Network, Agent Based Modeling for EIA

by
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Acknowledgement of contributions by
Dr. Donald Gautier, United States Geological Survey

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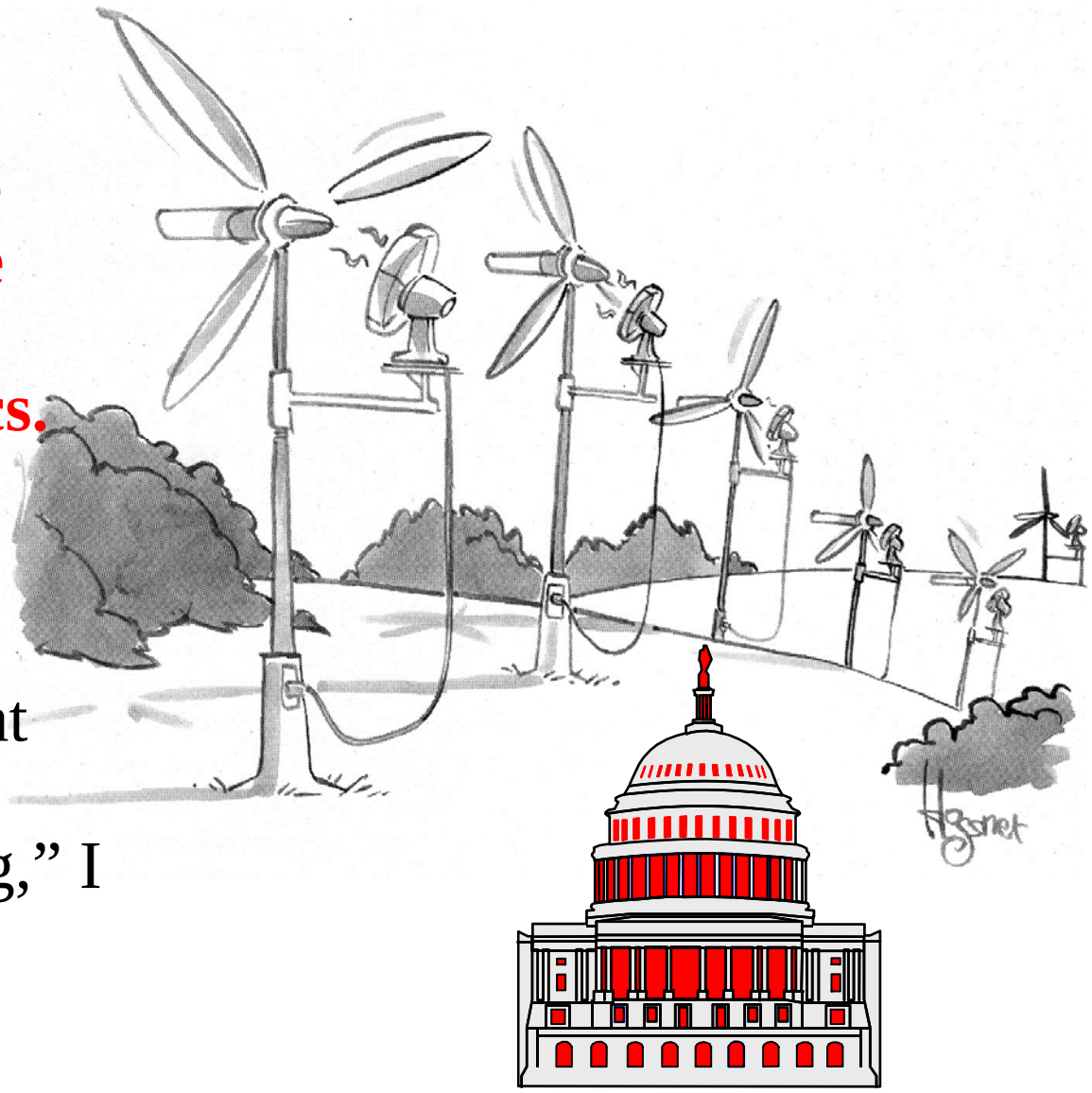
Bulletin from Sacramento

Governor Jerry Brown and the Legislature have just repealed the Second Law of Thermodynamics.

(They're encountering problems with enforcement, what they are calling "outright cheating," I am told.)



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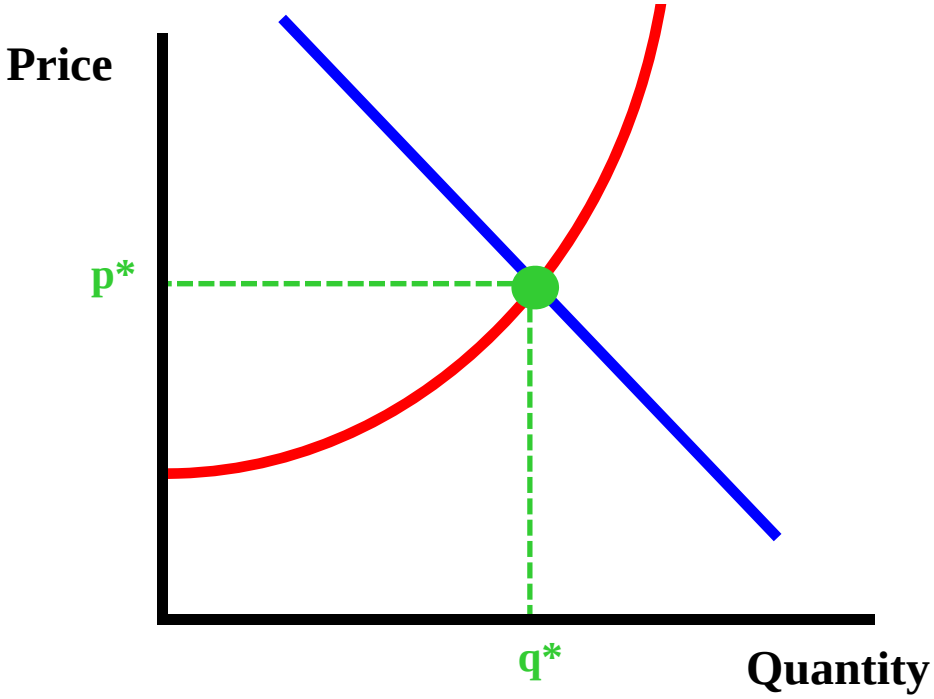
Everyone Knows That's Just a Flat INCORRECT Statement of the True and Correct First Law

For every economist, there exists an equal and opposite **politician**



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Network Oriented Fixed Point Modeling Was EIA's Method of Choice

- In its early years, the Energy Information Administration (EIA) used our Generalized Equilibrium Modeling System (GEMS) as its modeling platform. (You called it LEAP.)
- The GEMS was a Walrasian, network oriented, agent-based, fixed point seeking method that worked exceedingly well.
- During the days when GEMS (an early precursor to ArrowHead) was EIA's modeling system of choice, EIA spent a sizeable amount of money with one of the national laboratories and their contractors to validate it.
  - Architecture
  - Data
  - Network orientation
  - Solution
  - Underlying economic methodology and algorithm.

Network Oriented Fixed Point Modeling Was EIA's Method of Choice

- Documentation from that validation probably exists today in EIA's and the laboratory's archives.
- The GEMS was owned by Decision Focus Inc., a firm co-founded in 1977 by Dale Nesbitt.
- Some years later after budget woes eased, EIA adopted linear programming (a complementarity approach) for its models.

ArrowHead Network-Oriented Fixed Point Model

- Used broadly throughout industry for the past four decades.
  - That is not an accident.
  - It is easy to run and report.
  - It is easy to understand.
  - It is easy to visualize.
  - It comes right out of microeconomics textbooks (not out of operations research textbooks).
  - It allows colossally sized, detailed representations of markets without the ponderous software that complementarity or mathematical programming use.
  - It is simple and reliable.
- EIA's models have not been much used by industry. The reasons for that are important.
  - Methodology too indirect
  - Separate, unconnected, independently operating modules
  - Modification and customization too slow and hard
  - Architecture impossible
  - Non-modern programming
  - Too labor intensive

Fundamentals of Network Oriented, Fixed Point Models

- **The picture of the model IS the model**.
- Show mathematically why they are so much more modern, efficient, workable, and transparent than other methods, particularly the "full rank," indirect, brute force approaches based on monolithic optimization (including linear programming) and complementarity, which
  - impose inflexibilities
  - lack generality
  - are indirect
  - are size-restricted
  - do not admit of modern computer science.
- We are here to discuss why network oriented fixed point methods work so well and how EIA can use them.
- We offer graphical discussions but does not forsake the requisite mathematical discussions, not at all.

Endogenizing Uncertainty

- ArrowHead is named after Nobel laureate Kenneth Arrow
- Equilibrium under uncertainty
- That's one of the reasons we developed ArrowHead

Two Operating Models

- The **ArrowHead Global Gas Model** and the **ArrowHead Global Oil Model**
  - Both exist, operate, and are used today.
  - Adam's Seiminski's former company was a client while he was there
- People can put them on their desks on Monday; be trained to run them by Wednesday; and audit, edit, review, and personalize them within a few weeks.
- Operating system is fully source code based (**no** third party software), meaning that implementation is easily ubiquitous.
- By request, we omit our
  - Continental electricity-environment-renewables model
  - World coal model
  - All of the world commodity models (e.g., ammonia/urea, iron and steel, phosphate rock, etc.) that have also been built using our network oriented, fixed point modeling system.

ArrowHead Has Been Doing This for 39 Years

- 1970: Mexico CFE Model
- 1973: SRI-Gulf Model
- 1977: EIA LEAP Model
- 1979: TVA SAM Model
- 1981: EPRI IFM and LMSTM
- 1982: DOE World Oil Model
- 1983: North American Regional Gas (NARG) Model
- 1988: California Refining/Transportation Model
- 1989: World Gas Trade Model (WGM)
- 1991: Crude Quality Model
- 1991: Western European Gas Model
- 1992: Southern Cone (South America) Model
- 1993: OG&E, Duke, Minnesota Power, SCE, CIPSCO, PP&L competitive electric models
- 1995: Southeastern Australia Model
- 1995: PanEnergy North American Regional Electricity Model
- 1995Altos North American Electricity Model
- 1998: Altos Short Term NARG Model
- 2002: Completely Modernized Technology
- 2003: Modernized World Oil and Gas Models
- 2003: USGS and NPC partnerships
- 2007: Black and Veatch, Gas Strategies, Booz and Company, IPA collaborations
- 2007: NARE-Emissions Model
- 2009: WPM Model
- 2010: Deloitte acquisition
- 2010: Beginning ArrowHead Dev.
- 2012: ArrowHead formation

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History

Ron Howard, seminal co-inventor of Decision Analysis
Stanford Research Institute, Dale Nesbitt's advisor and friend

1977

SDG

ADA

DFI

- Energy
- Environment
- Transport
- Phones
- Tech
- Highways/Infra

USGS

PWC

1996

Altos

ArrowHead

2012

ArrowHead
- Deterministic
- Probabilistic

2010

Deloitte
ArrowHead

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Four Decades of Work in the Industry

- 4Gas/Carlyle
- AEP
- AGL
- Alton Storage
- Arco
- Bear Energy (now JP Morgan Energy)
- BHP
- BP
- BG Group
- Calpine
- California Energy Commission
- Canadian Energy Res. Inst.
- Centerpoint
- Cheniere
- Chevron
- CIA
- Coastal/Colorado Int. Gas
- Copano
- Deutschbank
- Dominion Resources
- DOE/EIA
- Duke Energy/Panhandle
- Eastern
- EGL
- El Paso
- Enbridge
- ENEL
- ENI
- Entergy
- ExxonMobil
- FPL
- Gaz de France
- Gazprom
- Koch
- MidAmerican (W. Buffett)
- Mitsubishi
- National Energy Board of Canada
- National Petroleum Council
- Nisource
- Nova Corporation
- Northwest Natural Gas
- Occidental
- Oregon LNG
- Osaka Gas
- PanCanadian
- PDVSA
- PetroSA
- PG&E
- Portland General Electric
- Poten
- Rebaska
- Reliant
- Repsol
- Rice University
- SCE
- Sempra
- Shell
- Southern Company
- State of Alaska DNR
- Statoil
- Suez Energy
- Total
- Toyota
- Tractebel
- TransCanada Pipeline
- TXU
- US Geological Survey
- Williams Companies
- Woodside

Dr. Dale M. Nesbitt

- Ph.D., Engineering Economic Systems, Stanford University, 1975, dissertation defense with honors, "Policy Ordering in semi-Markovian Decision Processes."
- Employment History
  - Employee #70 at legendary **Xerox PARC** (1972-4).
  - **Stanford Research Institute**, Decision Analysis Group (1974-7).
  - Co-founded and built **Decision Focus Inc (DFI)** into $25 million (sales) company (1977-95).
    - Their energy practice has become ArrowHead
  - Co-founded four new companies (1996-07)
    - **Altos Management Partners Inc.** (management consulting)
    - **ArrowHead Inc.** (enterprise software)
    - **Reticle Inc.** (high surface area carbon, water deionization/desalination)
    - **Ferritech Inc.** (biotechnology/ferric oxidation)
    - Acquired by **Deloitte** 2010
  - Founded **ArrowHead Economics** in 2012 to pursue probabilistic multiagent (Arrow) modeling
- Appointed to **Stanford** faculty in MS&E in 2013

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Dr. Antoine Calvez

- Ph.D. Particle Physics, UCLA (2011)
- Thesis – "Topics in Particle Astrophysics: Dark Matter, Gamma-Ray Bursts, and the Origin of Ultra-High-Energy Cosmic-Rays"
  - Monte Carlo simulation
  - Model building
  - Statistical analysis of high-energy cosmological data
- Working with ArrowHead to implement the intrinsically probabilistic energy model (market equilibrium under uncertainty)
- Methodology, I/O architecture and software development

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Dr. Donald Gautier

- Ph.D. in geology, University of Colorado
- 35 years experience; 200+ publications; and an international reputation for resource analysis
- Architect of USGS methodologies; chief of the World Petroleum Project
- Lead scientist - Circum-Arctic Resource Appraisal
- Designed and developed geological data and models for probabilistic resource cost functions

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Bill English

- Chevron 32 years, Chemical Engineer
  - Refining
  - Oil market analysis
  - Oil trading
- Oil, Gas, and Chemicals Industry Consultant 12 years
  - Oil upstream and downstream
  - Natural gas
  - Natural gas liquids
  - Chemicals
- Clients' investment strategies regarding drilling, process plants or pipelines
  - Network modeling of oil/gas/NGL production, transportation, refining, chemical processes, and demand
  - Economic environment for these facilities.

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Randy Begotka

- Over 20 years' experience helping companies in energy and other industries make strategic decisions using data and analytics
- ArrowHead Economics
  - Worked with Dr. Nesbitt launching ArrowHead
  - Major role in managing client projects
  - Worked with ArrowHead technology for over 10 years
  - Heads up Business Development, Marketing, and Partner Relations
- Co-founder of e-Acumen, energy services company providing analytics for:
  - Enterprise risk management
  - Short-term supply-demand-price analysis
  - Trading and investment decisions
- Worked with many North American and world energy and trading companies providing leading edge solutions for decision support and advanced analytics
- Master's and Bachelor's from Cornell University in mathematics and computer science

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Everyone Thinks They Are an Economist

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1. Overview

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- Consistency requires one to be as ignorant today as he was a year ago.

- Bernard Berenson (1865-1959)

Consistency

If one synchronized swimmer drowns, do the rest have to drown too?

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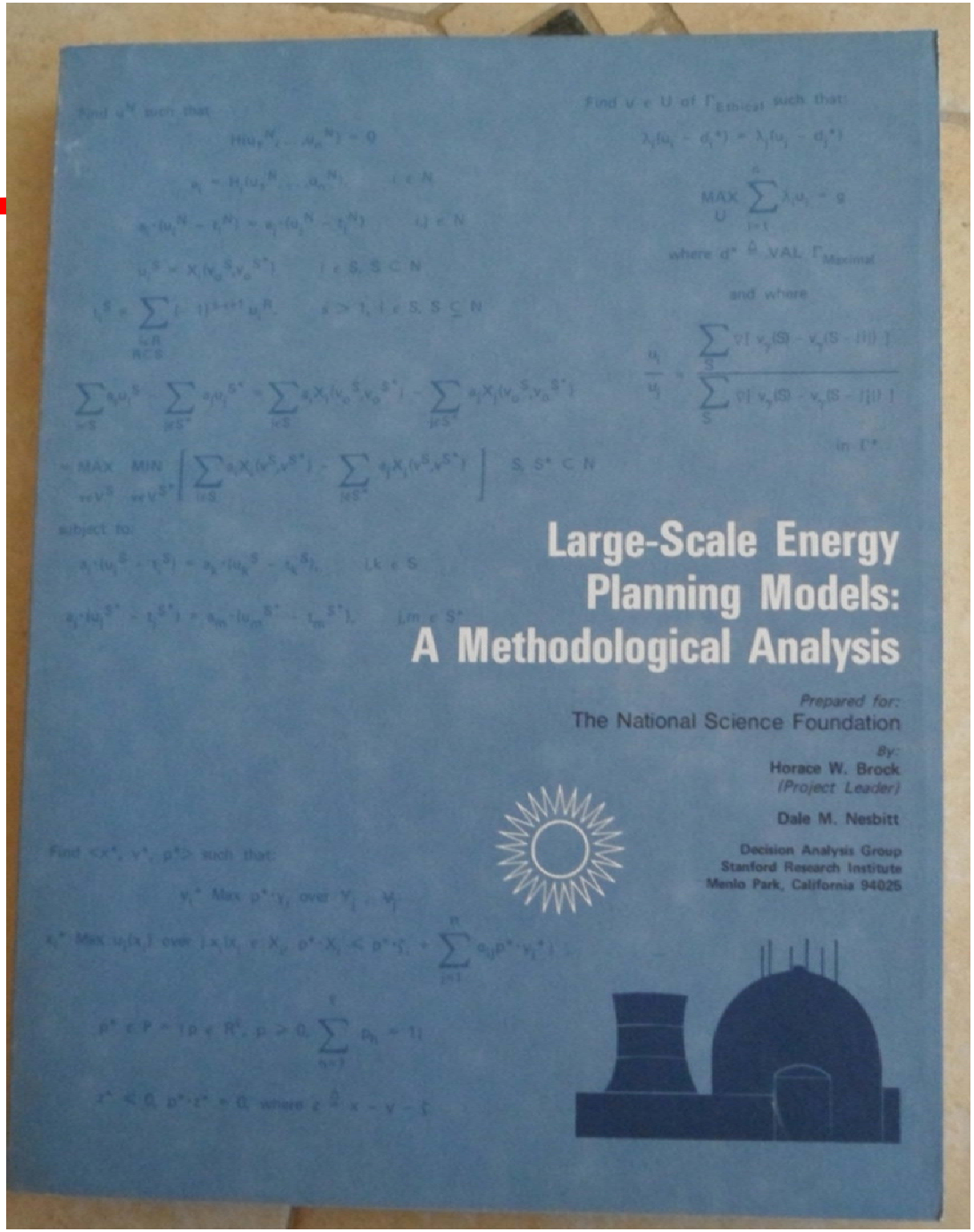
The Brock-Nesbitt NSF Report Became Quite Famous



