EnSys WORLD Model Features

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WORLD MODELLING SYSTEM – AN OVERVIEW

Increasing interest is being shown in the EnSys ***WORLD*** modelling system by private sector and government entities, viewing ***WORLD*** as a unique means to address petroleum industry developments and issues at the national, regional and global levels. This document provides an overview of ***WORLD*** features, applications and systems aspects.

Section 1 Highlights key ***WORLD*** features.

Section 2 Gives a brief background to the evolution of WORLD, illustrates actual applications and potential analytical scope.

Section 3 Overviews ***WORLD's*** regional formulation capabilities.

Section 4 Itemizes the types of data and assumptions underlying a ***WORLD*** case and the types of results output.

Section 5 Provides a systems overview of ***WORLD***, outlining the data and program sub-systems that make up the full modelling system and briefly indicating model size and performance statistics.

Supporting Appendices

Provide details on, respectively:

A ***WORLD*** regional and sub-regional make-up
B ***WORLD*** process units and key operating modes
C ***WORLD*** finished products and blend qualities
D Acronyms and abbreviations

1. WORLD KEY FEATURES

The features of the ***World Oil Refining Logistics and Demand model ("WORLD")*** distinguish it in its ability to address complex future and present-day issues.

Model

- Linear programming modelling system.
- Simulates the activities and economics of the world regional petroleum industry against short, medium or long term horizons.
- Integrates and captures the interactions between:
  - crude supply
  - non-crudes supply
  - refining operations
  - refining investment
  - transportation of crudes, products and intermediates
  - product blending/quality
  - product demand
  - market economics and pricing.

Regional Formulation

- Discrete representation of the world's major regions.
- Data-driven redefinition of model regions.
- Facility to sub-divide regions by refinery category, e.g. small, simple versus large, complex, even represent individual refineries
- Facility to independently model single regions, prototypical or individual refineries.

Crude Oils

- Representation of over 120 world crude oils.

Refining Technology

- Detailed, tested, state-of-the-art representation of fifty-plus refinery processes.
- Advanced representation of processes for reformulated, ultra-low sulfur/aromatics and military fuels.

Gas/NGLs, GTLs, Oxygenates and Petrochemicals

- Integrated representation of:
    - Gas/NGLs inputs to petroleum sector.
    - Merchant oxygenates production (separate from in-refinery production.)
    - GTL gas-to-liquids merchant processes.
    - Facility to integrate petrochemical operations and their inter-actions with refining.

Product Formulation and Demand

- Detailed breakout of major, minor and military petroleum products and demands.
- 30+ discrete products can be simulated.
- Detailed representation of reformulated as well as conventional fuels including RFG and ultra-low-sulfur diesel
- Optional detailed representation of military fuels.
- Rich array of available product specifications for conventional, reformulated, and military/experimental fuels with user control over activation.
- Available effective, linearized versions of EPA Complex Model for gasoline emissions control.
- Facility to represent tranches of demand, hence supply and demand "curves" for demands and, in sub-global models, imports and exports.

Transportation

- Comprehensive inter-regional transportation of crudes, products and intermediates.
- Multiple tanker types and costs.
- Import tariffs.
- Capacitated pipeline movements.
- Minor transportation modes.
- Multi-mode movements.

Industry Structure and Investment

- Advanced refinery process capacity investment feature.
- Regional differentiation of refining costs.
- Effect of environmental regulations on capital and operating costs.
- Impact of economies of scale.

Data and Case Management

- Supporting detailed databases:
  - crude and non-crude supply
  - refinery capacity and construction
  - transportation
  - product quality
  - product demand

  facilitate adaptation to new studies and model formulations.
- Databases are designed to work from major data sources, e.g. EIA and OECD/IEA.
- Ability to set sub-regional demand growth rates by product type to user-selected future horizons.

System Performance and Flexibility

- Advanced matrix generation and report writing code enables virtually all model changes to be data-driven.
- Complete system runs routinely on Pentium PCs (using barrier method optimizers.)

Documentation and Training

- Comprehensive model user documentation.

- Training and seminars.

User Interfaces

- All refinery technology data are held in a single Excel workbook database with all process vectors weight and sulfur balanced
- All case input data are held in a set of four inter-linked Excel workbooks, making for easier case management and reduced input errors: master, supply/demand/quality, capacity & construction, transport

Support and Analysis

- The authors (highly experienced industry consultants) support ***WORLD*** and are available to assist or undertake analyses.

Commercial Availability

- ***WORLD*** is available for licensing – recognizing internal use by a client does require a significant commitment of expertise and resource
- EnSys supports and works closely with clients who have licensed ***WORLD***
- Alternatively, EnSys is open to a range of short or long term consulting arrangements

2. WORLD MODEL EVOLUTION AND APPLICATION

Evolution

Assessment of issues surrounding the future of U.S. and global refining can only be taken so far by static or simplified analyses. The world petroleum industry is technically complex, has the economic attributes of a co-product industry, its different aspects and regions are highly inter-related. It contains considerable ability to adjust to changed circumstances. Finally, it is faced today by major challenges presented by environmental, product quality, conservation, substitution, supply/demand and technology/cost developments.

The ***WORLD*** model was designed to bring all of the key elements of the world petroleum industry together into one simulation tool, with the specific goal that it realistically address "what if?" issues that are departures from present day "Business As Usual."

