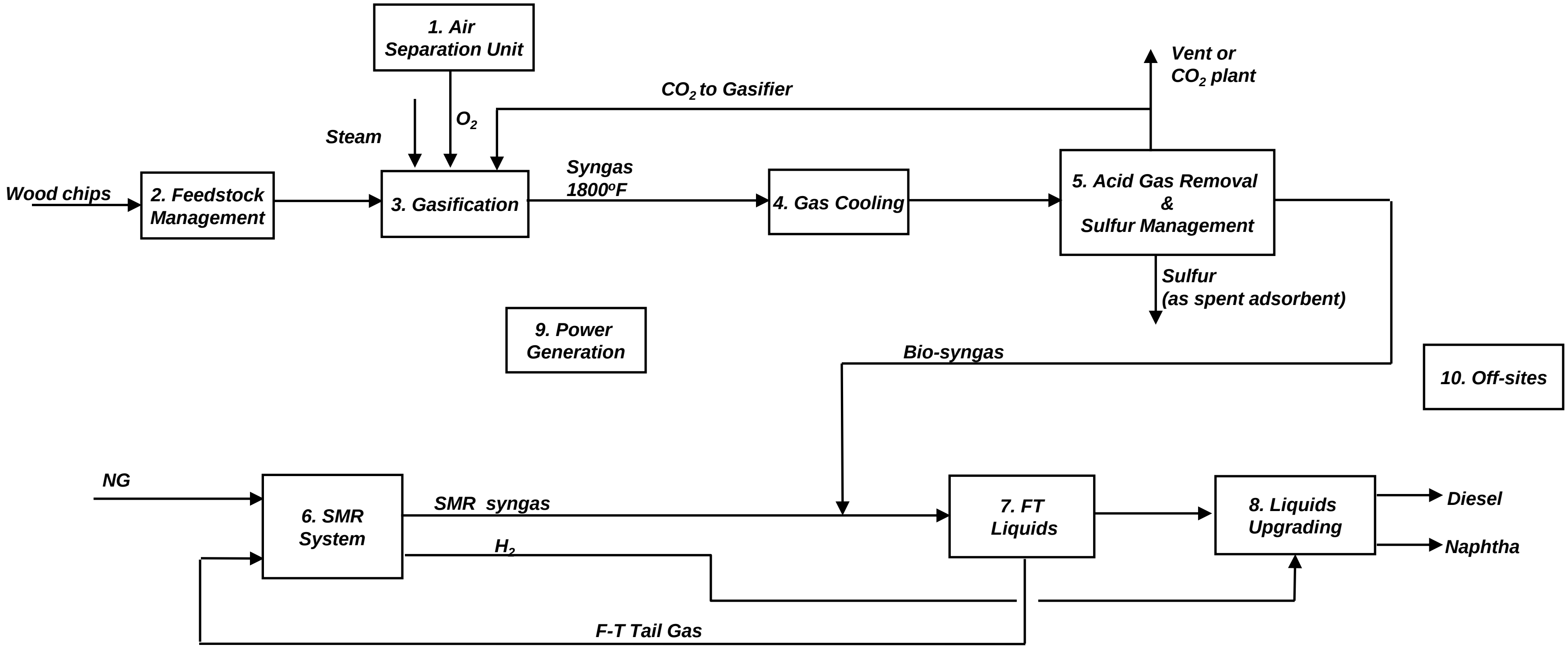
- **Classical flowsheet synthesis**
  - **Heat/Material/Utility/Emissions defined for 900 dry ton/day biomass**
  - **Multiple process/system configurations evaluated within UNISIM**
    - Air Separation Unit
    - Feedstock Management
    - Gasification
    - Gas Cooling
    - Acid Gas Removal and Sulfur Management
    - SMR (Steam Methane Reforming) System
    - FT Liquids
    - Liquids Upgrading
    - Power Generation
    - Off-sites
- **Selection criteria**
  - **Risk profile**
  - **Technology readiness**
  - **Ability to bid project immediately**

Block Flow Diagram



- Novel combination of existing technologies
- Optimized facility for yield while satisfying CO_2 footprint constraints