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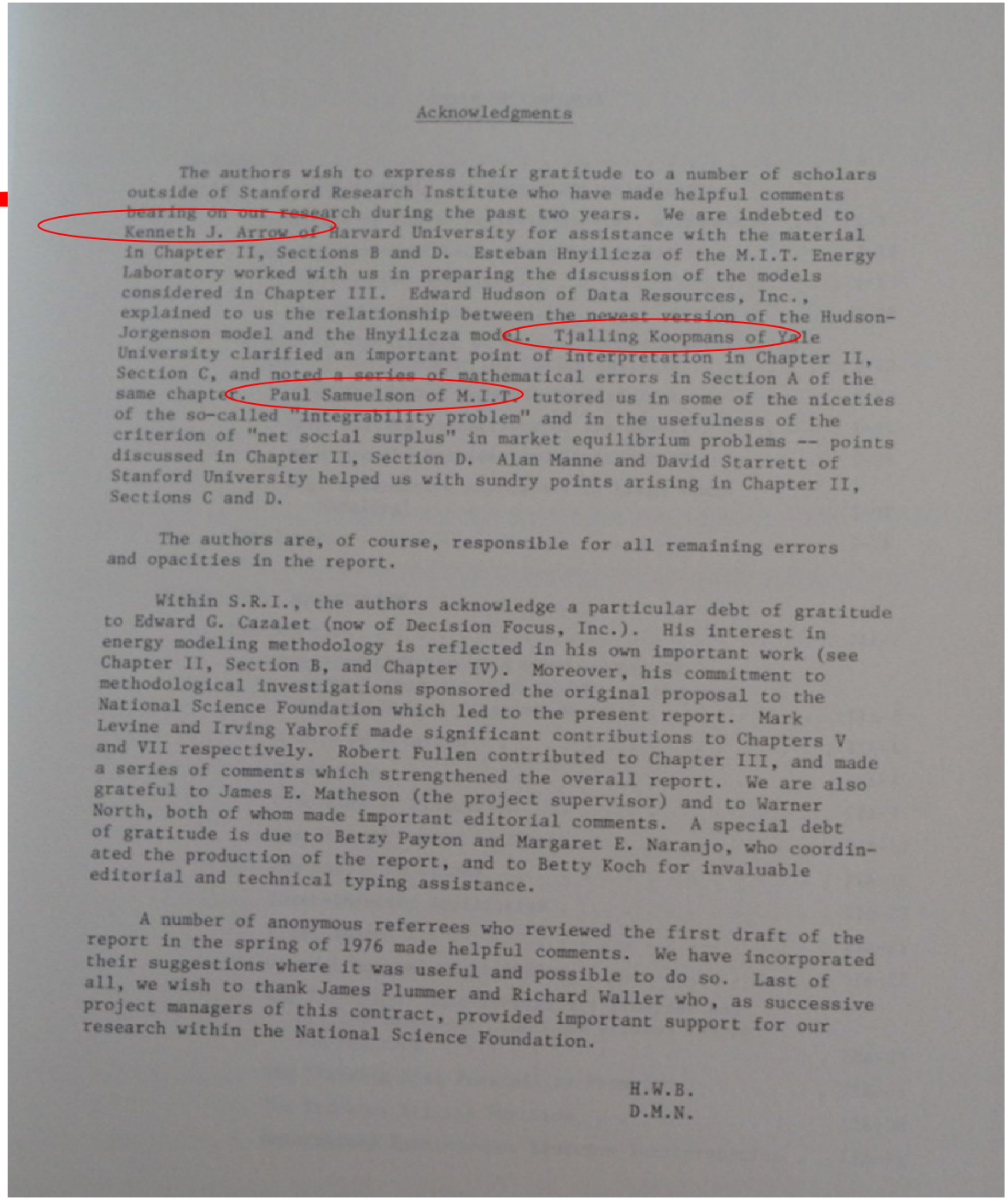
Three Nobel Laureates Reviewed and Approved It— Koopmans and Samuelson Were Very Significant to the LP Discussion



Acknowledgments

The authors wish to express their gratitude to a number of scholars outside of Stanford Research Institute who have made helpful comments bearing on our research during the past two years. We are indebted to Kenneth J. Arrow of Harvard University for assistance with the material in Chapter II, Sections B and D. Esteban Hnyilicza of the M.I.T. Energy Laboratory worked with us in preparing the discussion of the models considered in Chapter III. Edward Hudson of Data Resources, Inc., explained to us the relationship between the newest version of the Hudson-Jorgenson model and the Hnyilicza model. Tjalling Koopmans of Yale University clarified an important point of interpretation in Chapter II, Section C, and noted a series of mathematical errors in Section A of the same chapter. Paul Samuelson of M.I.T. tutored us in some of the niceties of the so-called "integrability problem" and in the usefulness of the criterion of "net social surplus" in market equilibrium problems -- points discussed in Chapter II, Section D. Alan Manne and David Starrett of Stanford University helped us with sundry points arising in Chapter II, Sections C and D.

The authors are, of course, responsible for all remaining errors and opacities in the report.

Within S.R.I., the authors acknowledge a particular debt of gratitude to Edward G. Cazalet (now of Decision Focus, Inc.). His interest in energy modeling methodology is reflected in his own important work (see Chapter II, Section B, and Chapter IV). Moreover, his commitment to methodological investigations sponsored the original proposal to the National Science Foundation which led to the present report. Mark Levine and Irving Yabroff made significant contributions to Chapters V and VII respectively. Robert Fullen contributed to Chapter III, and made a series of comments which strengthened the overall report. We are also grateful to James E. Matheson (the project supervisor) and to Warner North, both of whom made important editorial comments. A special debt of gratitude is due to Betzy Payton and Margaret E. Naranjo, who coordinated the production of the report, and to Betty Koch for invaluable editorial and technical typing assistance.

A number of anonymous referrees who reviewed the first draft of the report in the spring of 1976 made helpful comments. We have incorporated their suggestions where it was useful and possible to do so. Last of all, we wish to thank James Plummer and Richard Waller who, as successive project managers of this contract, provided important support for our research within the National Science Foundation.

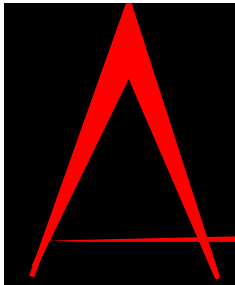
H.W.B.
D.M.N.

National Science Foundation Analysis of Modeling Methodologies

- **See Brock, H. and Nesbitt, D., Large Scale Energy Economic Models: A Methodological Analysis, Stanford Research Institute report to the National Science Foundation, 1977.**
- Brock and Nesbitt were commissioned by the National Science Foundation to write a definitive methodological comparison of the major energy models then in existence including the SRI-Gulf model (direct predecessor to ArrowHead).
- That report compared and contrasted the most important approaches: linear programming, nonlinear programming, neoclassical econometric modeling, Generalized Equilibrium modeling (which is what we called MarketBuilder modeling in those days), and system dynamics.

Widely Reviewed in Academia and Industry

- It was peer reviewed and approved by thee Nobel Laureates
  - Dr. Paul Samuelson
  - Dr. Kenneth Arrow
  - Dr. Tjalling Koopmans
- and by leading economists Dr. Dale Jorgenson, Dr. Edward Hudson, Dr. John Pearson, Dr. David Starrett, Dr. David Nissen, Dr. James Sweeney, Dr. Esteban Hnyilicza, Dr. William Hogan, and others.
- The report has been used as a textbook at Harvard and Stanford.
- The peer reviewed report proved conclusively that the Generalized Equilibrium approach could easily be specialized to simulate the textbook, economic, supply-demand situation of pure decentralized, microeconomic, profit-maximizing producers interacting with pure decentralized, microeconomic utility-maximizing consumers.



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2. The Philosophy of Network Models

Let’s look at an appallingly simple example

Why Should You Use Networks to Represent Systems of Equations?

- Simplest possible example—2 linear equations in 2 unknowns

$$3x + 4y = 8$$

$$2x - 2y = 5$$

- Nobody would build a model this simple (unless he or she were an LP or GAMS guy!)

How Would We Solve the System Iteratively?

- For illustrative purposes only, reorganize equations so that each begins with a different variable.

$$x = -\frac{4}{3}y + \frac{8}{3}$$

$$y = x - \frac{5}{2}$$

Are These Optimality Conditions (First Order Necessary Conditions) for Any Problem?

- Is there any function ϕ such that

$$\nabla\phi = \begin{bmatrix} \frac{\partial\phi}{\partial x} \\ \frac{\partial\phi}{\partial y} \end{bmatrix} = \begin{bmatrix} 3x + 4y - 8 \\ 2x - 2y - 5 \end{bmatrix} \quad \text{or} \quad \begin{bmatrix} \frac{\partial\phi}{\partial y} \\ \frac{\partial\phi}{\partial x} \end{bmatrix} = \begin{bmatrix} 3x + 4y - 8 \\ 2x - 2y - 5 \end{bmatrix}$$

- Nope! There is no function ϕ whose maximum gives first order necessary conditions which are our posed model!
- This is almost always the case. Models are **NEVER INTEGRABLE**.
- That means that any maximization problem is contrived, synthetic, contextually meaningless

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OR People Want to "Sniff Out" an Equivalent Optimization Problem

- If all you have is a hammer, everything looks like a nail.

Iterative Algorithm

- Guess y_0.
- Use first equation to calculate x_1.

$$x_1 = -\frac{4}{3} y_0 + \frac{8}{3}$$

- Use second equation to calculate y_1.

$$y_1 = x_1 - \frac{5}{2}$$

- Use first equation to calculate x_2.

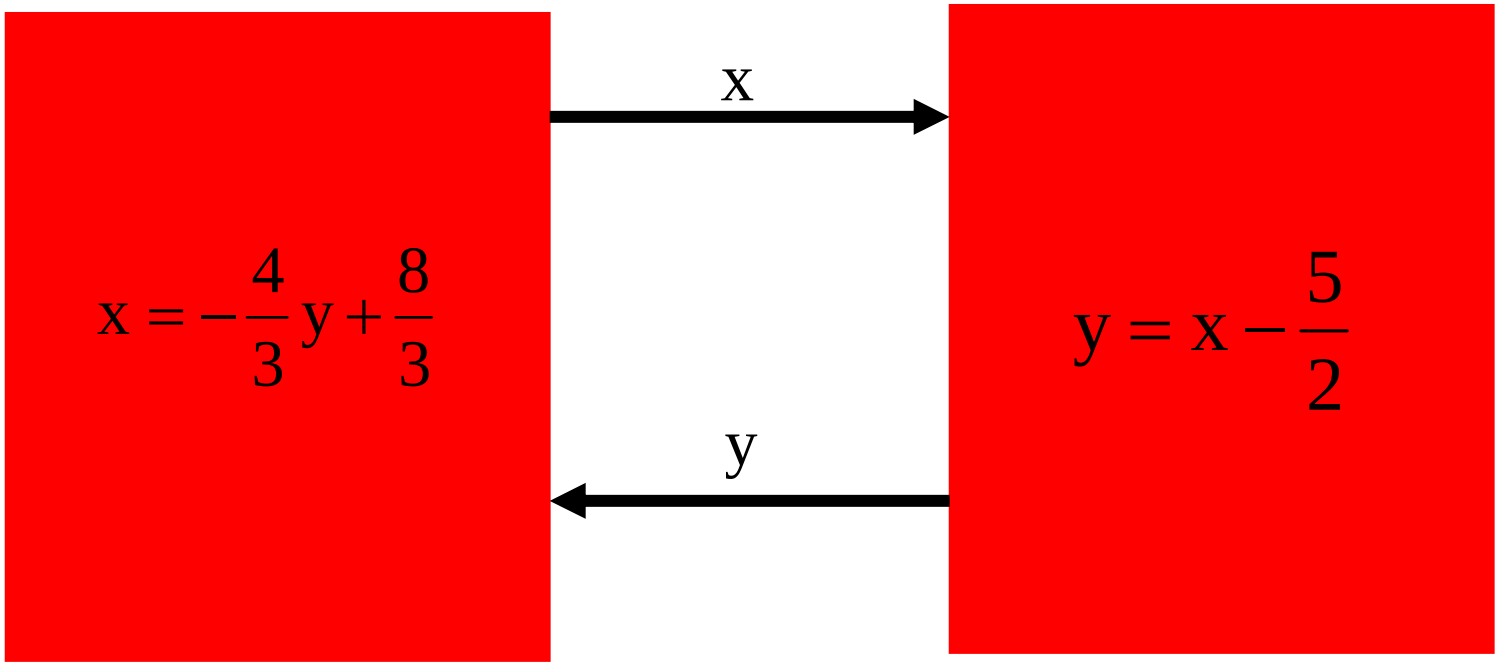
$$x_2 = -\frac{4}{3} y_1 + \frac{8}{3}$$

- Use second equation to calculate y_2.

$$y_2 = x_2 - \frac{5}{2}$$

- Continue to convergence

This Strongly Suggests a Network Methodology



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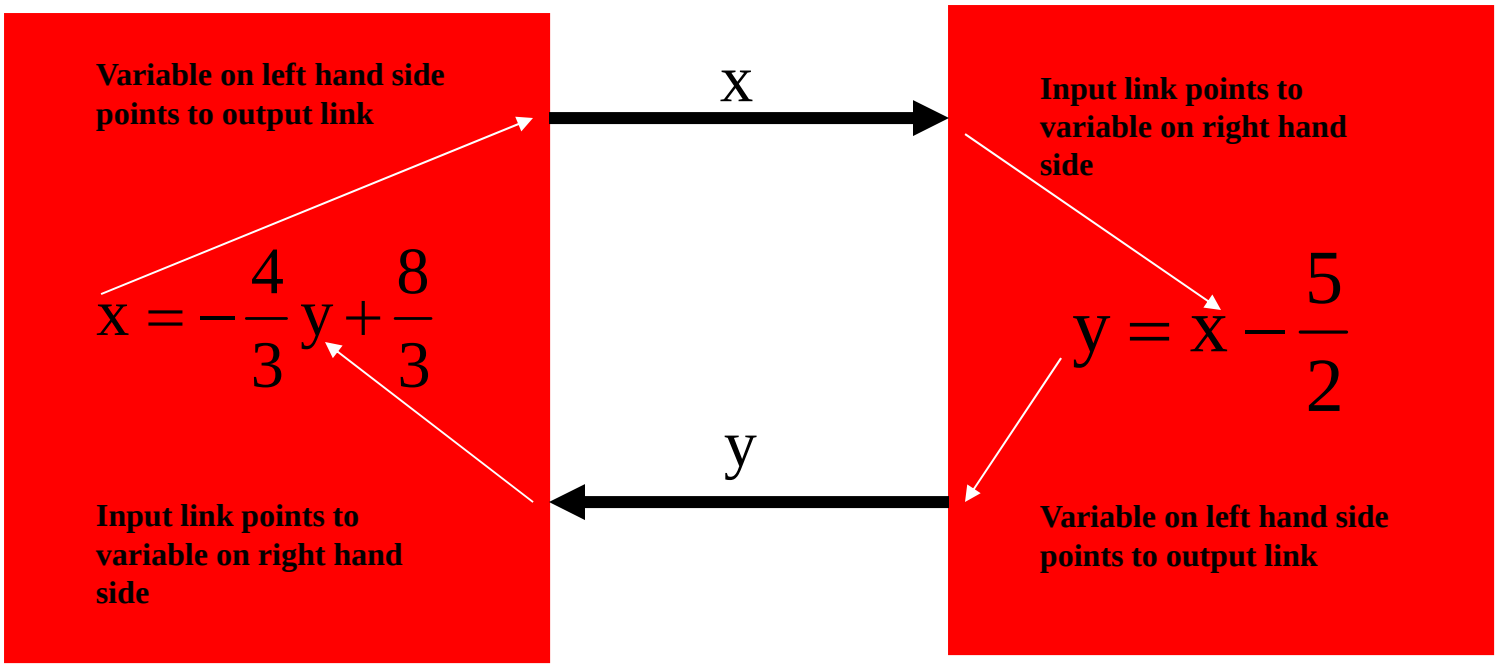
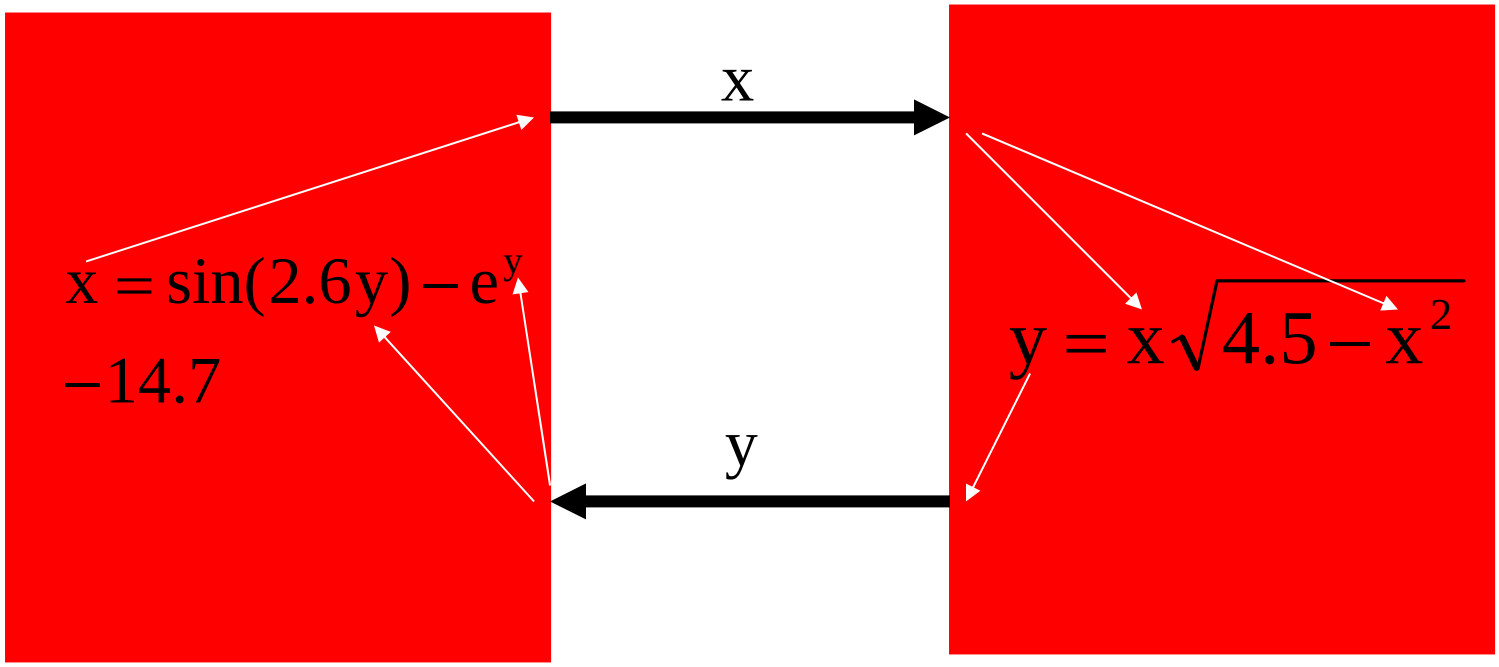
Network Conventions