WORLD was developed by a team of international petroleum consultants with many years' experience in oil industry management, planning, systems, and in analysis of issues, developments and projects. Key to WORLD's evolution have been associations and assignments with: Queen Mary College London, OPEC, NASA, Oak Ridge/U.S. Navy, U.S. Energy Information Administration, U.S. EPA, U.S. Department of Energy Offices of Strategic Petroleum Reserve, Energy Emergencies, Policy and with private oil companies. In 1992, ***WORLD*** was adopted by the U.S. Energy Information Administration as its primary global petroleum analytical tool and in 2000 by the OPEC Secretariat.

Current and Past Applications

Developed and proven over the last twelve years, ***WORLD*** offers broad analytical scope in its global, regional and single refinery forms.

- EIA employ ***WORLD*** as a key component of each Annual and International Energy Outlook cycle, projecting alternative BAU scenarios out to 2020.

- EIA have also applied ***WORLD*** successfully to policy analyses including Alaskan crude exportation, gasoline Btu tax and anti-dumping disputes

- The ***WORLD*** refinery technology database is also the database employed by EIA in the Petroleum Market Module of the National Energy Modeling System. Recent significant applications include the Spring 2001 EIA study on ultra-low sulfur diesel

- EnSys' applications of ***WORLD*** have included:

  - assessment of the detailed US refining impacts (investments, product switching, market shares, exports, imports, supply and market pricing) of ultra-low sulfur gasoline and diesel (including prospectively off-road diesel) set in a global context of movements in Europe and elsewhere to ultra-low standards and using latest projections on available refinery process technologies and economics. Study horizons include: 2006, 2010 and potentially 2015 and 2020

  - analysis of the world-wide crude oil market and refining impacts of growing Caspian crude production with emphasis also on the effects of alternative Caspian crude export routes

  - sensitivity of year 2010 global GTL and refining investments to reductions in GTL capital costs from their current level of approximately $24,000/bbl/day

  - impacts on US Gulf Coast (PADDIII) refining of ultra low sulfur gasoline and then diesel regulations. Emphasis on desulfurization investments and ULS diesel production costs at different sulfur specifications (50 – 8 ppm) and different levels of phase-in (0%, 25%, 50%, 75%, 100%). Phase-in results formed the basis of an Argonne/DOE report on phase-in economic benefits

  - global "business as usual" outlook for 2010 taking account of changes in crude supply and product demand and three different scenarios of tightening in product quality. Emphasis on related requirements for new and revamp process investments for upgrading and desulfurization

  - impact on 2010 markets and regional refining investments and margins of higher natural gas production, hence lower residual and

heating oil demands, and of higher natural gas with substantial GTL liquids supply

- effect on US, OECD and global refining activity, investment and trade of applying carbon taxes to refinery fuels and petroleum products in OECD regions

- impacts of US and overseas fuels reformulation and refinery environmental regulation on year 2000 regional refining investments, utilizations, import/export trade patterns and US energy security

- cost impacts of low sulfur gasoline and of potential US diesel reformulation to close to Swedish standards, including effects of newly evolving refinery technologies

- price impacts on tight world markets of early SPR drawdown at the time of the Iraqi invasion of Kuwait

- effects on markets of large ramp-up in jet fuel demand at the onset of Operation Desert Storm against various "what if" scenarios including refinery outages and disruption of key tanker arteries

- calibration to first quarter 2000 world market/supply conditions leading in to simulation of the impacts of hypothetical major supply disruptions and SPR drawdowns. Emphasis on the market pricing and related economic impacts of sweet versus sour SPR crude draw mix

■ Private sector clients have applied ***WORLD*** to assessments of:

- longer term strategic investment opportunities
- shorter to medium term refining tightness and margins, based on the balance of known capacity additions with demand growth and crude slate
- support of shorter to medium term trading decisions
- assessment of European 2005 gasoline and diesel fuel regulations.

Potential Applications

Interest in ***WORLD*** among the private sector is growing. EnSys is experiencing a shift in ***WORLD*** use toward a mix of corporate/market and policy issues. Areas of active interest include:

- impacts on US and world regional refining and trade of the trend to ever lower sulfur fuels

- new developments in Caribbean and Atlantic basin crude production, including Venezuela, Colombia, Newfoundland, West Africa and US Gulf Coast deep offshore, and their implications for future crude trading patterns and refinery economics, especially in the US Gulf Coast, US Northeast and Europe

- impacts of new refining technologies and of natural gas to liquids (GTL) processes on future refining configurations, economics and markets

- medium term outlook to 2005/2010 for global product and refining supply demand, especially resuming high growth rates in Asia-Pacific and the growing dominance of distillates (jet, kero, diesel, heating oil) outside the US; implications for product prices and refining margins

- implications of growing inter and intra regional crude and product trade for tanker supply / demand and freight rates, recognizing tanker scrapping and replacement costs

Analytical Flexibility

WORLD is a modelling system – not a single model. Using it, different model formulations can be developed, e.g. to give more detailed representation of a given world region (for instance, Northern Europe or Asia-Pacific) or of given refinery classes (for example, U.S. refineries that are high-cost producers of diesel fuels).

These options and other built-in features lead to a wide range of analytical flexibility e.g. for:

- Model variants that focus in detail on **one region or nation** but maintain a full global accounting
- Analysis of outlooks for or impacts on **different types of refineries**

- Rigorous simulation of **refinery emissions** and loss, control technologies and costs.
- **Impacts** of new refining process technologies.
- **Cogeneration** options
- Simulation of **global industry GHG (CO2) emissions from production, transport, processing and consumption** under different scenarios.