No technology demonstration required – Selected for next project phase

Lifecycle GHG emissions

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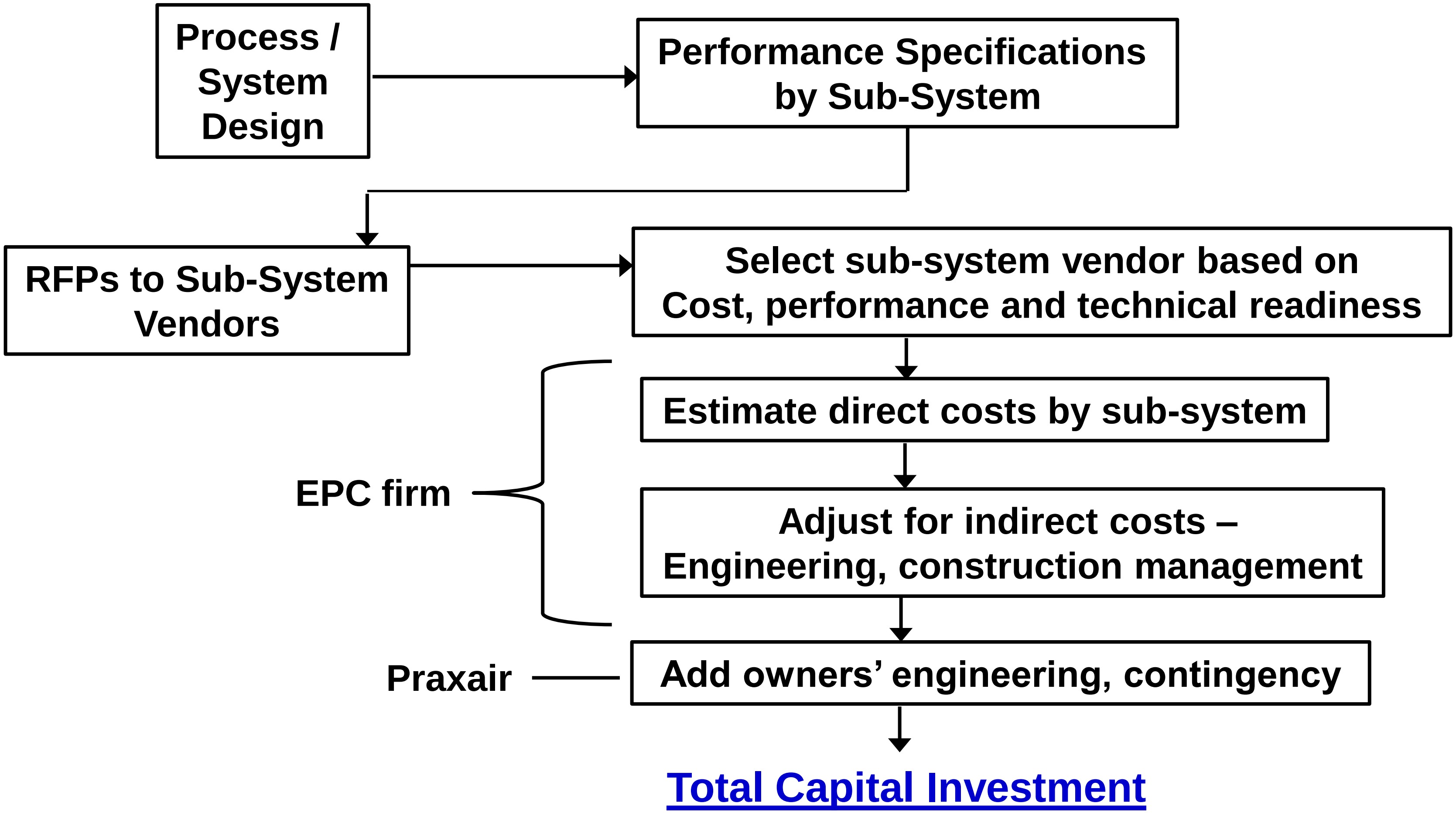
- **Estimate reduction in lifecycle greenhouse gas emissions versus petroleum derived fuels**
  - **CO_2 footprint**
- **Renewable Fuels Standard**
  - **60% reduction in GHG emissions – cellulosic biofuels**
  - **50% reduction in GHG emissions – advanced biofuels**
- **Modeling platform – GREET (Greenhouse gases, Regulated Emissions and Energy use in Transportation) model from Argonne National Lab**