- "Network Nodes" are equations.
- "Links" are unknowns.
- An interconnected network always has the right number of equations and unknowns. In fact the network IS a graphical representation of the equations.
- Otherwise, it is not fully specified.
  - You have to have n equations and n unknowns.
  - You always will for a complete system

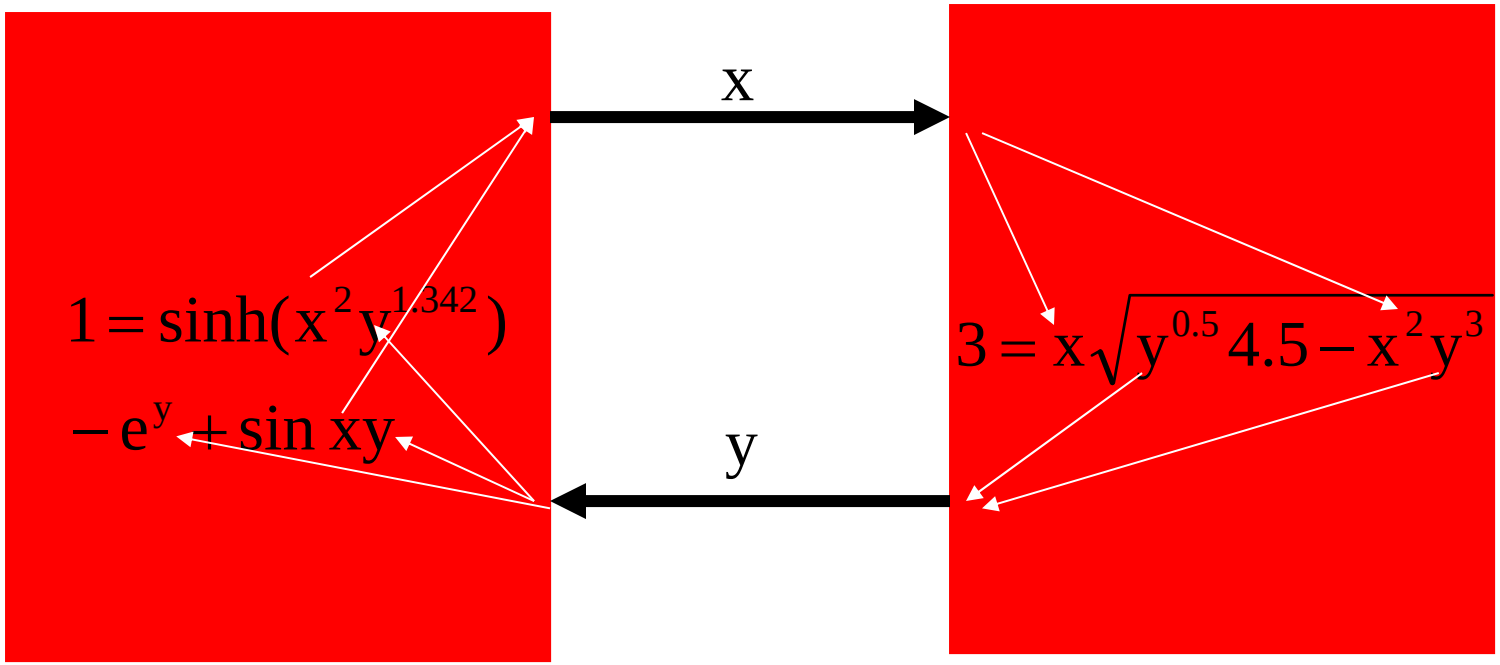
Links Point to Elements Within the Equations



You Can Use Any Nonlinear Node Equation You Want



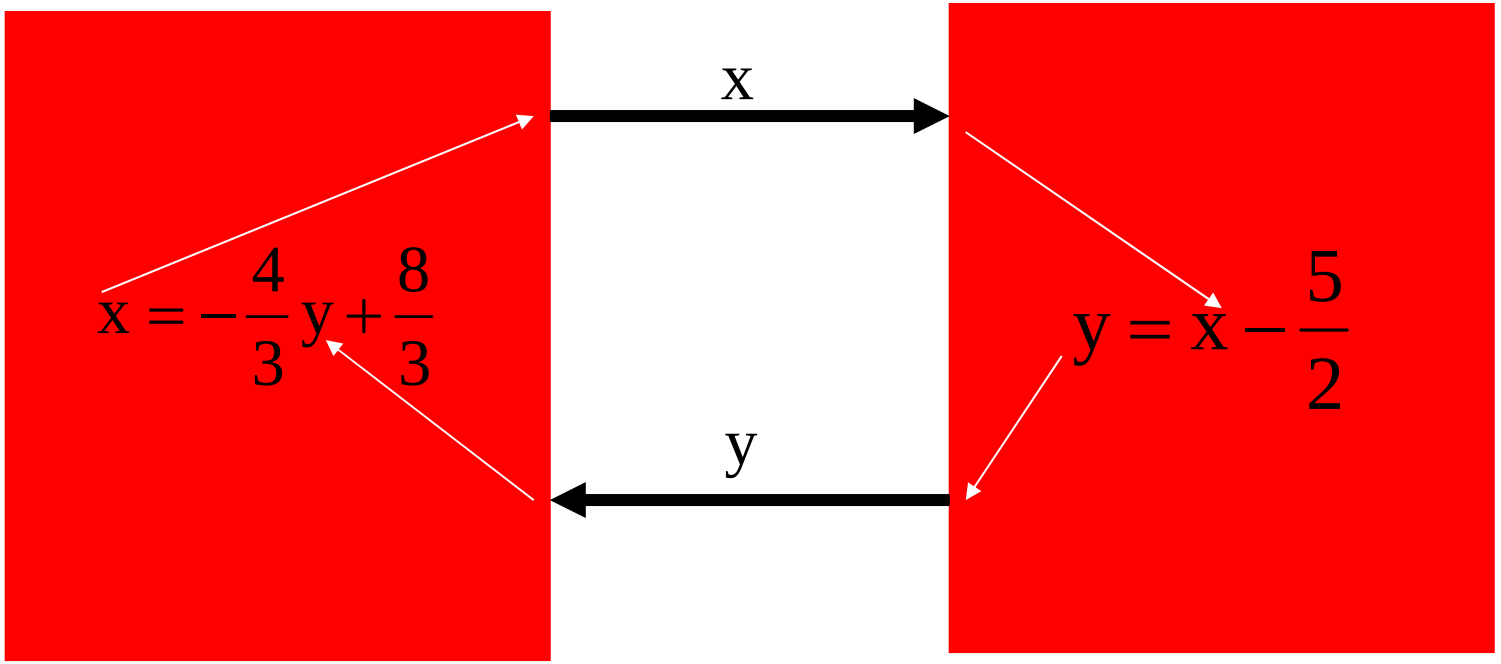
You Can Use Transcendental Equations In The Nodes Too



- There is no restriction.
- The assumed linear functional forms are just to simplify the concept

Embedded Solution Algorithm "Visits" Each Node Successively

- Takes information associated with input link
- Makes node calculation
- Associates it with output link
- Moves to next node



The Problem Is a “Fixed Point” Problem

$$x = -\frac{4}{3}y + \frac{8}{3}$$

$$y = x - \frac{5}{2}$$

$$x = -\frac{4}{3}\left(x - \frac{5}{2}\right) + \frac{8}{3}$$

$$x = f(x)$$

We say that x is a “fixed point” of f

And How Do People Solve "Fixed Point" Problems

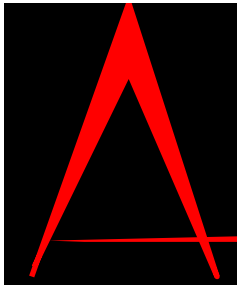
$$x = f(x)$$

- Pick x_0 arbitrarily

$$x_1 = f(x_0)$$
$$x_2 = f(x_1)$$
$$x_3 = f(x_2)$$
$$\ldots$$
$$x_{k+1} = f(x_k)$$

- and iterate until

$$\left| x_{k+1} - f(x_k) \right| < \varepsilon$$



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With Such Solutions…

- Do you need a Jacobian matrix of f? **NO!**
- Do you need a Hessian matrix? **NO!**
- Do you need a contrived optimization problem (as with complementarity)? **NO!**
- Do you need a FORTRAN like monster like GAMS? **NO!**
- Do you have to program anything except for the fixed point mapping f? **NO!**
- Is the algorithm robust? **YES!** There are locally convergent acceleration algorithms. (There are no globally convergent algorithms.)

How Do You Know You Have the Solution?

- **Just check to verify that all the nodal equations are satisfied!**
- What could be easier!
- There isn't any complex test such as gradient vanishing or Kuhn Tucker conditions or arcana like that.
- You don’t even **calculate** any Jacobians, Hessians, or complex operations research terms (no need, and certainly no need to waste valuable computer time).
- Anyone who has written software based on gradients or Hessians knows the meaning of the world “error.”
- The simplicity and computational efficiency are appealing.

When the Network Is Larger, It Becomes a Vector Valued Fixed Point Mapping Problem

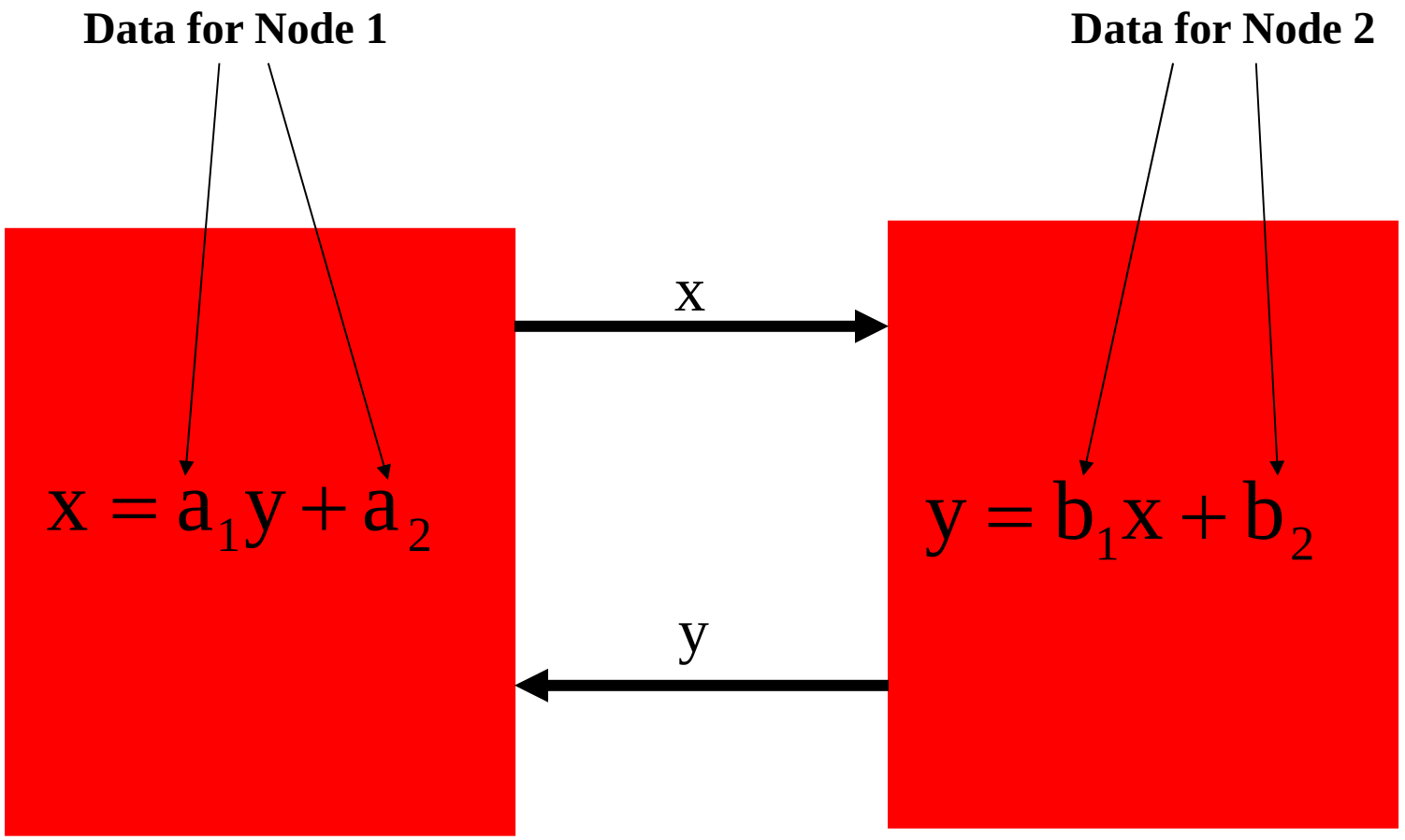
$$\underline{x} = \underline{f}\left(\underline{x}\right)$$

- Vector fixed point problems and the algorithms to solve them have been **WELL researched**, and they are **VERY efficient** compared to global optimization methods or "complementarity" problems that devolve from global optimization.

Vision of a Network Model (Like ArrowHead or ArrowHead)

- The only software you have to write is the **individual node equations**.
- If those node equations are pre-programmed, you don't have to write any software!
- You just have to understand and accept the node equations.
- The node equations are right out of the microeconomics textbook. They are not arbitrary at all.
- Preprogram a large array of node software and allow you to interconnect it using networks.
- You can write any new node logic you want.

A General Model with Coefficients as Node Data



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"Double Click" On Node 1 Opens Table of Node 1 Data

- An Excel spreadsheet with every data element for each individual node

Node 1 Coefficients	
a1	16.03
a2	-4.1

“Pivot” On Entire Network Opens…

- An Excel Pivot Table with every data element for every node (1 and 2)

Node 1	a1	16.03
Node 1	a2	-4.1
Node 2	b1	6.7
Node 2	b2	2.05

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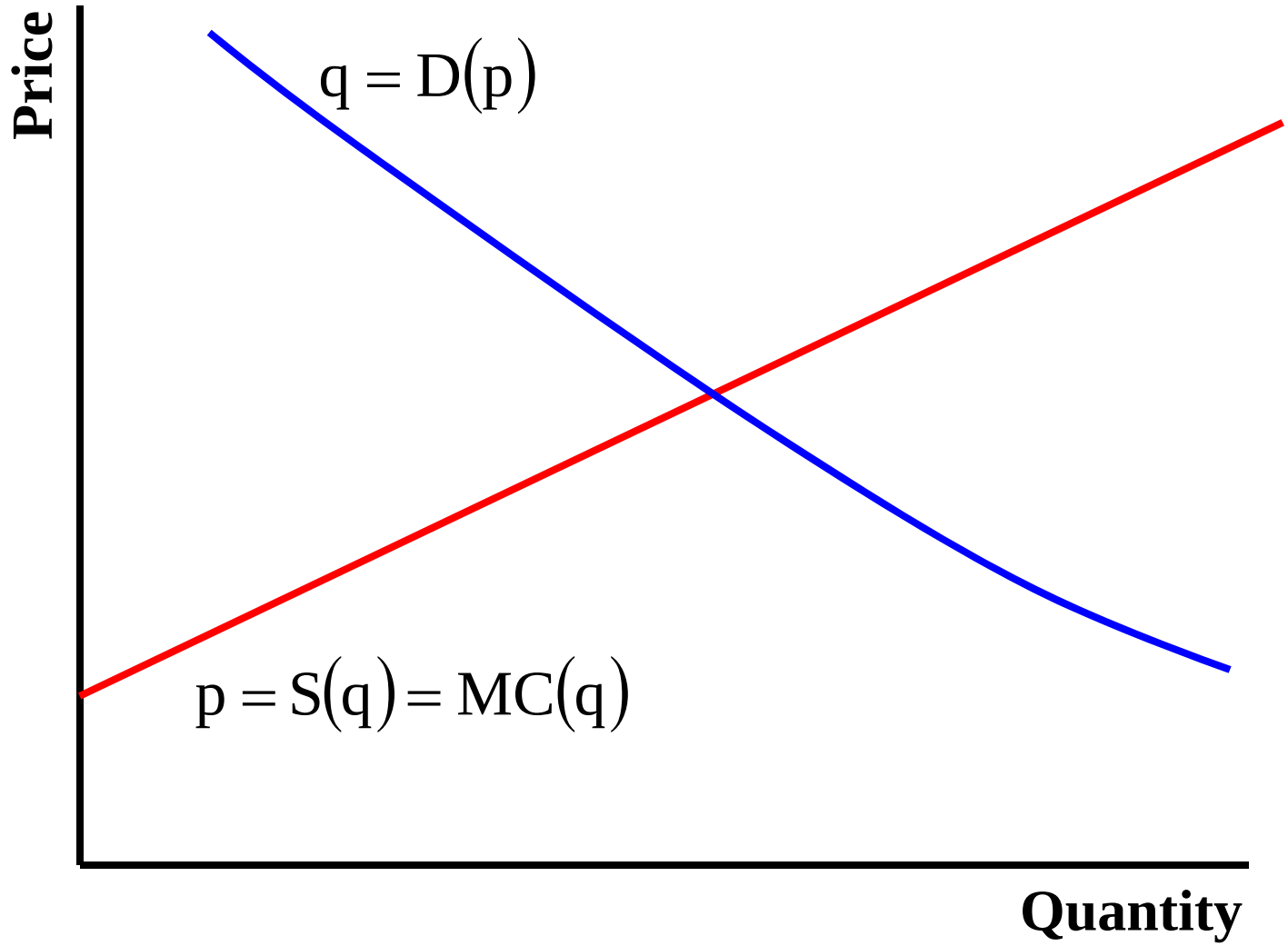
3. How Does This Work in Economics?