3. REGIONAL FORMULATION CAPABILITIES

The ***WORLD*** system was explicitly designed to permit flexibility in regional formulation and disaggregation. The regional composition of ***WORLD*** is data driven, that is, regional make-up can be modified solely by altering data tables without alteration of code.

In the ***WORLD*** model, crude supply/ product demand and refining regions are decoupled, i.e. they may be defined separately from each other. In the usual global formulation however, these regions are set up as coincident.

The current ***WORLD*** regions are aggregates of some 18 sub-regions. Base ***WORLD*** data are held at three levels: country/sub-country, sub-region, region. Regional reformulation which differently aggregates or dis-aggregates the existing sub-regions is straightforward, e.g. to break out Japan as a separate region. Reformulation at the country level, e.g. to show Saudi-Arabia as a discrete region, can also be achieved purely by data manipulation and extension such as to incorporate additional transportation movements.

Any given refining region may be disaggregated by refinery sub-group, e.g. to distinguish large, complex from small, simple refineries, identify logistics sub-groups, or even single refineries.[1]

APPENDIX A details the current ***WORLD*** make-up of regions and countries.

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1 This is possible since EnSys maintains capacity data at the individual refinery level, enabling a high degree of flexibility in aggregation.

4. MODEL INPUT REQUIREMENTS AND OUTPUT RESULTS

WORLD INPUTS (CASE ASSUMPTIONS)

The ***WORLD*** model is a linear programming model which simulates the operation of the world regional petroleum industry based on user-specified assumptions regarding the time horizon and scenario of interest. For a complete ***WORLD*** case, the following are the main input assumptions to be specified by the user:

Feedstocks

- Crude supply by nation by crude type (including SPR crudes in SPR draw cases.)
- FOB price of the balancing marker crude whose input is allowed to float (generally Saudi Light.)
- Fixed availabilities of non-crude inputs to the refining supply system, notably NGLs, grain ethanol, synthetic petroleum fuels[2], returns from the petrochemicals sector such as steam cracker gasoline.
- Base available regional capacities for production of "merchant" MTBE and other ethers; also GTL liquids.
- Variable availabilities with regional prices for methanol[3], natural gas, purchased electricity.
- For regions where remote ("stranded") gas is considered a feedstock for GTLs, remote gas prices.
- Amounts of crude-based streams, notably resid, allowed to refinery fuel[4].

Products

- Demands for generally around 28 petroleum products by region, essentially all fixed except for elemental sulfur and fuel grade coke which are priced and treated as by-products.
- Key qualities of all major products[5].

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2 *Synthetic petroleum fuels include gasoline and other products derived from coal and gas, for instance in South Africa and New Zealand.*

3 *The price of methanol in **WORLD** is a function of the region and the regional price for natural gas.*

4 *Operating with no constraints on the composition of the refinery fuel pool allows an unrealistically large flexibility for disposition of residual fuel. Consequently, residual fuel and other crude-based inputs are set based on historical data and likely trends with total fuel consumption balancing on process gas plus purchased natural gas.*

5 ***WORLD** incorporates both base grades of each product with standard qualities and the*

Refining

- Base "nameplate" capacities of some 50 process units covering primary processing (distillation), secondary processing, yield and quality upgrading, ancillary units (hydrogen production, sulfur recovery, utilities generation) representing established technologies, and new technologies centred mainly on reformulated fuels production.
- For each unit in each region, estimated effective availability factor reflecting such factors as long run utilization rates, refinery practice of double training key units such as sulfur recovery, poorer operating practices in some world regions, or effects of scheduled shutdowns in a short-term seasonal case.
- For each regional refinery, controls on operations of major units, e.g. severity, feed composition.
- For cases with refinery investment option:
  - factors to represent capital cost/location factor and capital recovery factor (cost of capital)[6] in each region.
  - Any limits on capacity additions in the form of revamping, de-bottlenecking and major new unit investments, e.g. no net increase in PADD 1 distillation capacity. (***WORLD*** allows all three modes of capacity expansion under user control.)
- Differences in regional environmental costs can also be accounted for.

Transportation

- Allowed inter-regional movements for each crude and each product; this in part to control the number of transportation options by

capability to input and track quality differences between world regions. Quality variation is tracked firstly by establishing regional splits between different base grades of the major products, e.g. gasoline (4 conventional and 1 reformulated grade), middle distillates (3 grades), residual fuels (4 grades). Gasolines are differentiated principally on octane (lead-free basis), distillates and residual fuels on sulfur and viscosity/pour point. Further regional differences within major grades can then be entered; the impacts of these differences on blend pool qualities are tracked and accounted for in the model.

6 *Capital recovery factor may be directly input or may be calculated from the cost of capital,*

eliminating extremely unlikely or essentially duplicate routings and in part to prevent movements that are not allowed for political reasons, no Libyan imports to U.S.,

- Transportation cost for each crude, product and shipped inter-refinery intermediate stream.
- Related import duty, lightering, canal or other tariffs
- Optional differentiation of tankers by class with fleet capacity limits
- Multi-mode transport movements.
- Transportation capacity limits on major inter-regional pipelines.

General

- Selected limitations on individual activities, e.g. requiring certain minimum volumes of FCC feedstocks to move into the U.S. to reflect the existence of several refineries for whom this is their primary feedstock, a "micro" factor that in the aggregated model would otherwise be subsumed.