Cellulosic RIN credits most valuable

Methodology for Capital Cost Estimate



Opportunity to automate process for estimating capital costs

Project Economics

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- **Inputs**
  - Capital cost
  - Production capacity
  - Availability estimate
  - Fixed and operating costs
  - Feedstock and product pricing forecasts
  - Financing options
  - Construction period
  - Project life
  - Process performance
- **Modeling tool**
  - Excel-based DCF model
- **Outputs**
  - Revenue and OP projections
  - IRR
- **Project selection criteria**
  - Risk
  - Financing considerations
  - IRR

Compare with crude oil price forecast

Current Modeling Approach …

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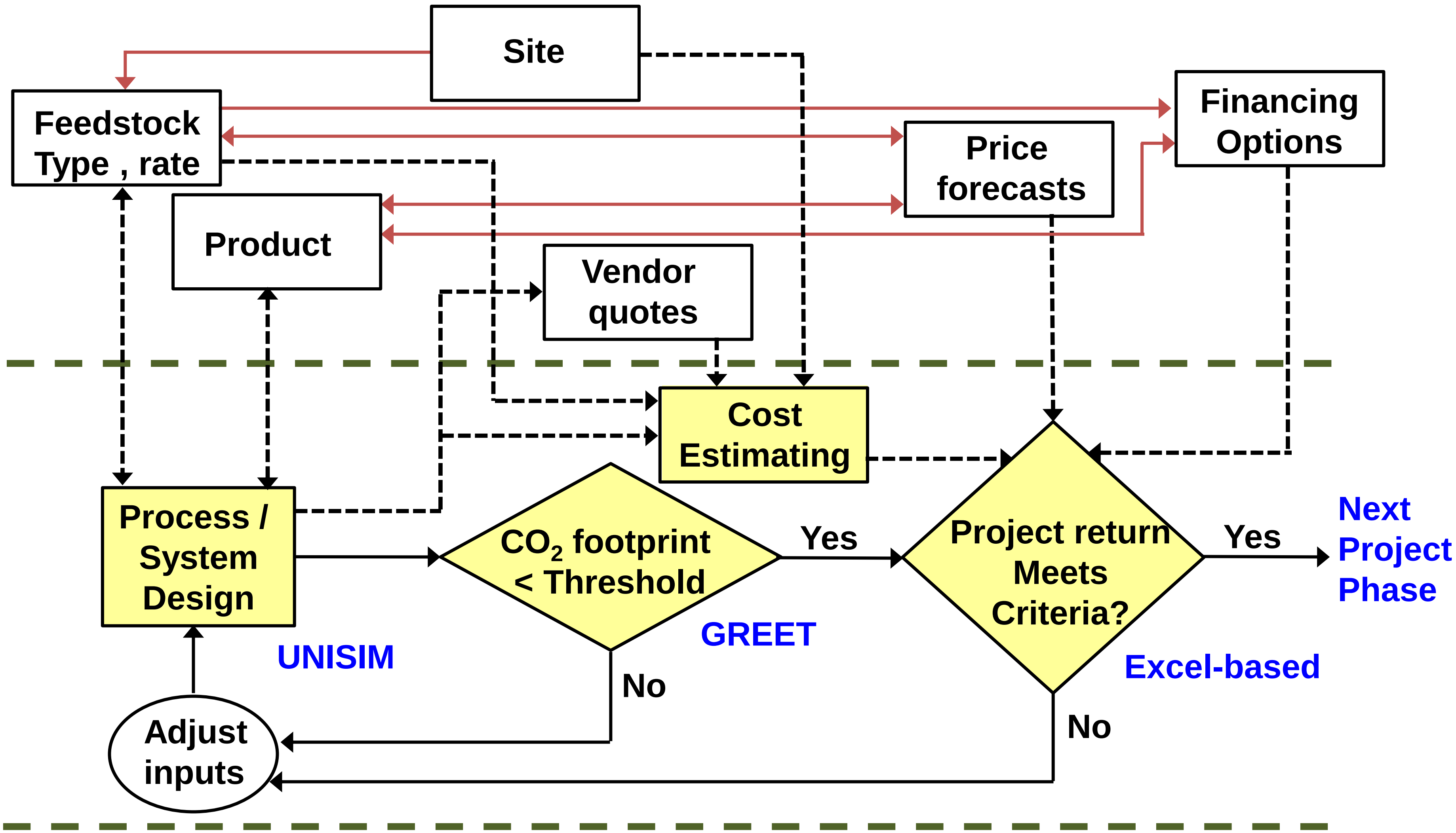
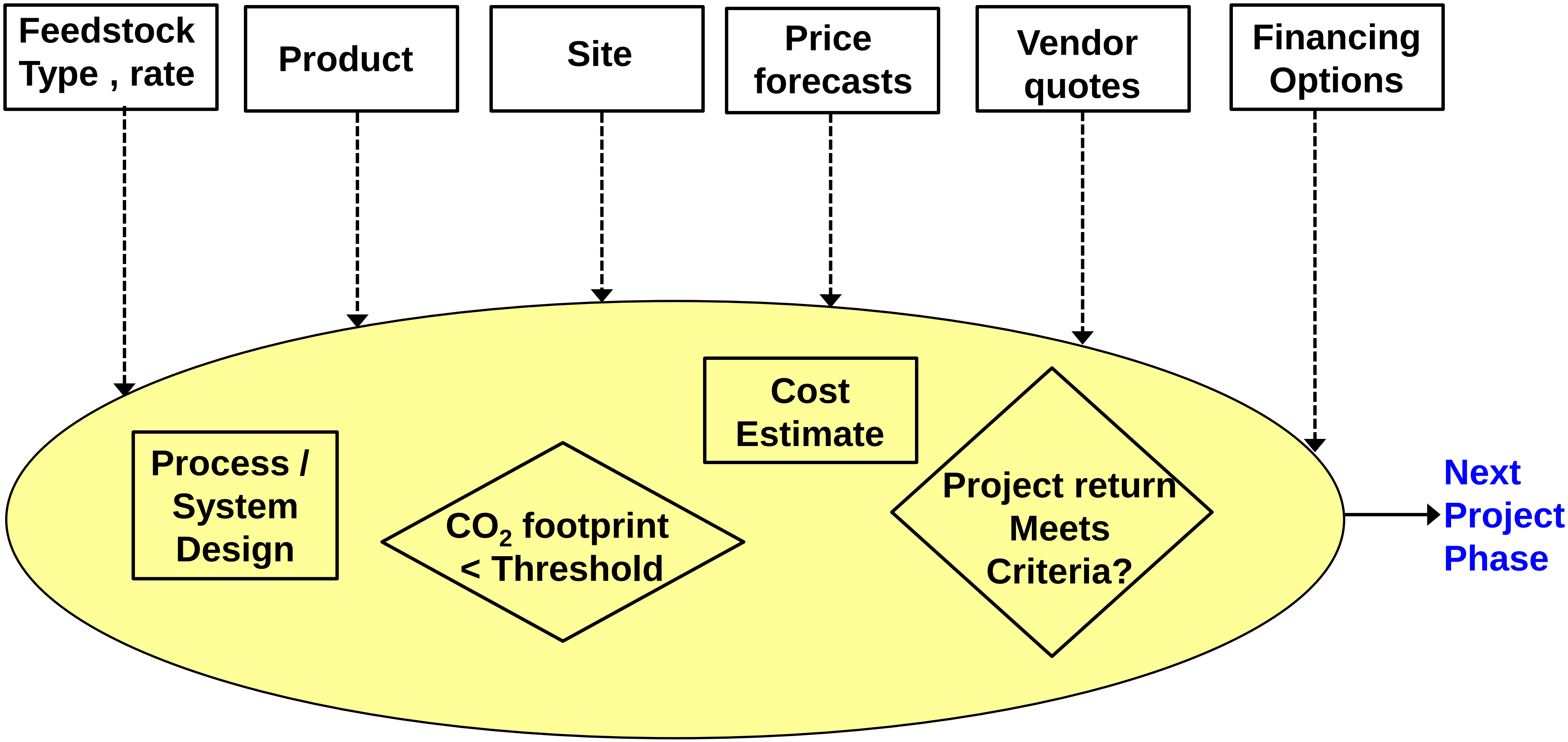


With Better Modeling Tools



Ultimate objective – Single integrated modeling platform