Single Supply-Demand Curve



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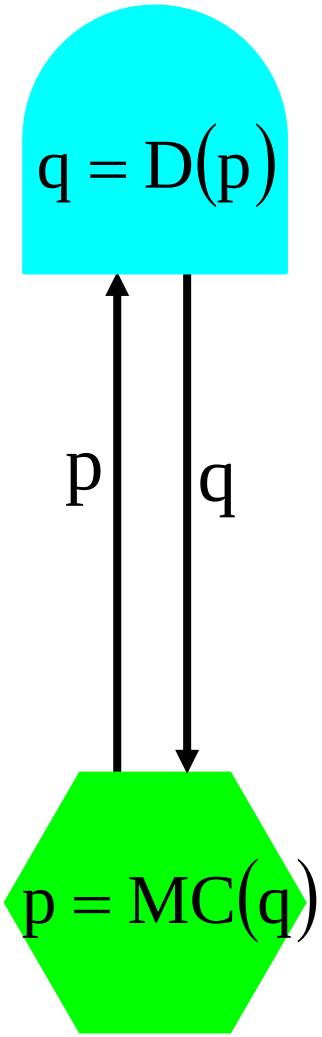
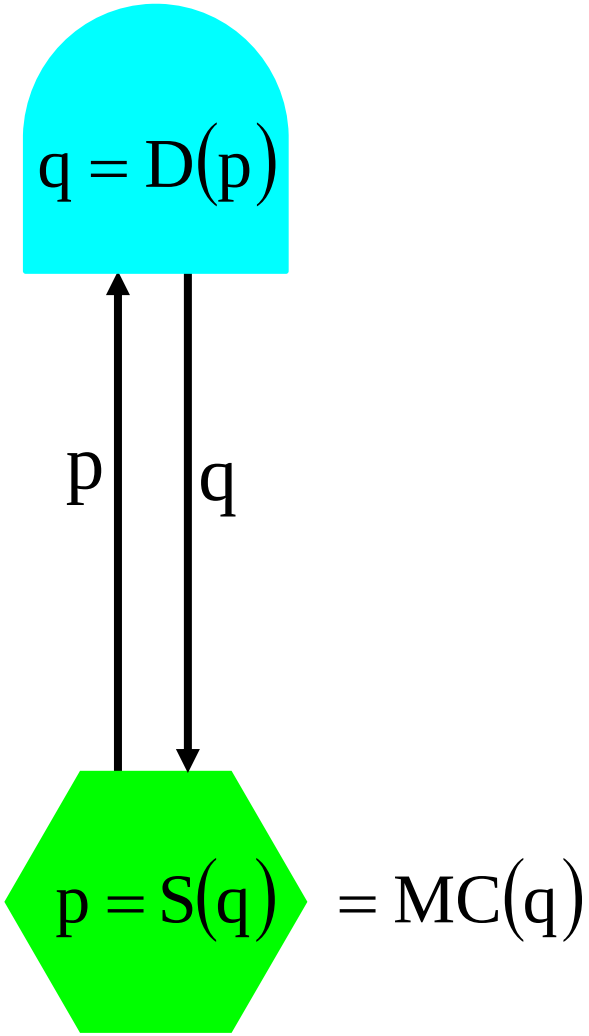
Supply-Demand Curve Model with Links



Economic Models Are Best Formulated as Fixed Point Problems



- Guess p_0
- Calculate

$$q_1 = D(p_0)$$

- Calculate

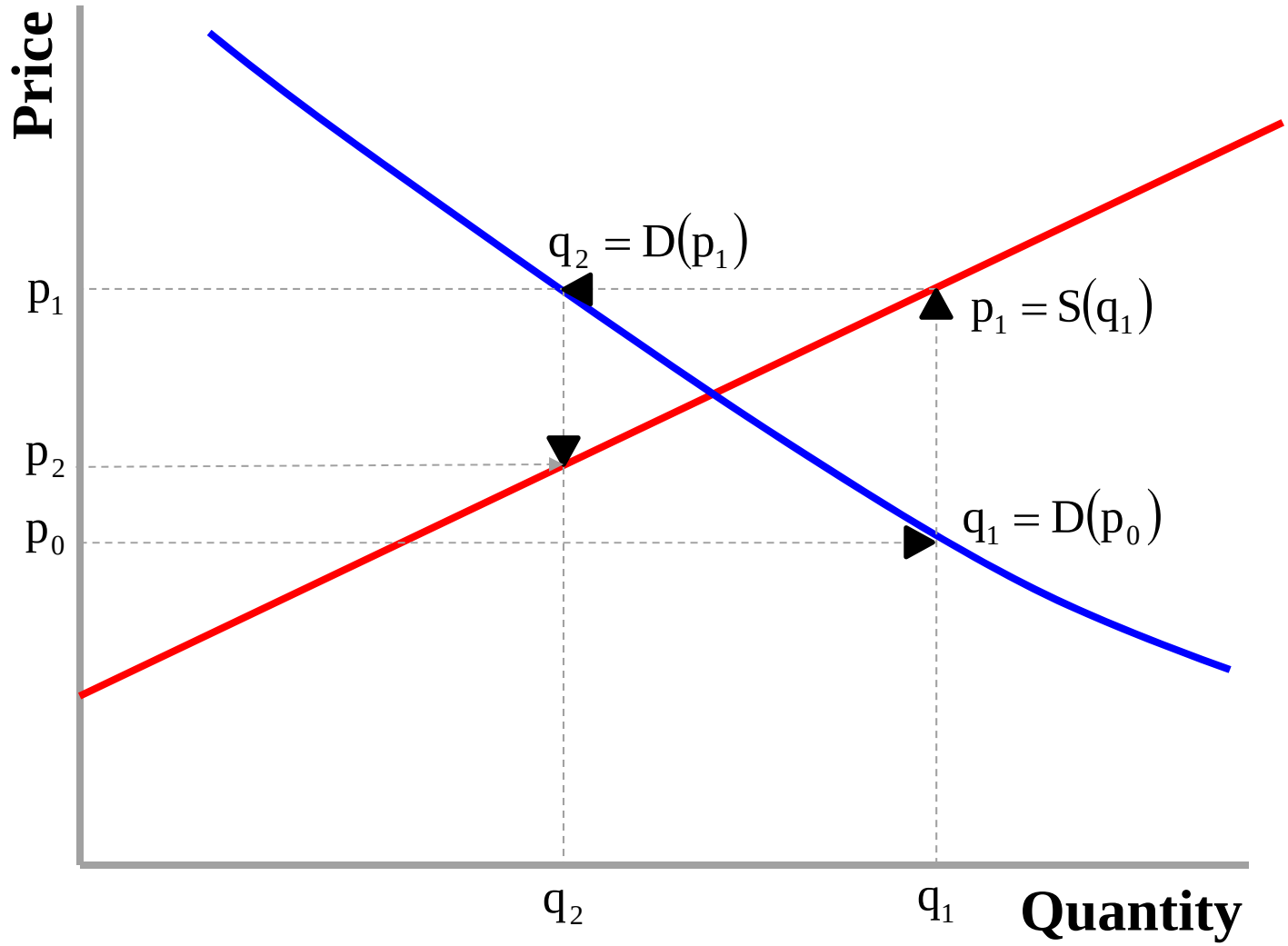
$$p_1 = S(q_1)$$

$$p_1 = S[D(p_0)]$$

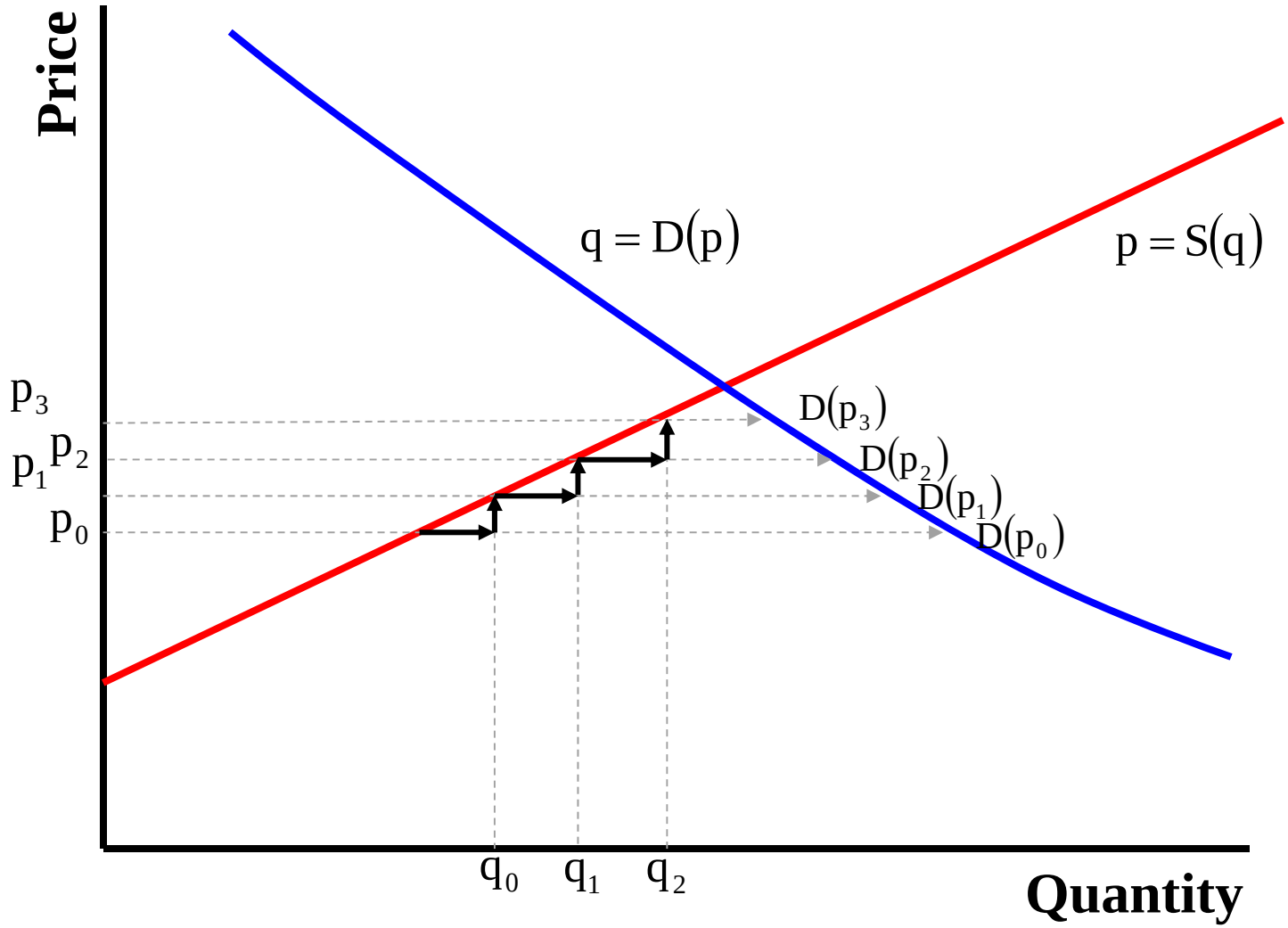
$$p_1 = f(p_0)$$

$$p = f(p)$$ fixed point

Fixed Point Is an Economic Cobweb



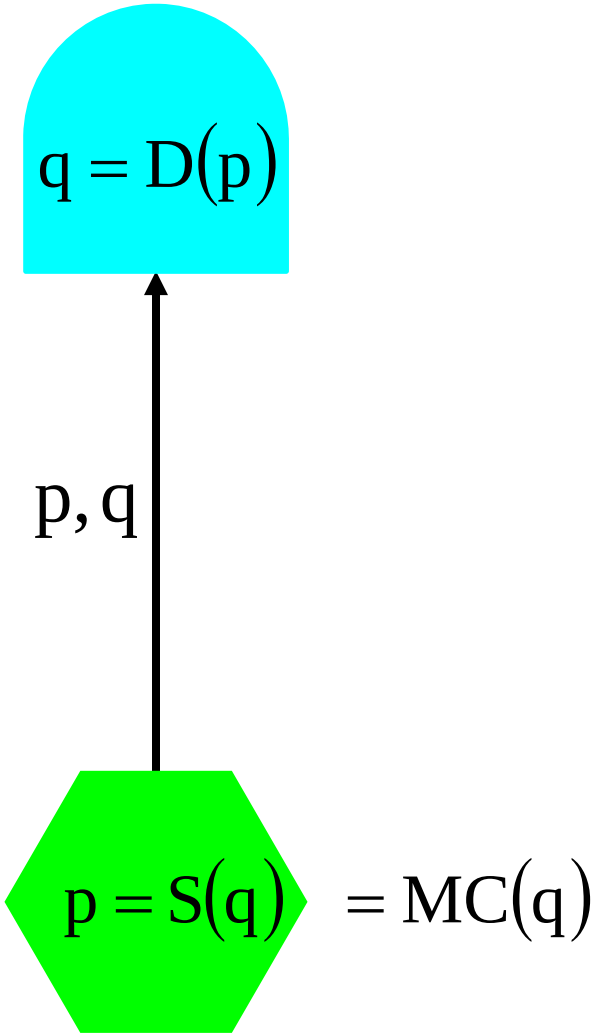
Fixed Point With Relaxation



Results

- Local convergence with acceleration methods is proved; you will find one solution that exists.
- There are no meaningful necessary or sufficiency conditions for uniqueness (as there are not with global welfare maximization)
- There are no meaningful necessary or sufficiency conditions for existence.

Links with Two Unknowns, Price and Quantity, Point in the Direction of Physical Flow



Could EIA Do This?

- People can start it on Monday
- Be fluent on Wednesday after two days training
- Be modifying the network to make it intrinsically EIA's
- Be done in about a month (gas) and six weeks (oil)
- Have definitive results all along the way, becoming more definitive at the end of the period
- The external cost would be a pittance compared to what you are probably paying

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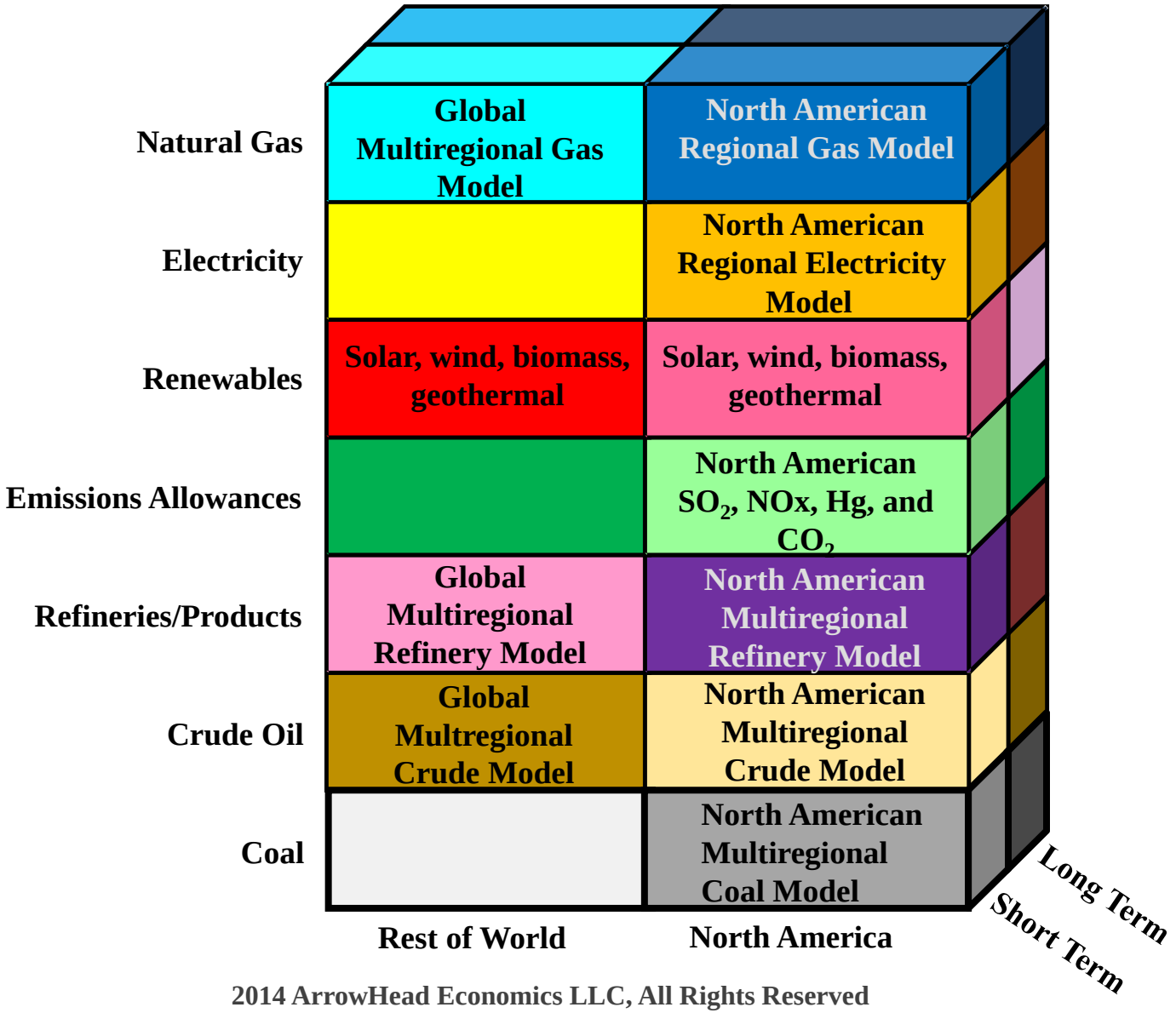
4. So What Have You Put Together Like This ArrowHead?