Underlying Premises

The case inputs above define the present-day or future scenario to be simulated. Development of future horizon cases in particular requires careful consideration of the uncertainties underlying projections and thus how the parameters that influence the industry could evolve. For instance, the following are among key basic factors influencing any current forward-looking study:

- The overall assessment and outlook for global oil price / gas price / supply / demand balance.
- Crude production outlook including balance of future OPEC versus non-OPEC production.
- Specific country crude production and mix.
- Product demand growth rates, absolute and relative.
- Extent of new gas distribution projects and their influence on regional substitution of residual and heating oil demands.
- Evolution of gasoline, distillates and residual fuel qualities by region, especially based on mandates for clean and reformulated fuels.
- Potential substitution of petroleum products by alternative fuels.

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tax region, economic life, and depreciation schedule.

- Availability of new refining technologies and their costs.
- Evolution of regional capital cost location factors for process unit investments depending on the effects of environmental legislation.
- Forecast transportation routes, modes, capacities and rates.

While certain of these parameters will often have been set by the world regional supply/demand forecast used for a particular study, numerous parameters ranging from details of non-OPEC regional growth rates for individual products to specific refining assumptions have to be derived from ancillary sources and/or by analyst judgement.

Given the above inputs, the ***WORLD*** model simulates the operations, technology and economics of the world regional industry, using all the available options – crude shipping, refinery processing, investment (when allowed), blending, intermediates and product shipping – to satisfy the specific product demands feasibly and optimally (i.e. at minimum global cost); this while respecting all the constraints on the system, notably supply limits, shipping limits, process capacity and operational limits, product blending specifications, regional product demands.

WORLD OUTPUTS

The outputs from a simulation can be categorized into three groups:

I Physical Information

- Marginal and total crudes and non-crudes intakes.
- Generation and consumption of utilities and variable non-crude feedstocks (methanol for refinery and merchant [MTBE] use, natural gas for refinery use and as merchant GTL feedstock.)
- Crude, non-crudes, products and intermediates movements.
- Refinery and "merchant" process unit capacity additions (when allowed) in every region through revamping, debottlenecking and major new unit investments.
- Process unit operations, regional refining and merchant plant through-puts and utilizations.
- Blending activities and blend compositions.
- Product demands (sales), generally fixed.

II Refining and Market Economic Information

- Marginal costs on every crude where there is an active movement into the region. These equate to FOB prices at port of origin and to CIF prices at port of delivery.
- Finished product marginal costs (equating to open market prices) in every region[7].
- Values of intermediate streams in every regional refinery.
- Economic rents (expansion incentives) on process units at their capacity limit (either where investment is not activated or where allowed active investment is limited and at its maximum.)
- Costs (relaxation incentives) on limiting product specifications.
- Costs (relaxation incentives) on other imposed constraints, e.g. process unit operations, specific movements.
- Costs of investments in new capacity (when allowed.)
- Refining margins.

III Regional and Global Economic Information

The specific cost and activity data available from a ***WORLD*** solution are used to report the revenues, rents, and costs associated with:

- Crude producers
- Non-crude producers
- Refiners
- Shippers

by region, building up to the consumers' cost by region and globally. The net import bill can also be reported (currently for U.S. regions only).

Comparing these outputs across cases, it is possible to identify the physical, market and regional economic effects on producers, refiners, shippers and consumers of changes in the world petroleum supply situation – whether changes in BAU assumptions or the effects of a disruption.

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7 *Note that the only prices input are generally those for (a) the marginal crude, (b) variable non-crudes (gas and methanol), (c) minor refined products (sulfur and fuel grade coke). All other crude, non-crude product prices are derived as outputs. These output prices are affected principally by (a) the level of the input marker crude price and (b) the slackness or tightness in refinery upgrading capacity relative to light versus heavy product demand*

Overall, the ***WORLD*** model:

- Realistically simulates the refining operations and economics of the world's regions.
  (Because it contains detailed refining matrices.)
- Ensures a feasible solution to meeting world regional demands identifying material balance flows across regions and globally.
  (Provided input assumptions allow a feasible solution.)
- Reflects and simulates the effects of the economic cost/profit forces driving industry activities.
  (Since the majority of crude and product trading today is related to open market prices, and also because virtually all refiners run and optimize their refineries based on market economics using LP models fundamentally similar to the ***WORLD*** *model.)*
- Provides an integrated simulation which generates internally consistent physical flows, refining market, regional economics and interactions.

In its global formulation, the ***WORLD*** model simulates regional effects. Insights at the level of individual countries or refinery types can be obtained where the model has been appropriately disaggregated.

5. WORLD SYSTEM OVERVIEW

SOFTWARE AND HARDWARE

The ***WORLD*** model comprises a series of linked sub-systems which together permit cohesive data management, matrix generation, optimization and report writing under direct used control. At the core of the system is extensive, proprietary, program code written in Haverly Systems' OMNI language. This handles two main functions:

1. The manipulation of "case" and "permanent" input data into a generated industry-standard LP matrix[8].

2. The generation of multiple reports from matrix data and run solution files.

A key feature of OMNI is that it enables the model to be highly data-driven, i.e. the code has been written so that most model changes, such as adding new regions, process units, crudes, products, specifications, as well as changing virtually any data items can be handled without modification to the code; data table modifications are all that is needed.

The MPS LP matrix data file is input to, analyzed and optimized by one of the leading optimizer software packages. New generation "interior point/barrier method" optimization software, such as Cplex from ILOG, XpressMP from Dash Associates, provide the best performance and consistency. A model such as ***WORLD*** appears to find the weaknesses in optimizers in terms of both their diagnostic and optimizing capabilities and therefore optimizer selection is critical to smooth model development and use.

The ***WORLD*** model contains, manipulates, and computes many thousands of input data items. These include:

- Detailed crude and non-crude availabilities.
- Detailed product demands (historical and projected) and specifications.