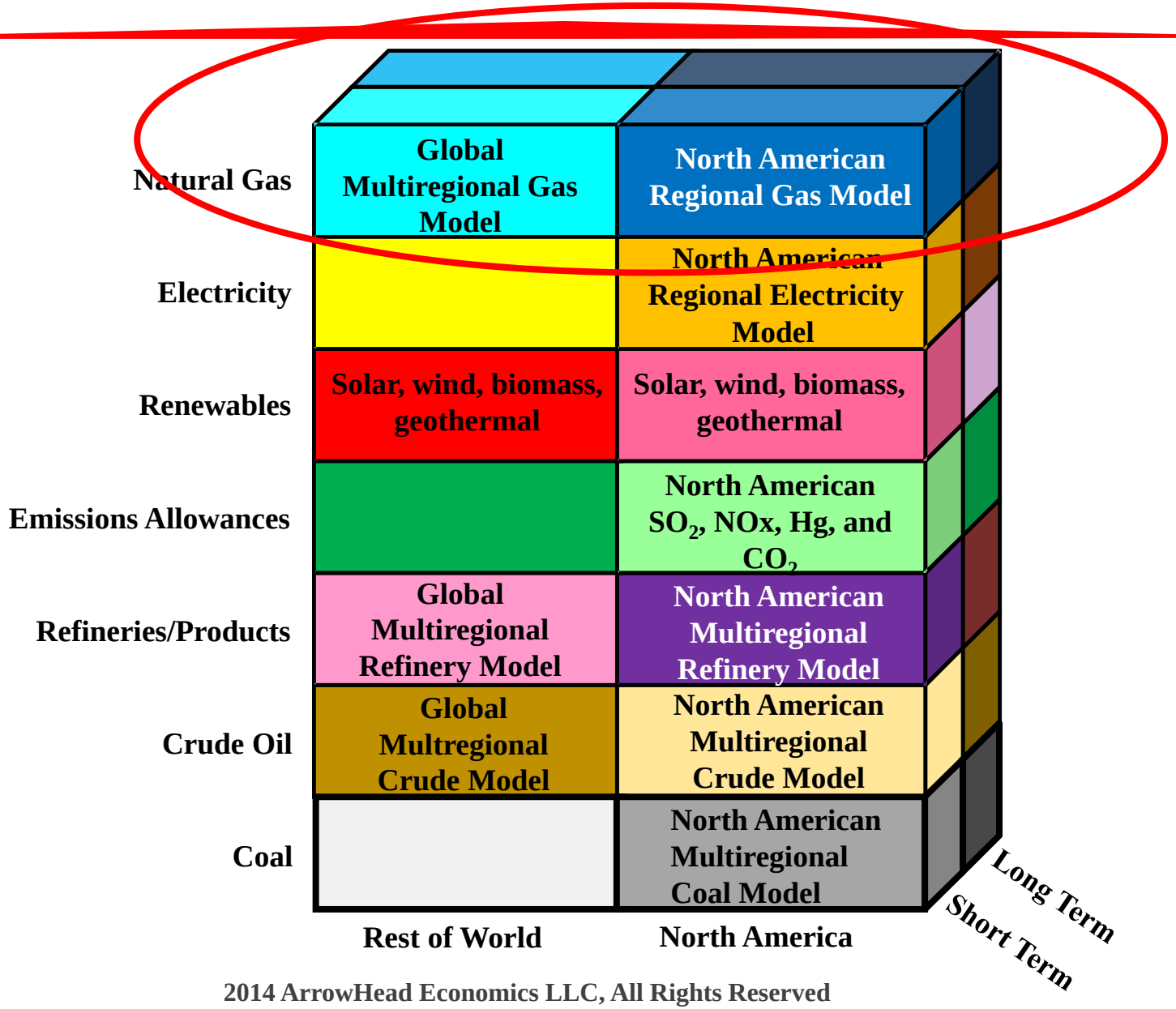
Could EIA use it?

Could EIA modify it or point its own data into it?

Suite



Global and North American Natural Gas



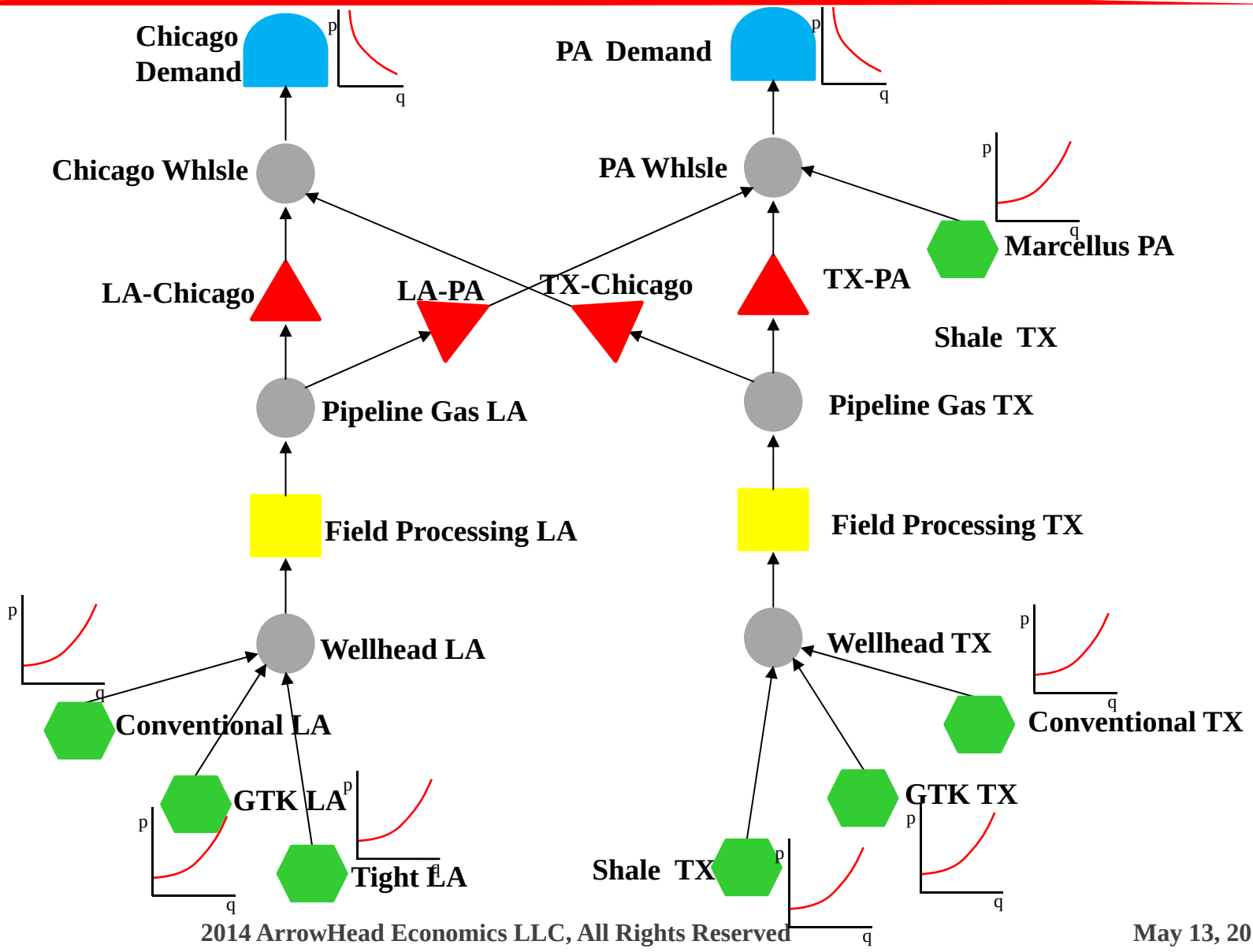
How Would You Go About Building a North American Gas Model?

- Array supply regions and develop supply curves for every type of supply
  - Existing reserves
  - To-be-proven reserves (resource)
  - Growth, conventional discrete, associated, shale, tight sands, CBM, continuous, etc.
- Array demand regions and develop segmented demand curves for each.
- Array pipelines
  - Presently existing pipeline infrastructure (cost, capacity)
  - Prospective pipeline infrastructure (capex, opex, capacity)
- Assemble cost and capacity for existing and prospective LNG import and export facilities

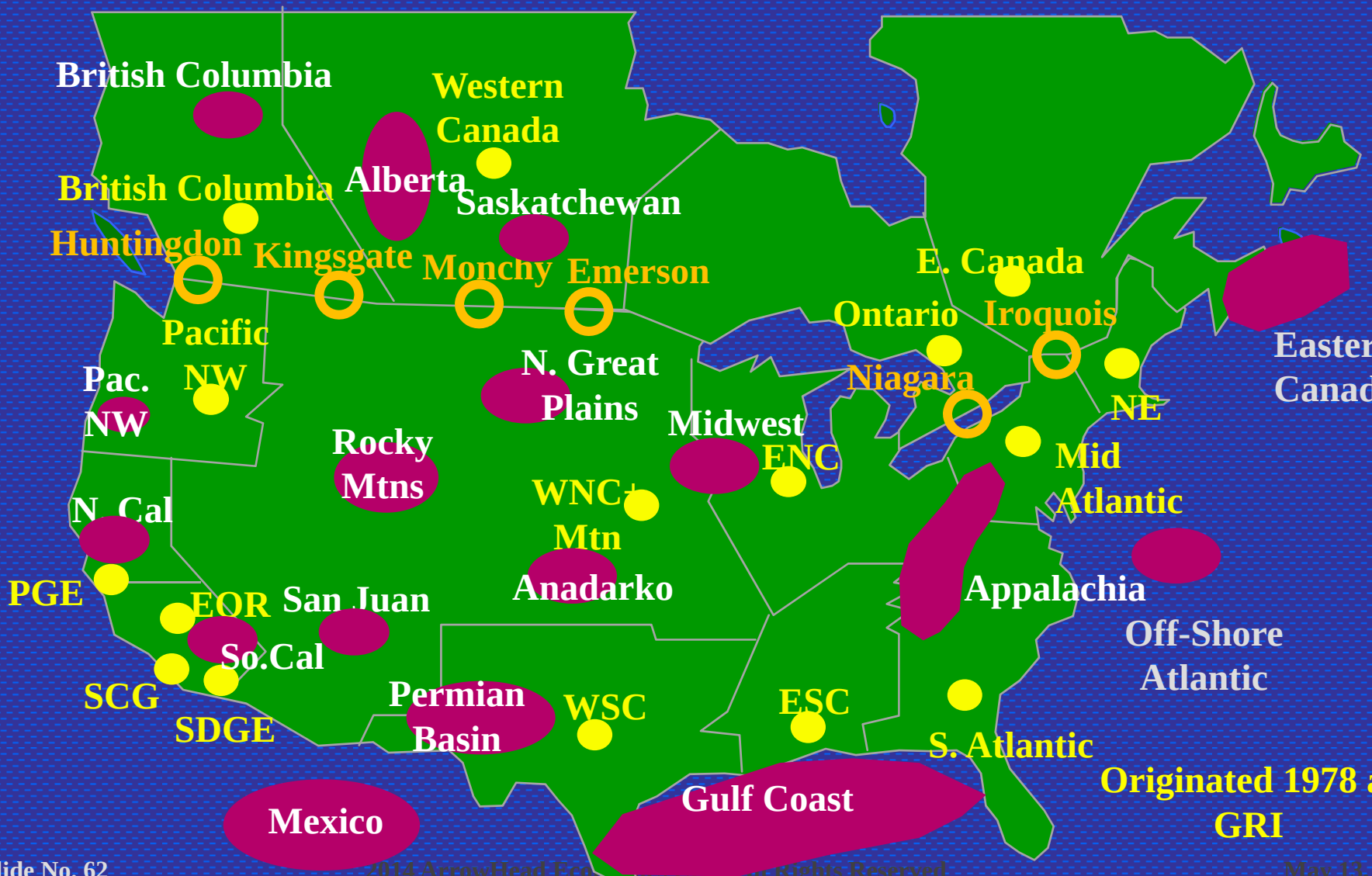
How Would You Do It?

- I would put a big piece of butcher paper on the wall.
- I would draw
  - Existing and prospective supply nodes where the supply is
  - Gathering and field processing where gathering and field processing are
  - Coproduction of NGL where they exist
  - The commodities and units associated with every link (e.g., bcfd, Tcf/yr, MMbbld, tons/yr)
  - Existing and prospective pipelines leaving supply regions
  - Pipeline junction points (e.g., Tuscola, Illinois)
  - Existing and prospective LNG import facilities
  - Existing and prospective LNG export facilities
  - Existing and prospective, segmented gas demand (residential, commercial, industrial, transportation, electric generation, refining)
- I'd have out the pencil and eraser and draw every existing and prospective supply chain from source rock to burnertip.
- I would structure the problem and the detail required.
- I can do this with confidence because I know that the network is "data" to the modeling system.
- **I would never to what OR people do—write "equations."**

1. Network Centric Model (Right from the Butcher Paper)



North American Regional Gas Model (NARG)



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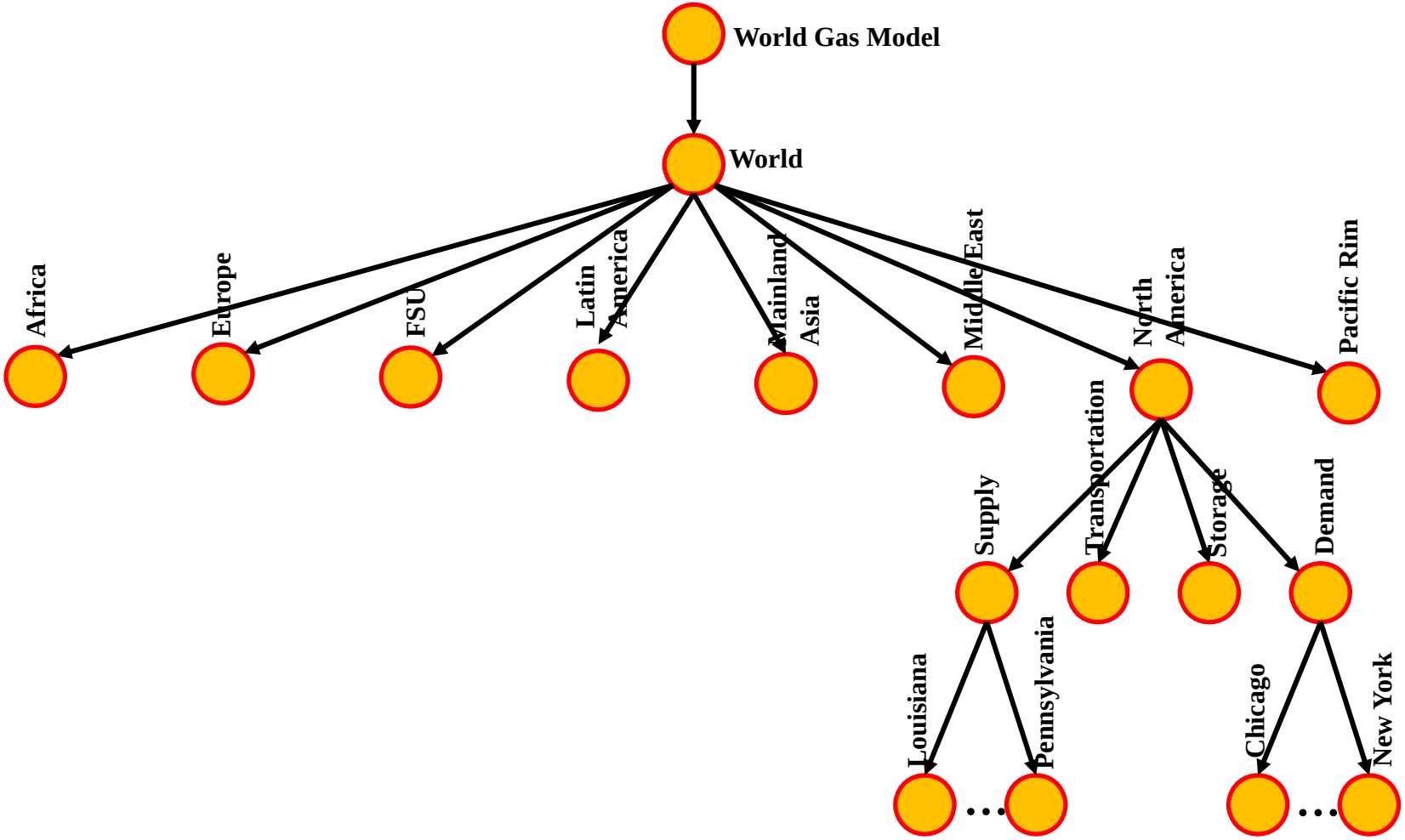
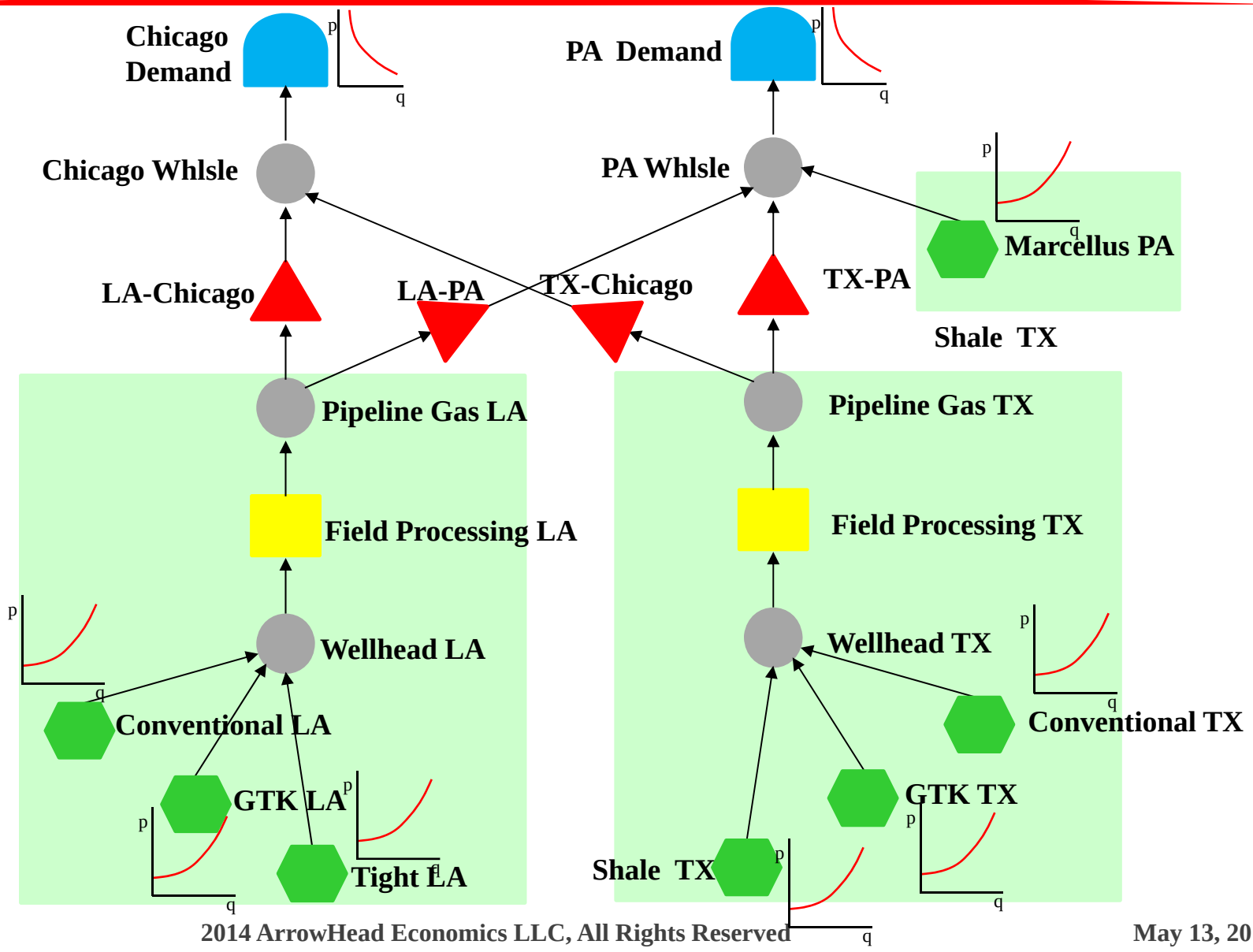
I Would Then Regionally Hierarchicalize the North American Model