8 *The long-established industry norm for LP matrix card image data sets is the so-called "MPS" format. Regrettably, there is no universal standard for format of LP solution output files.*

- Process capacity data by unit by refinery worldwide.
- Transportation routing, mileage and cost data.
- Process yield and product blending data.
- Process cost data.

To manage these data, EnSys has developed sophisticated spreadsheets which output OMNI format case data tables. The spreadsheets, are written in Excel. Model data, case and run management can thus be handled from within Windows with optimizer functions handled by opening MS-DOS windows under Windows 98/2000/NT.

WORLD model run times are highly practical. Time depends on model size, but an 11-region formulation of ***WORLD*** in investment mode can take as little as two minutes to solve on a Pentium PC depending on CPU speed and optimizer. These run times apply for feasible cases using the barrier method. Infeasible cases generally require dropping back to Simplex and run times are longer.

Overall, current and forthcoming high-end PCs, in combination with the new generation optimizers and the PC version of OMNI, represent a fundamental breakthrough in terms of large LP model practicality and cost.

For PC installation of the ***WORLD*** model, the minimum hardware and software requirements are:

- Pentium or equivalent, preferably Pentium III or higher and 500 + MHz
- Main memory of 64+ megabytes, depending on model formulation
- PC OMNI Assembler package
- CPlex or XpressMP optimizer
- Microsoft Office 97 or 2000

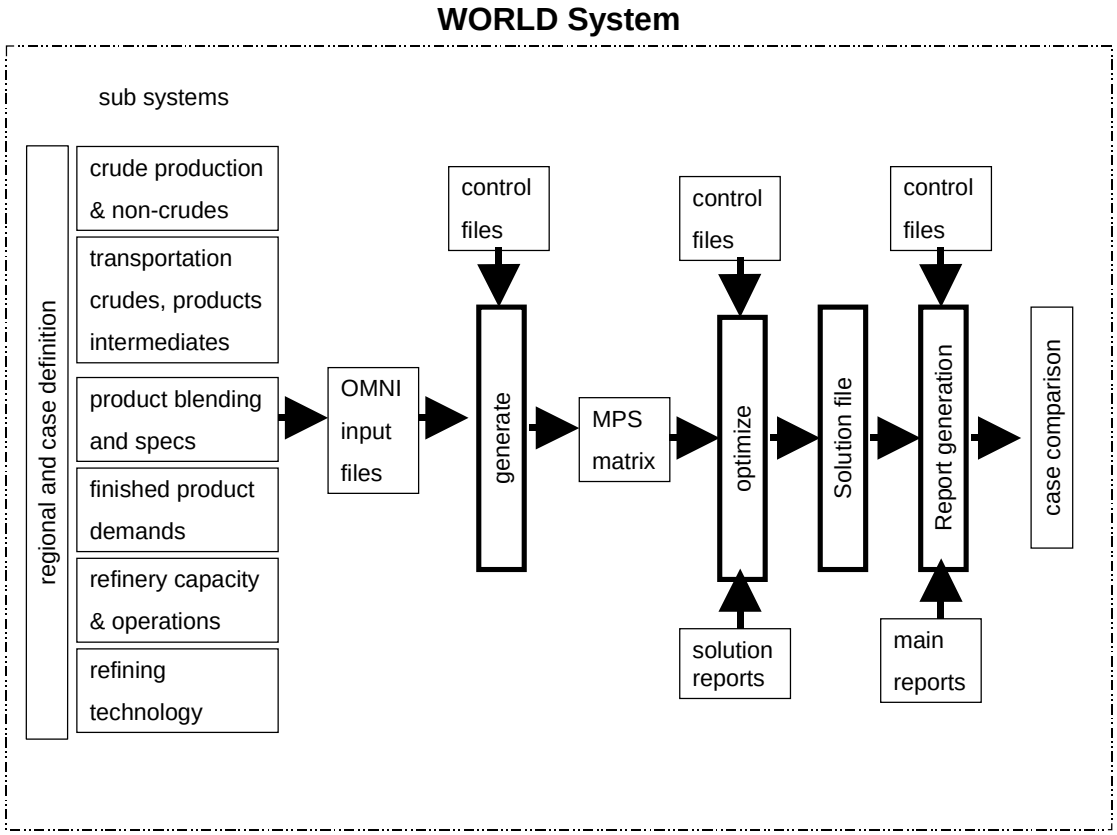
DATA SUB-SYSTEMS

The ***WORLD*** model can be viewed as a combination of core data and program components or sub-systems. The data sub-systems are focused on data management and the preparation of input data tables. There are 5 such sub-systems, comprising inter-linked Excel spreadsheets which maintain all model input data and output these as ASCII (text) files which are read by the OMNI matrix generator. The five Excel spreadsheets encompass:

1. Master case controls and scenario options.

2. Supply, demand and quality, encompassing: crudes, NGLs and other non-crudes production levels, country and regional product demands by major category and grade within category, product specifications.
3. Refinery and merchant oxygenates capacity and operations, including data by unit by refinery worldwide.
4. Transportation of crudes, products and intermediates including shipping rates and capacity limits.
5. Process technology – crude oils, refining processes, refined product blending, merchant oxygenates and GTLs processes.

A fuller description of the primary components of these sub-systems follows.