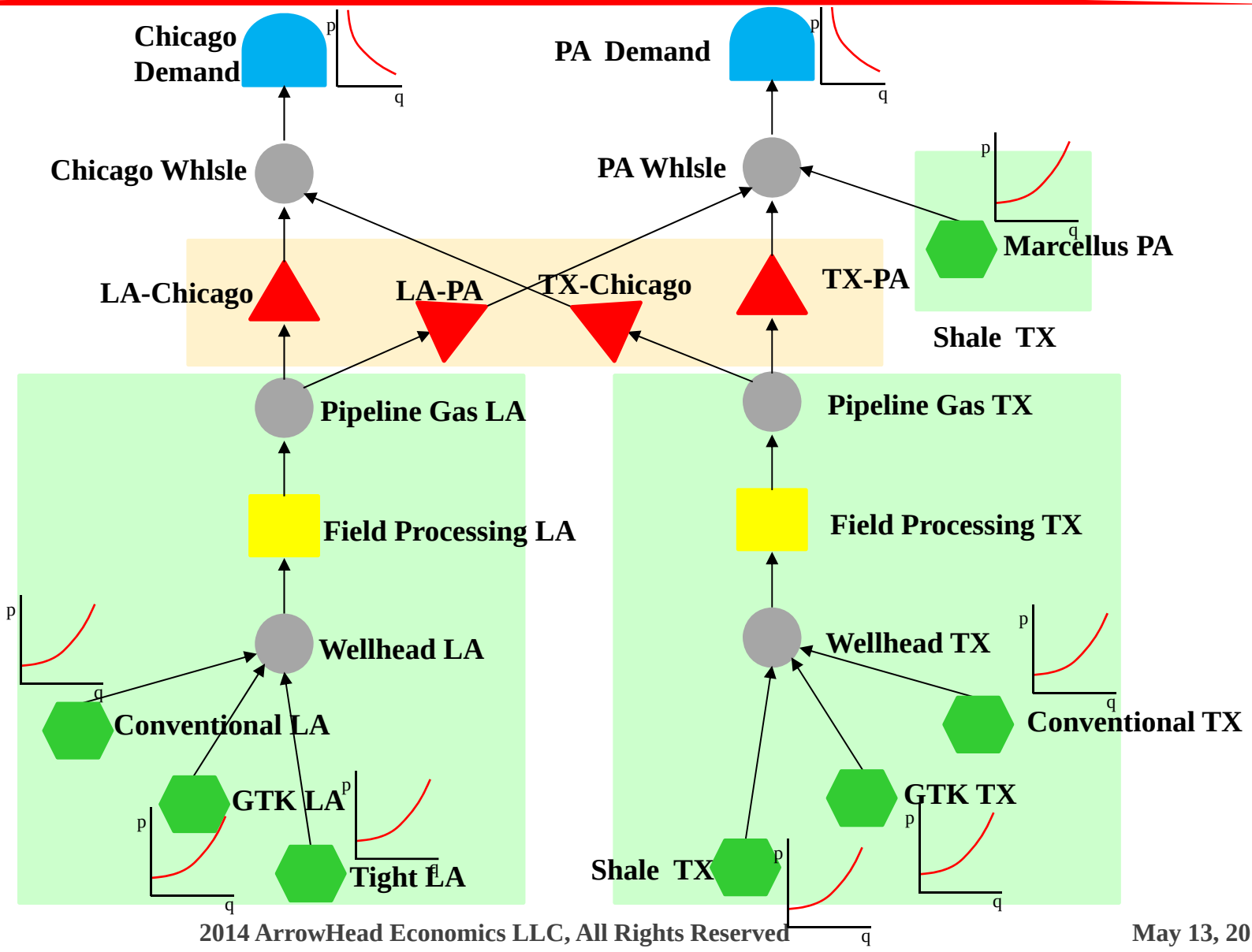
Hierarchical Regional Organization (GIS Form)



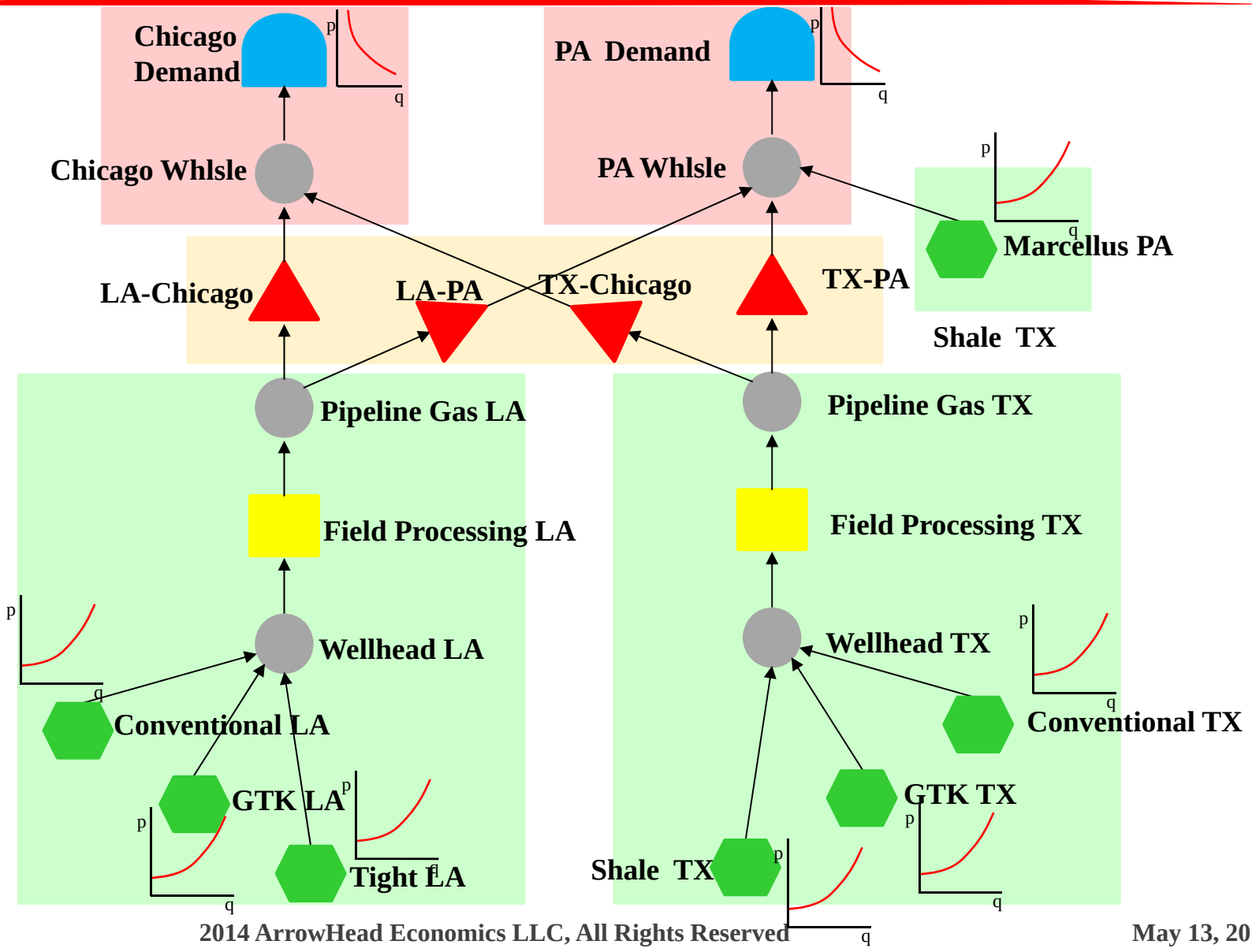
Group Supply Regions and Structures



Group Transportation Regions and Structures



Group Demand Regions and Structures



Then I would Drag and Drop My Network into a Graphical Network Modeling System

- **I would demand that there be a visual network software system that allows trivially easy, visual, modern computation network entry.**
  - Visual drag and drop of nodes and links.
  - Automated script language that creates nodes and links.
  - Cut/copy/paste and other advanced node/link management features.
- I would use the butcher paper as a template.
- I would drag node and links in from the software palette and replicate the butcher paper drawing.

Palette of Agent Nodes

Demand

Simple Supply

Discrete Choice

Storage

Transportation

Upper Bound

Electric Generation

Hub

Conversion

Refinery

External Price

Depletable Resource

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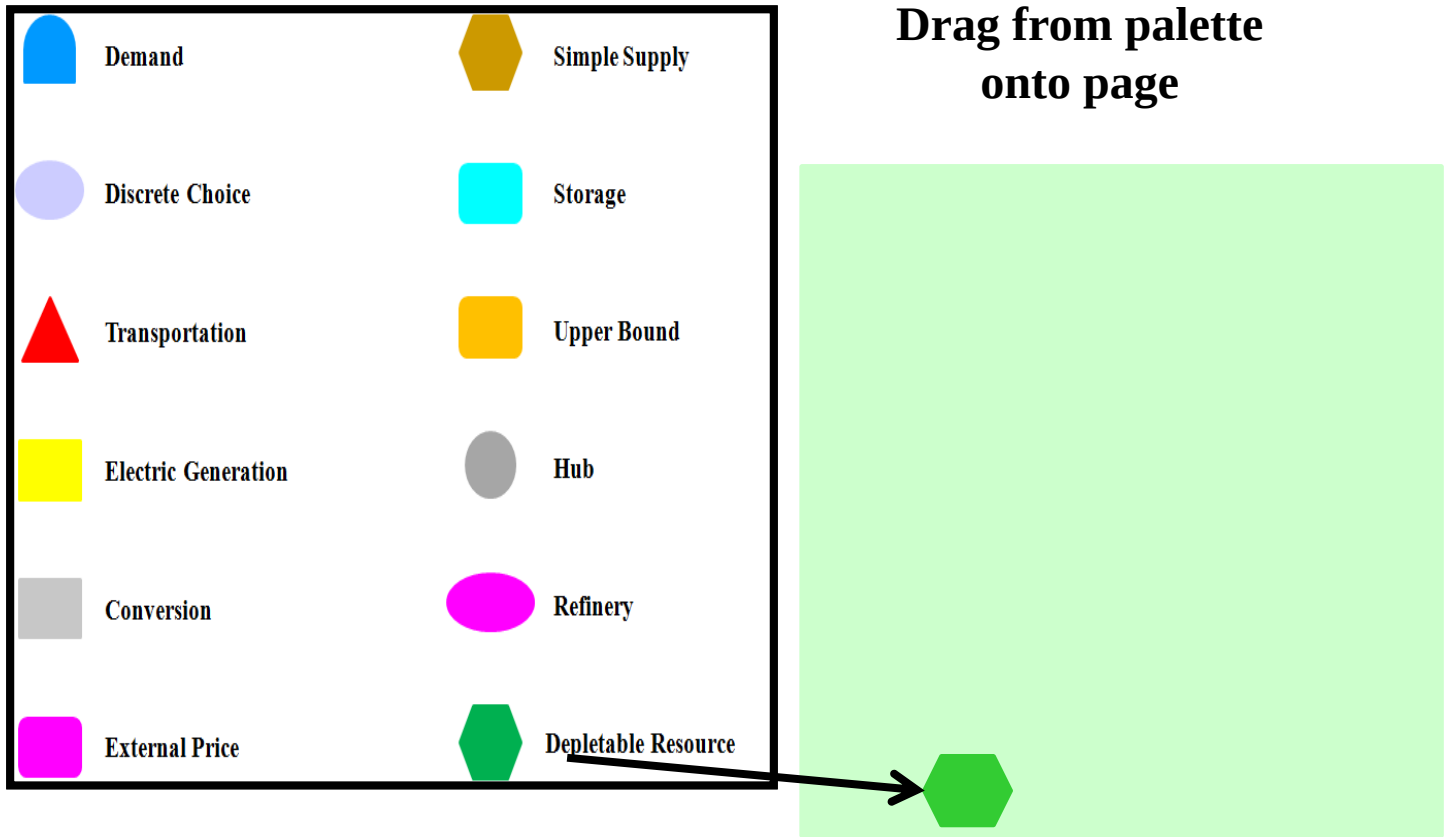
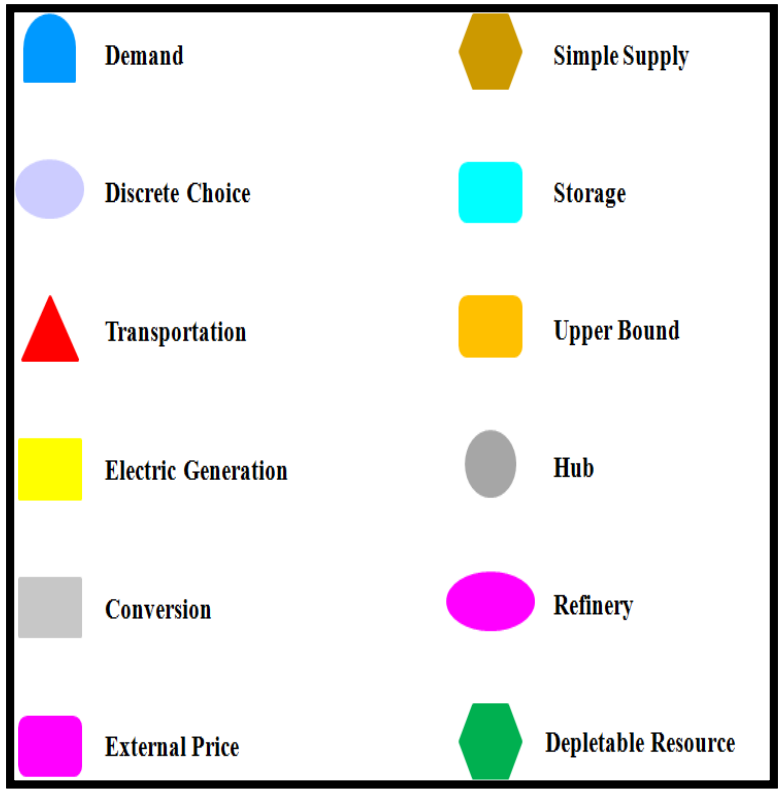
Here Is What a Drag and Drop Session Looks Like

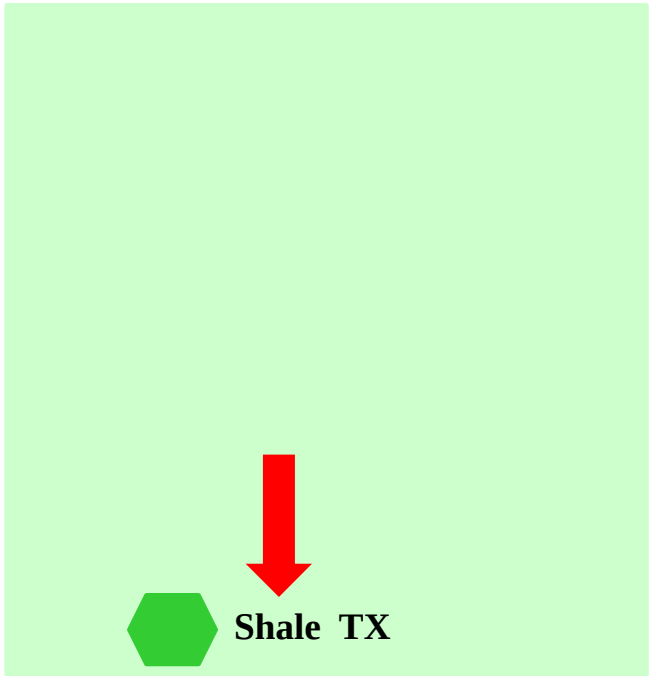
1. Drag a depletable resource supply node in from the node palette and drop it.



Here Is What a Drag and Drop Session Looks Like

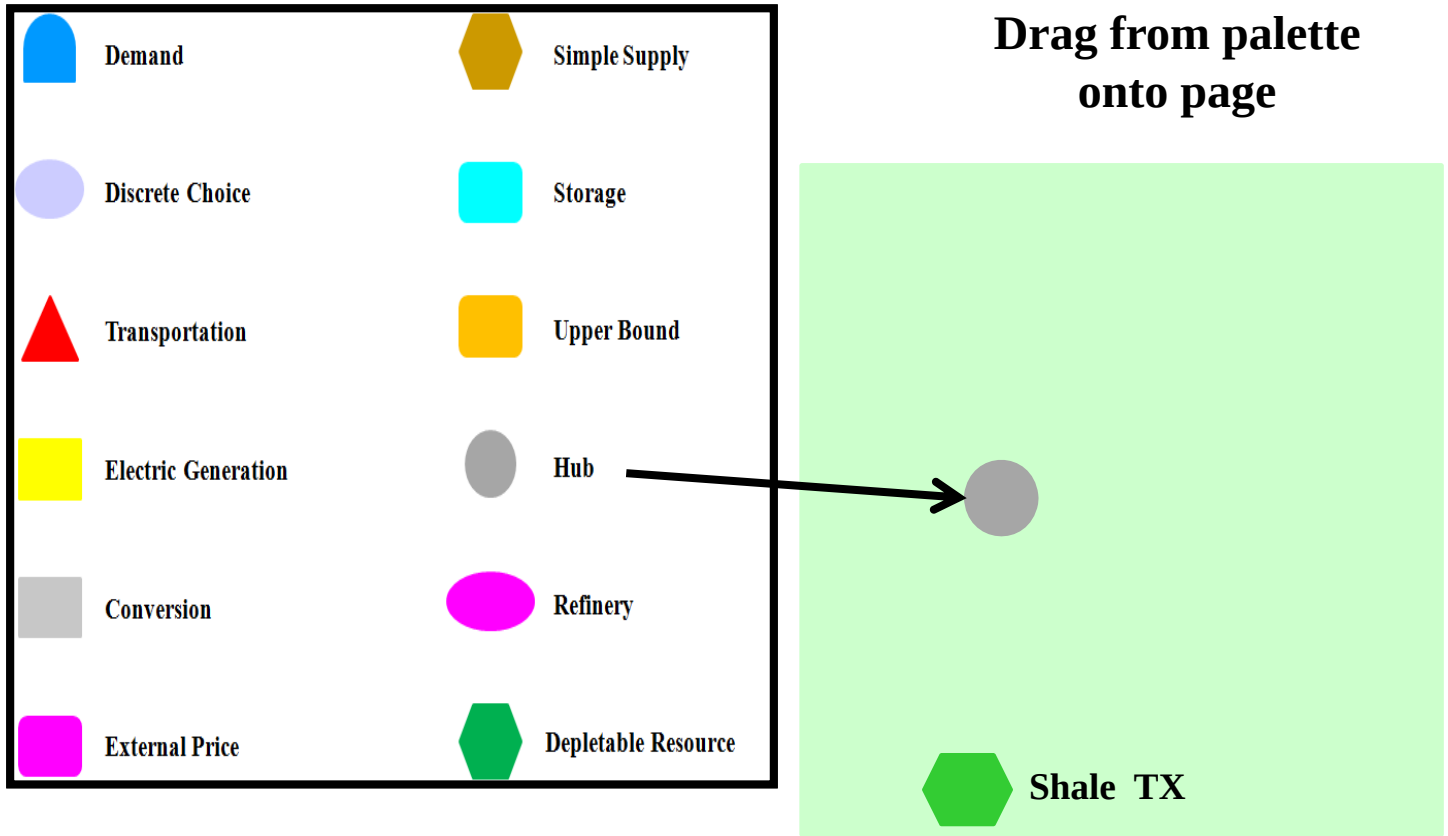
2. Type in the name on the node you just dragged in.





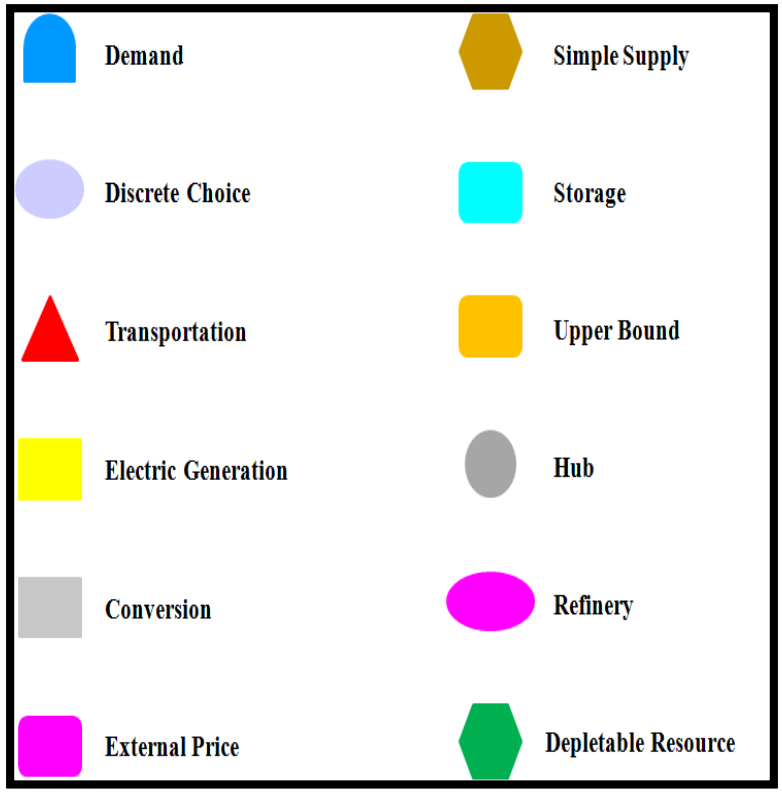
Here Is What a Drag and Drop Session Looks Like

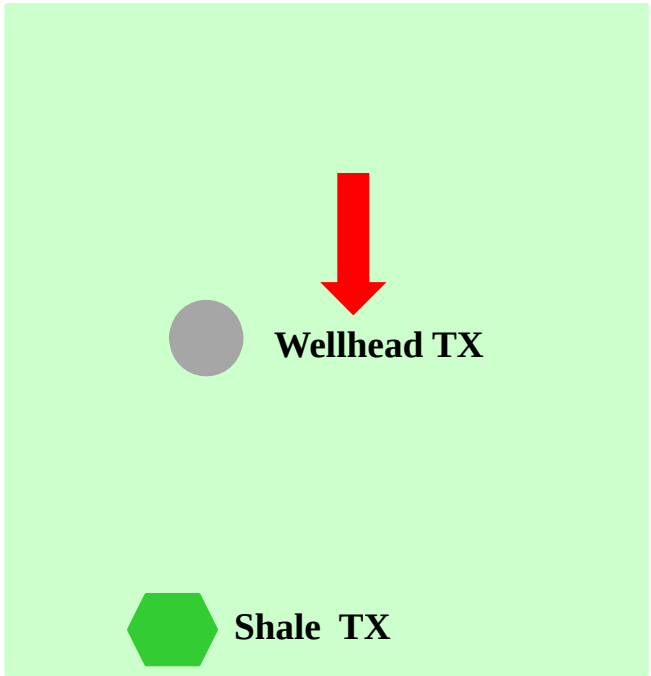
3. Drag a market hub node in from the node palette and drop it.



Here Is What a Drag and Drop Session Looks Like

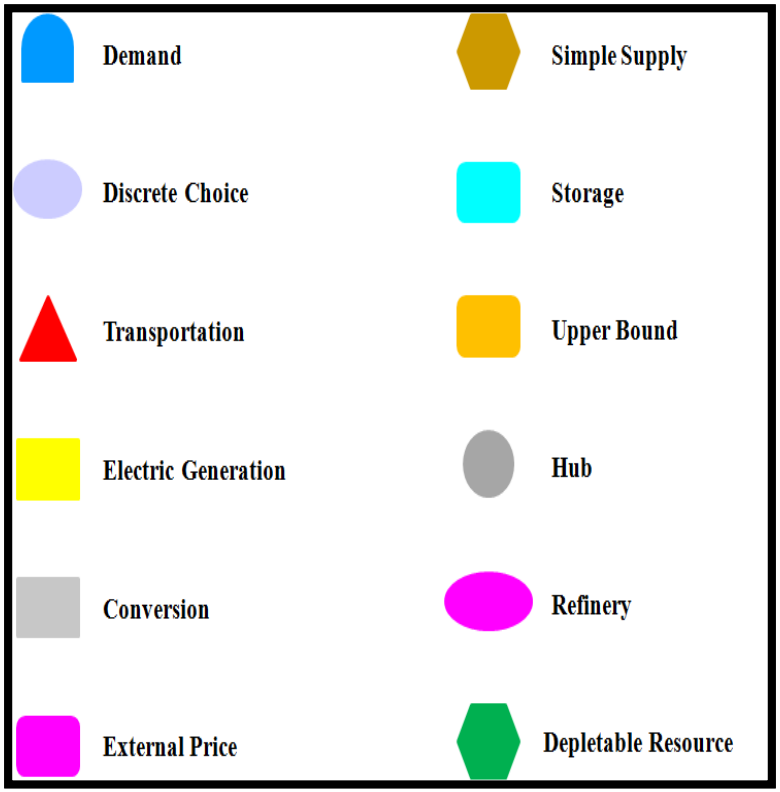
4. Type in the name of the hub

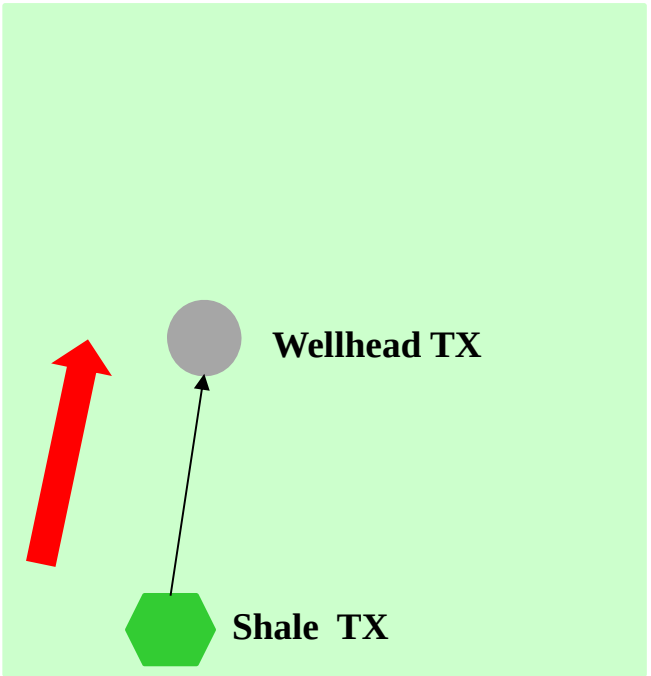




Here Is What a Drag and Drop Session Looks Like

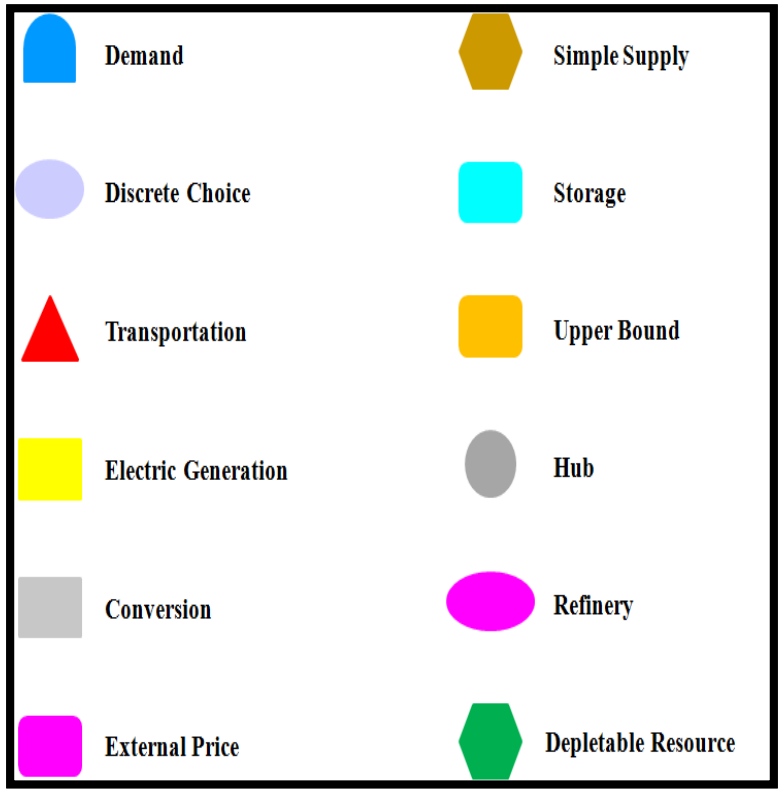
5. Drag the link by clicking on the origin node and dragging to the destination node.

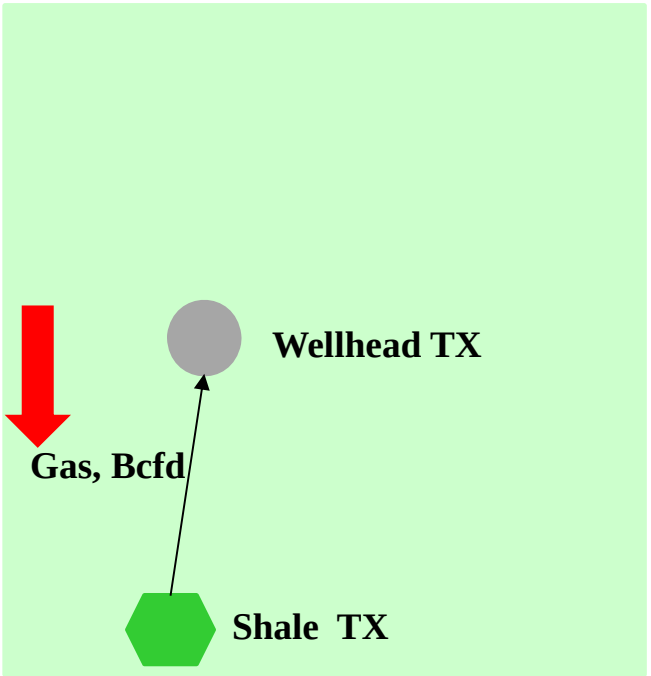




Here Is What a Drag and Drop Session Looks Like

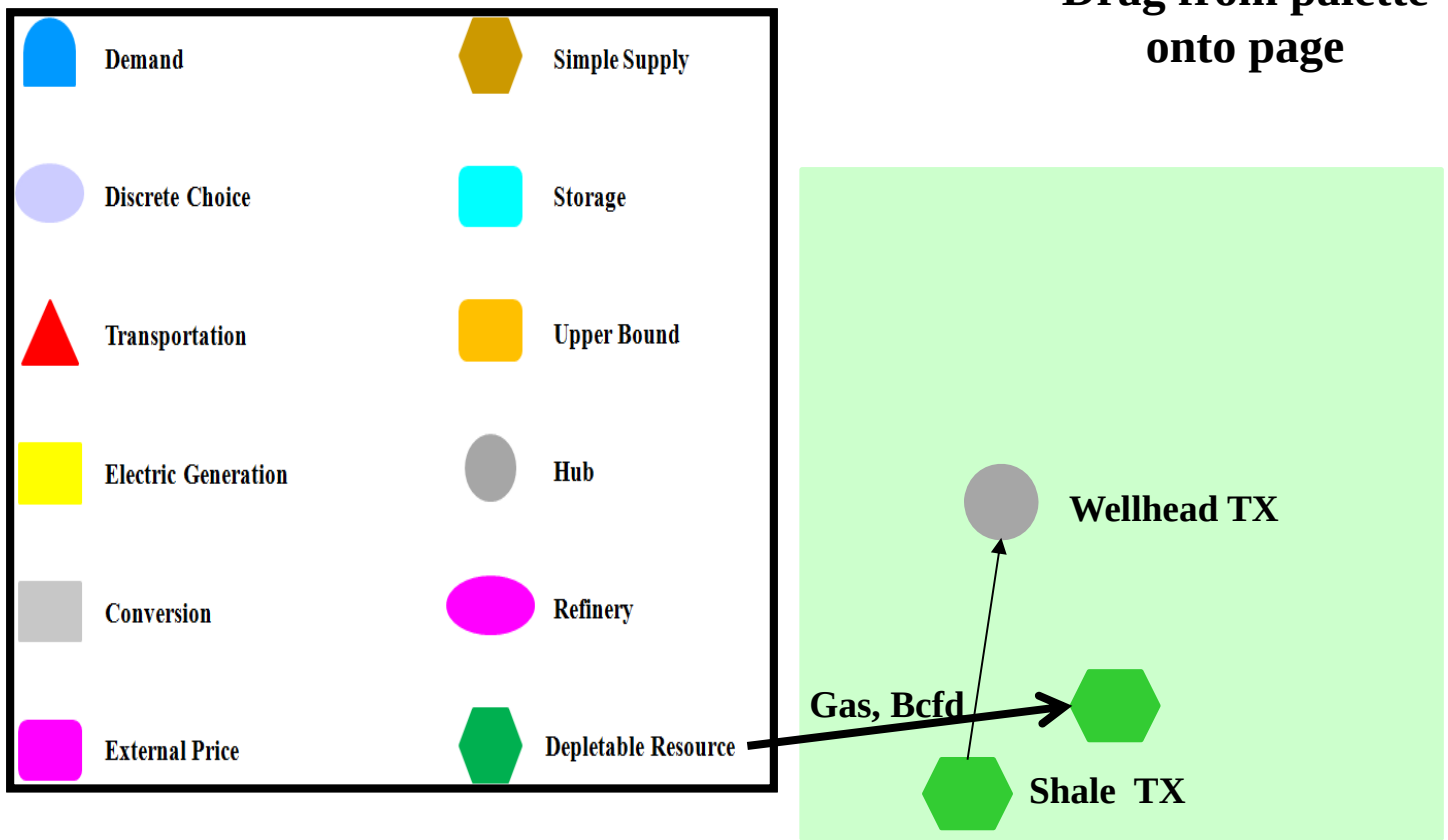
6. Type the commodity name and the units onto the link