Process Technology:

A. Crude Oils and Refining Technology

- **Representation of over 120 world crude oils** encompassing main grades from every producing country; also synthetic and specialty naphthenic crude oils.
- A detailed and tested representation of **over fifty refinery processes including advanced technologies and operating modes for reformulated** and military fuels.
  (See APPENDIX B for list of processes and key operating modes.)
- Specific capability for **reformulated gasoline**, ultra low sulfur/**sulfur-plus- aromatics diesel**, multiple jet fuel grades and several residual fuel oil grades.
- User activated investment feature builds up **full annualized investment costs for capacity addition which are tailored by region** for location factor and capital recovery (cost of capital), can be used to reflect refinery scale (e.g. to capture the economy-of-scale disadvantage of small refineries.)

B. NGLs, Petrochemicals, Merchant GTLs and Oxygenates Plants

- Optional user generation of a **"petrochemicals"** facility in any or all refining regions. This can be used to incorporate ethylene cracking or potentially other processes within the model and is currently being used to simulate **merchant MTBE and GTL** plant operations, investment and shipping for forward horizons. It is also used to simulate NGLs' availability going as inputs to oil refineries and LPG product demand.

Supply / Demand / Quality:

A. Crude Production and Non-Crudes Supply Sub-System

- National crude oil production levels (actual or projected) with grade breakdowns.
- U.S. crude production broken down by major grade within state.

- U.S. and foreign SPRs represented with crude grades and proportions.
- Syncrudes from tar sands (Canadian, Venezuelan.)
- NGLs' production by country/region with facility to break out C_2's/C_3's/C_4's/C_5+ or to aggregate C_3's/C_4's.
- Other non-crude inputs including full blended ethanol, splash blended ethanol, petrochemical sector returns, synthetic petroleum products, methanol.
- Natural gas purchase for fuel/feedstock uses.

B. Finished Product Demand Sub-System

- **Can directly utilize major available historical data sources** including: Petroleum Supply Annual for the U.S.A., OECD/IEA statistics, EIA International Energy Annual, UN data etc.
- Data are by PADD for U.S. and elsewhere by country with major products demands.
- PADD and country data are first aggregated into "sub-regions" for easy final aggregation and for projection of demands (see APPENDIX A.)
- Facilities incorporated to aggregate and disaggregate product data within categories, including military fuels.
  - BAU data can be overridden and adjusted to reflect non-BAU scenarios.
- **Incorporates annual growth rates** to project demands by major product groups by region to any future horizon.

C. Product Blending and Specifications Sub-System

- **Detailed** representation of **blending options**, component qualities and specifications for major, minor and military products.
- Some **30 discrete products** can currently be represented including essentially all products represented in the EIA Petroleum Supply Annual, plus reformulated and military grades. (See APPENDIX C for list of products.)
- **Reformulated gasoline blends** are available for use in addition to conventional grades. Qualities cover all anticipated specifications; also **linearized versions of EPA equations for control of gasoline emissions are available.**

- Discrete representation of conventional versus **low sulfur/ aromatics diesel** down to sub 10 ppm sulfur levels**.**
- Capability to model **severe reformulations of gasoline, diesel** and jet fuels
- Separate blending capabilities for **Jet A/A-1, JP-8, JP-5, JP-4** and potential high density JP8X / JP-11 fuels with rich representation of blend properties.
- User option to select recipe blend representation of minor products such as JP-4, JP-5.
- **Multiple residual fuel sulfur grades** represented.
- **User control of activated product specifications activated** case-by-case.[9]
- **Winter/ summer/regional variation of product specifications.** (See APPENDIX D for listing of model blend properties.)
- Input product specifications are based on refinery blend targets or reported regional actuals rather than nominal specifications to avoid model over-optimization.

Capacity and Operations Sub-System

- **Every refinery worldwide with capacity by process unit type** is represented in a spreadsheet database; basis is reviewed Oil & Gas Journal data plus other in-house sources.
- Incorporates **known capacity addition projects by refinery**; enables base individual and regional capacities to be generated for different horizons within the three or so year time-frame of known additions. (***WORLD*** investment feature – if activated – enables further capacity additions beyond announced projects.)
- Standard process unit stream day factors are incorporated for each type of unit. An additional **capacity utilization factor** enables the user to adjust nameplate capacity to effective available capacity to accommodate such factors as: estimated seasonal shutdowns – or shutdown deferrals, typical long term industry utilization rates, lack of inter-connection of all process units in a region.[10]

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9 *The **WORLD** model contains a very rich set of product specifications. For most studies, only a sub-set of these is needed. A model feature enables the user to control the specifications actually generated for each product, hence model emphasis and size.*

10 *Recognizing the model's implicit assumption that all units in a region are inter-connected and capturing the reality that they are not through adjusting utilization rates is significant in*

- Sub-system provides for **user control of operations on key units** including: FCC, catalytic reforming, distillate hydrotreating, refinery fuel pool (See APPENDIX B for details.)
- Facility to generate and/or purchase steam and power.
- Additives purchasing and blending including diesel pour depressant, ignition improver, specialty jet additives and gasoline manganese additive.
- Capacity and project data for "merchant" units, notably for MTBE and GTLs.

Crudes, Products and Intermediates Transportation Sub-System

A. Transport

- Develops fully built-up movement/import costs under a wide variety of scenarios.
- Inter-regional movements database.
- Is based on WorldScale rates
- User selects vessel size and clean/dirty type for each marine movement.
- User controls which movements are generated.
- Movements reflect pipeline and canal routings and tariffs.
- Crude, product and intermediate import tariffs (flat rate and ad valorem) for U.S., Europe and other world regions.
- Capacitated representation of major inter-regional pipelines.
- Multi-mode movements

B. General Limits

- Simple vector bounding feature allows user to control activity of any individual vector in the model; most often used to control movement vectors e.g. to reflect crude exporting policies and to ensure a proportion of a country's crude production is run in local refineries.

preventing model over-optimization.

PROGRAM SUB-SYSTEMS

Overview

A. *WORLD* Generation Sub-System

The OMNI matrix generation code is almost entirely data driven by control tables and tables output by the refinery technology and case data spreadsheets. Matrix configuration and size is dynamically controlled based on number of regions defined, refineries per region, active units and process operating modes in each refinery, whether investment is activated, active regional and global product types, active product specifications, allowed transportation movements.

Table-driven matrix generation code improves generation efficiency and model run time by identifying and eliminating inactive process units, operating modes (vectors) and intermediate streams dynamically, based on case data.

B. Optimization Sub-System

WORLD works with all optimizers that accept the MPS format matrix output by OMNI and which generate OMNI-compatible solution files. ***WORLD*** has been optimized mainly using MPSIII, OSL, XpressMP and CPlex. With built-in proprietary EnSys scaling methods, the model runs stably without degeneration or other problems.

Matrix statistics are problem dependent but, with EnSys' 11 region model running in investment mode geared to forward reformulated fuels analysis, matrix size is 8,000 rows by 30,000 columns and 256,000 non-zero elements.

C. Reporting and Analysis Sub-System

WORLD OMNI report code generates data driven reports covering:

- World regional supply/demand balances including refinery gain, catalytic coke production and natural gas consumption.
- Refinery operations, utilizations and investment.
- Refinery feedstock/production balances.
- Crude movements, in detail and in aggregate.

- Intermediates and products movements.
- Assignment of non-crude inputs.
- Regional product production/import/export/demand balances, patterned after EIA/IEA reporting conventions.
- Product blending.
- Crude and product marginal costs/prices.
- Regional cost to the consumer.
- Regional economics including producers', refiners, and shippers' rents.
- Import bill (currently U.S. regions only.)

Generation of the reports is dependent on user selection.

In addition to the above, EnSys has developed the following reports:

- a "delta" report which – under user control of criteria – reports key differences between two solutions, e.g. a base case and a variant
- compact case "active solution" in ASCII format
- full case solution in comma delimited format for direct input to databases or spreadsheets for analysis and reporting.

APPENDIX A WORLD REGIONS AND SUB-REGIONS

Assignment of subregions to current demand regions of global *WORLD* model

Note: this assignment is relatively easily changeable.

WORLD			***WORLD***
Formulation 1			**Formulation 2**
Region	**Sub-regions**	**Sub-region Descriptions**	**Region**
A	USP1	US PADD1	1
B	CANE	Canada East	6
	USP2	US PADD2	2
	USP3	US PADD3	3
	USP4	US PADD4	4
C	CARX	Greater Caribbean	7
G	MEMG	Middle East – Middle Eastern Gulf	11
M	NAEM	North Africa - Eastern Mediterranean	10
N	EURN	Europe North	8
P	JAPN	Pacific High Growth - Japan	12
	PAHI-OECD	Pacific High Growth - Other OECD	12
	PAHI-NOECD	Pacific High Growth - Non OECD	12
S	EURS	Europe South	9
W	CANW	Canada West	6
	USP5	US PADD5	5
X	ASIA	Continental Asia	13
	ROAF	Rest of Africa	13
	ROSA	Rest of South America	13
		FSU/Eastern Europe	14
		China	15

A latest version of WORLD breaks US refining into 20 sub-groups organized by PADD and by potential to produce advanced fuels.

APPENDIX B WORLD PROCESS UNITS AND ADVANCED OPERATING MODES

PRIMARY DISTILLATION UNITS

crude atmospheric distillation
- standard base cutting scheme, heavy kero (500-550^{0}F) and heavy distillate (650-690^{0}F) trim streams

vacuum distillation

CRACKING AND DESULFURIZATION/HYDROTREATING UNITS

delayed coker
fluid coker
flexi coker
visbreaker/thermal cracker

fluid cat cracker
- vacuum gasoil (hydro-fined and non-hydrofined), distillate, low sulfur/desulfurized atmospheric resid and potential medium/high sulfur atmospheric resid cracking
- conversions 65 to 85%
- ZSM high octane/high light olefins modes
- low olefin mode
- correlation of product sulfur levels with feed sulfur
- FCC SOX emissions scrubber unit.

gas oil hydrocracker - with full and mild hydro-cracking variants
residuum hydrocracker
naphtha hydrocracker

naphtha hydrotreater
- Merox sweetening
- conventional hydrotreating
- FCC gasoline advanced hydrotreating processes (CDTech, OCTGAIN)

distillate desulfurization
- Merox sweetening
- conventional hydro-treating
- current and forward technologies for ultra low sulfur deep desulfurization/ de-aromatization, including to sub 10 ppm sulfur
- bio-desulfurization

FCC feed hydrofiner/gas oil desulfurization
- mild hydro-cracking modes

residuum desulfurizers - atmospheric and vacuum resid units
lube and wax units

EXTRACTION AND DISTILLATE UNITS

solvent deasphalting
middle distillate furfural extraction
middle distillate gas oil dewaxing

jet fraction end point recut (470^{o}F)

high density jet fuel pre-fractionation
high density jet fuel hydrofining

LIGHT ENDS AND GASOLINE UNITS

catalytic reforming

- discrete units for:
  - high pressure (semi regen)
  - low pressure (cyclic/semi regen)
  - low pressure continuous reforming
- severities (low pressure/continuous) from 90 to 105
- heavy (250-325°F), light (175-250°F) and very light naphtha (158-175°F) feedstocks
- FC heavy gasoline, coker heavy naphtha and hydro-cracker heavy naphtha reforming
- high octane catalyst mode (UOP R-62 type)
- very low pressure (low benzene) operation

reformer feed fractionation
reformate splitter
naphtha splitter
butanes/butenes splitter
FCC gasoline fractionation
coker naphtha fractionation
natural gasoline fractionation
cryogenic ethylene fractionation

thermal cracker ethane/propane/butane feed
thermal cracker naphtha feed
thermal cracker vacuum gas oil feed

ethane/propane/butanes/pentane dehydrogenation
ethylene to 1-butene dimerizaton
n-pentene/n-hexene hydrogenaton
butane isomerization

pentane/hexane isomerization
total recycle pentane/hexane isomerization
alkylation feed butylene isomerization/treating

alkylation unit
- ethylene, propylene, butylenes, amylene alkylation

polymerization unit
dimersol unit
benzene alkylation (UOP Alkymax)
cyclar unit
aromatics recovery
- benzene and heavier aromatics extraction

MTBE/TAME/THME/ETBE/TAEE/THEE (etherol) unit

DIPE (propylene ether) unit

UTILITIES/ANCILLARY UNITS

hydrogen generation - steam reforming
hydrogen generation - partial oxidation
hydrogen purification

hydrogen to refinery fuel
light ends to refinery fuel
refinery evaporation loss

refinery fuel pool "plant"
steam generation
power generation
H_2S and sulfur recovery

STREAM DISPOSITIONS

stream transfers/combination control
blend component disposition control

OXYGENATES REPRESENTED

MTBE, ETBE, TAME, THEE, TBA, Oxinol, Ethanol (splash and full blend)
Methanol, DIPE

ADDITIVES REPRESENTED

TEL/TML[11]
MMT
diesel ignition improver
diesel pour point depressant
specialty jet fuel additives

11 ***WORLD*** *Model incorporates leaded gasoline but is generally run with gasoline grades reduced to equivalent lead-free basis.*

APPENDIX C WORLD PRODUCTS & BLEND PROPERTIES

GASOLINES

Conventional
(environmentally unregulated)
- premium (US grade)
- regular (US grade)
- regular (foreign grade)
- local/low octane grade

- aviation gasoline

Conventional
(environmentally "baseline" regulated)
- premium (US grade)
- regular (US grade)

Oxygenated
- premium (US grade)
- regular (US grade)

Reformulated[1]
Federal
- premium
- regular

CARB
- premium
- regular

LIGHT DISTILLATES
- Jet A/A1
- JP8
- JP5
- JP4
- kerosene
- No 1 diesel

MIDDLE DISTILLATES
- No2 heating oil
- No2 conventional and LS/ULS/ULSA diesel fuels
- off-road diesels
- marine diesel
- military diesel grades

Additional product types or grades can readily be formulated either as specification or recipe blends.

_____
1. Summer/Winter distinctions.

RESIDUAL FUEL OILS

- < 0.3% sulfur
- 0.3 - 1.0% sulfur
- 1.0 - 2.0% sulfur
- > 2.0% sulfur/bunkers

LUBES AND WAXES

PETROLEUM COKE

- low sulfur
- high sulfur

ASPHALT

OTHER

- petrochemicals naphtha
- special naphthas
- petrochemical gasoil
- aromatics (total BTX/benzene/heavy)
- process gas
- sulfur

LPG

- mixed or individual streams

Gasoline and Distillate/Residual Blending Properties

GASOLINES

research octane
motor octane
road octane (R+M/2)
lead[12]

MMT (incorporating non linear effect)

RVP
vapor lock index
evaporative index
distillation:
percent @ 212
257
356^{0}F

oxygen content (wt%)
methanol content
aromatics content
butane content
benzene content
total/light olefins content
bromine number
atmospheric (hydroxyl) reactivity
sulfur (ppm)
gravity

total VOCs (EPA Complex Model)
total toxics (EPA Complex Model)
total NO_x (EPA Complex Model)

DISTILLATES/RESIDUALS/NAPHTHAS

flash point (index)
freeze point (index)
pour point (index)
cetane (index)*
luminometer no. (index)
diesel ignition improver (with non-linear effect)

RVP
distillation:
percent @ 392 400 440 465^{0}F

aromatics content
paraffins content
naphthenes content

viscosity @ 122, 104, 100
-4, -3, -40^{0}F

hydrogen content
net heat of combustion
static surface tension
dynamic surface tension

12 ***WORLD*** *incorporates lead blending but is generally run with gasolines reduced to an equivalent lead-free basis.*

APPENDIX D ACRONYMS AND ABBREVIATIONS

AEO	EIA Annual Energy Outlook
API	American Petroleum Institute
BAU	Business As Usual
BTU	British Thermal Unit
BPD	Barrels Per Day
BPCD	Barrels Per Calendar Day
BPSD	Barrels Per Stream Day
CARB	California Air Resources Board
DOE	Department of Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
IEA	International Energy Agency
IEO	EIA International Energy Outlook
LPG	Liquefied Petroleum Gas
MBD	Thousand Barrels Per Day
MMBPD	Million Barrels Per Day
NGL	Natural Gas Liquid
NIPER	National Institute for Petroleum and Energy Research
NPC	National Petroleum Council
NPRA	National Petrochemical Refiners Association
WORLD	World Oil Refining Logistics Demand (model)