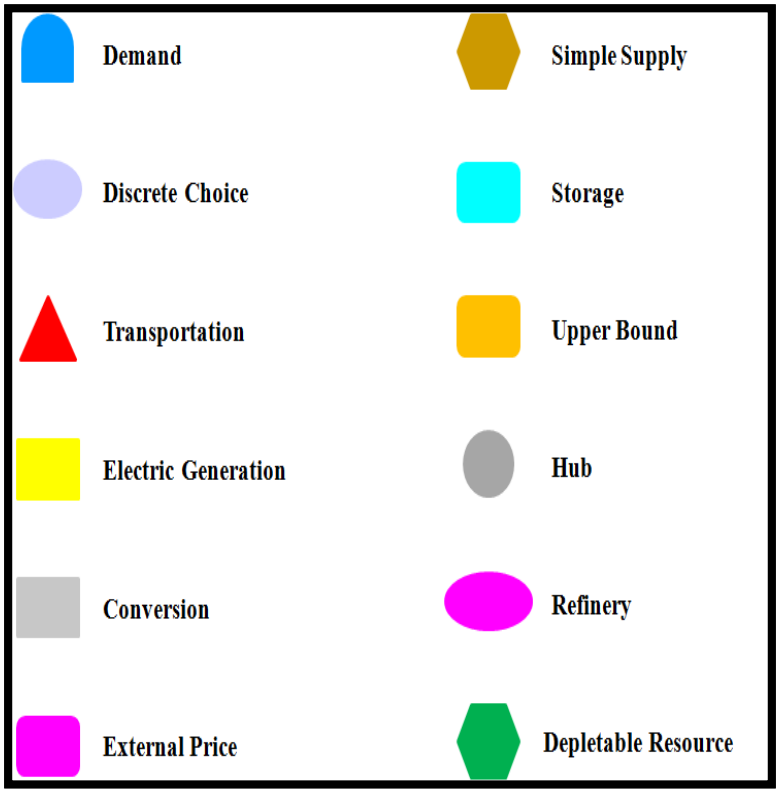
Here Is What a Drag and Drop Session Looks Like

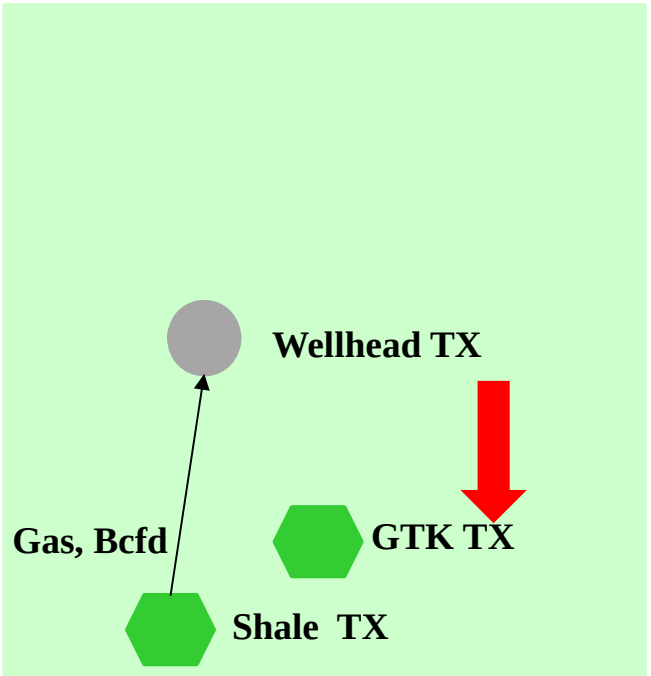
7. Drag in a depletable resource node from the palette



Here Is What a Drag and Drop Session Looks Like

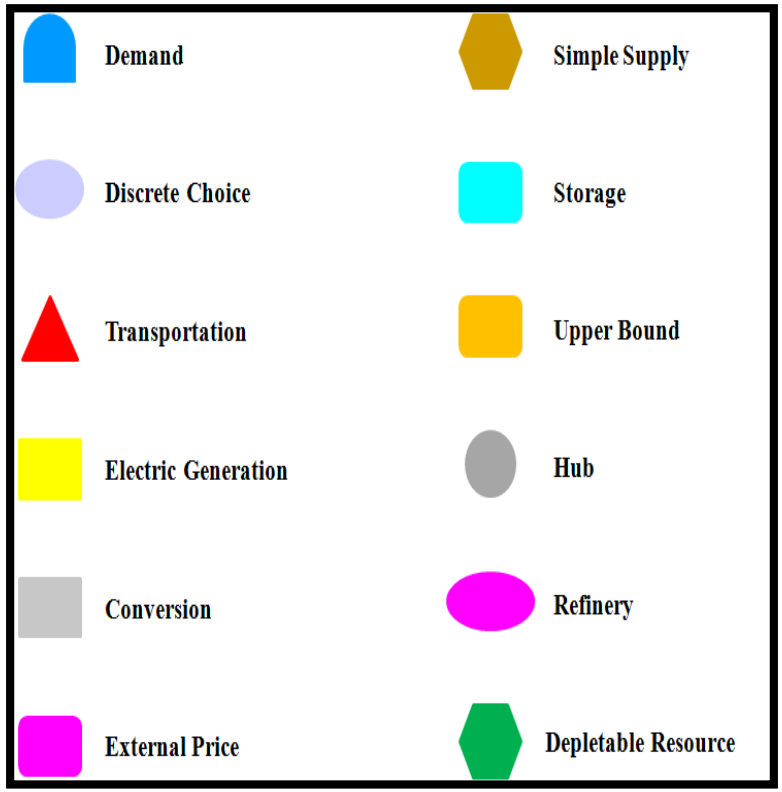
8. Type in the name of the new node

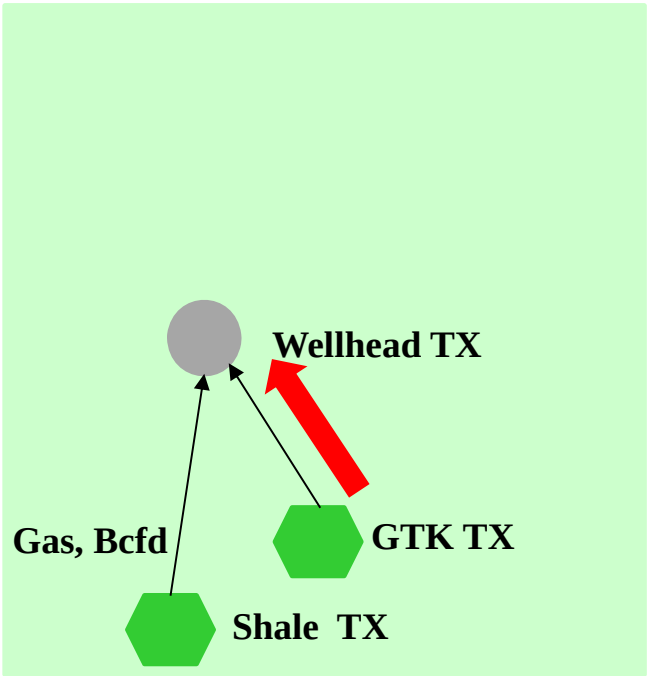




Here Is What a Drag and Drop Session Looks Like

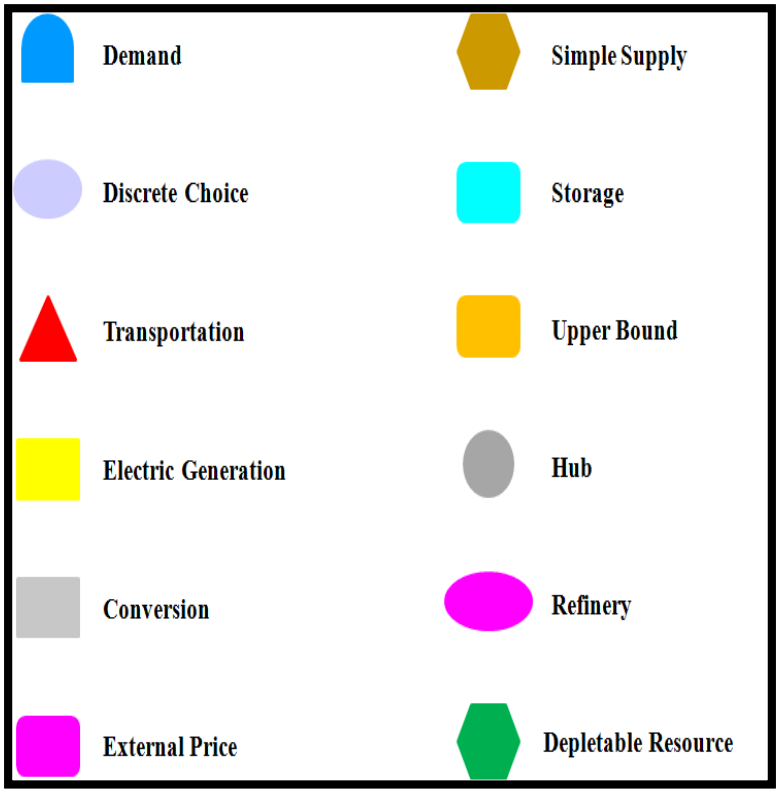
9. Drag the link by clicking on the origin node and dragging to the destination node.

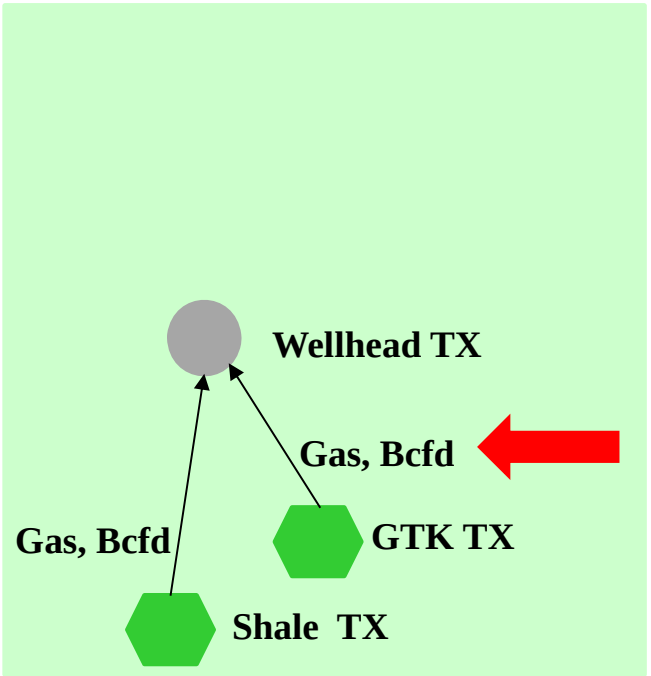




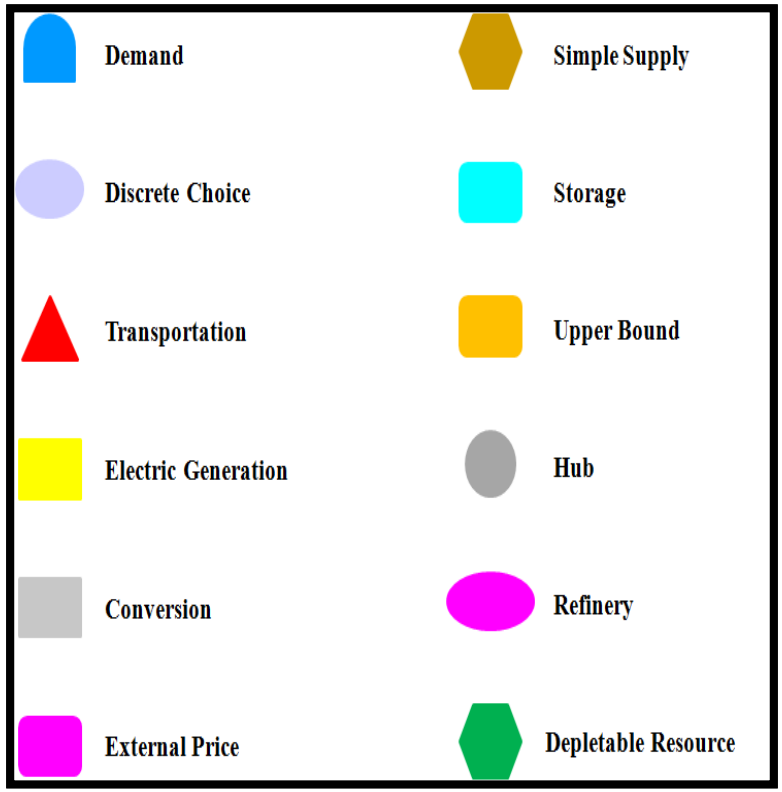
Here Is What a Drag and Drop Session Looks Like

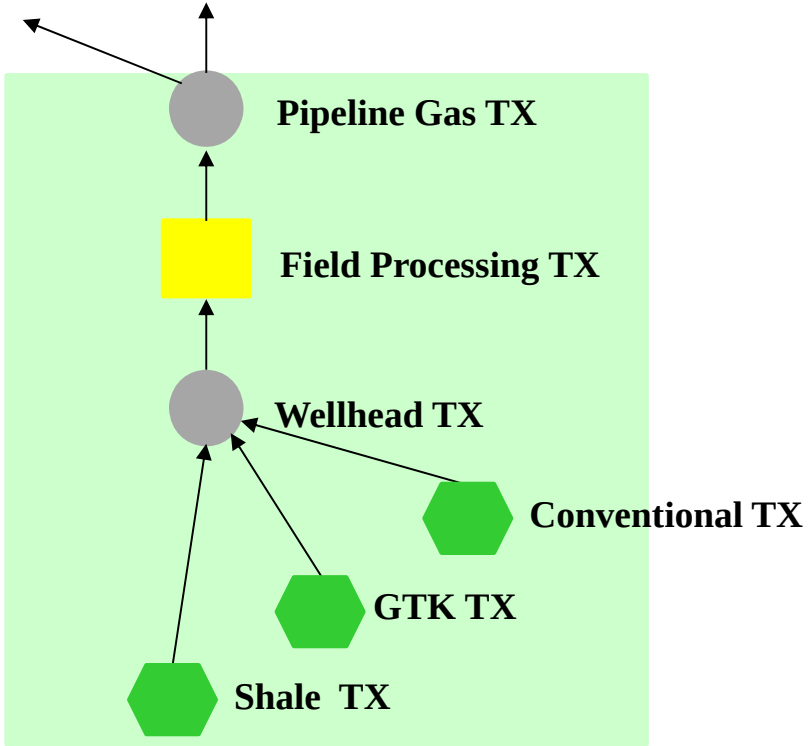
10. Drag the link by clicking on the origin node and dragging to the destination node.



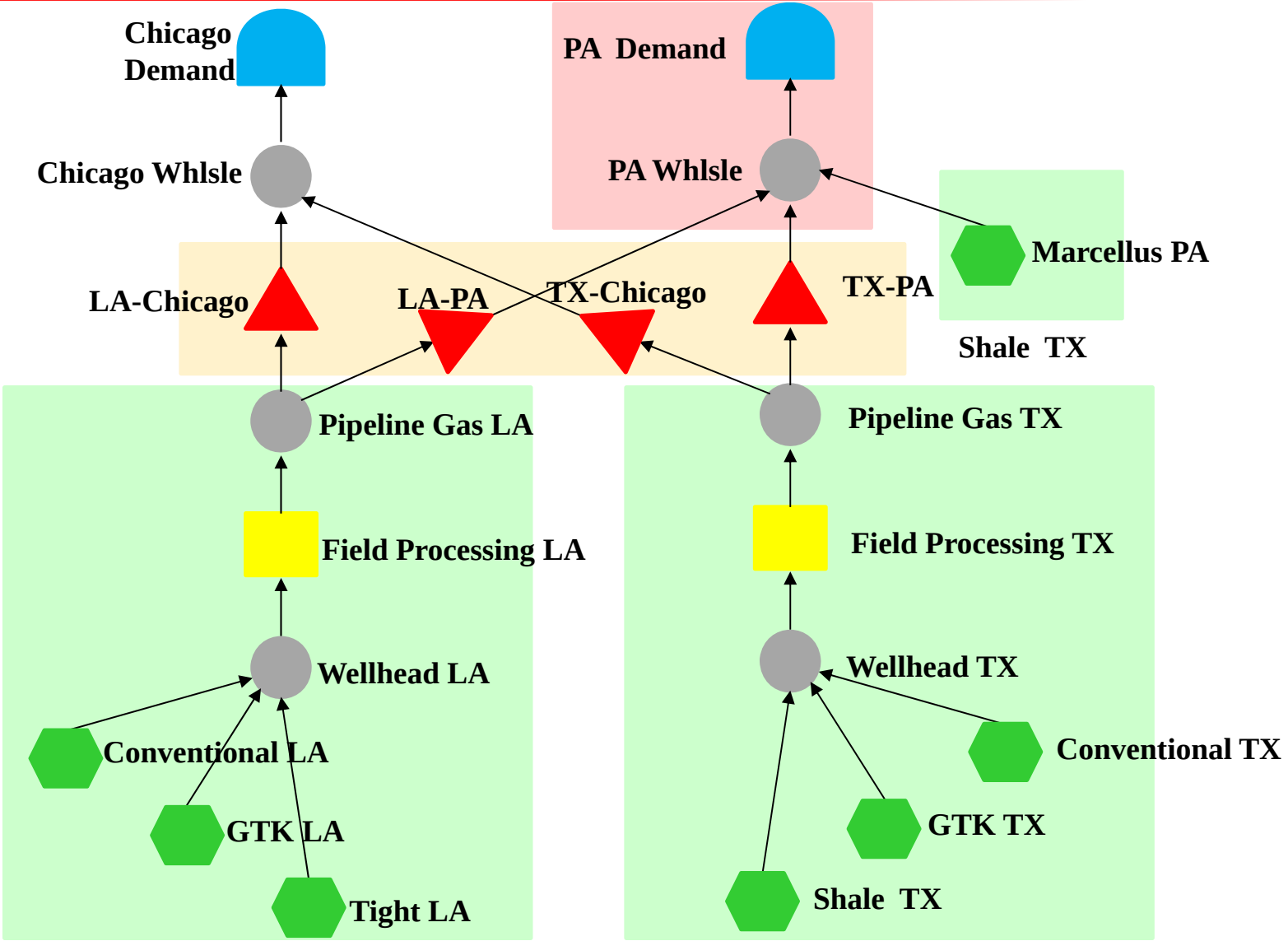


You Get to This Structure with About 30 Seconds of Work





You Drag and Drop This Onto Your Computer Page in a Couple of Minutes



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Model Viewer - ArrowHea

54.218.114.19:8081/ModelViewer

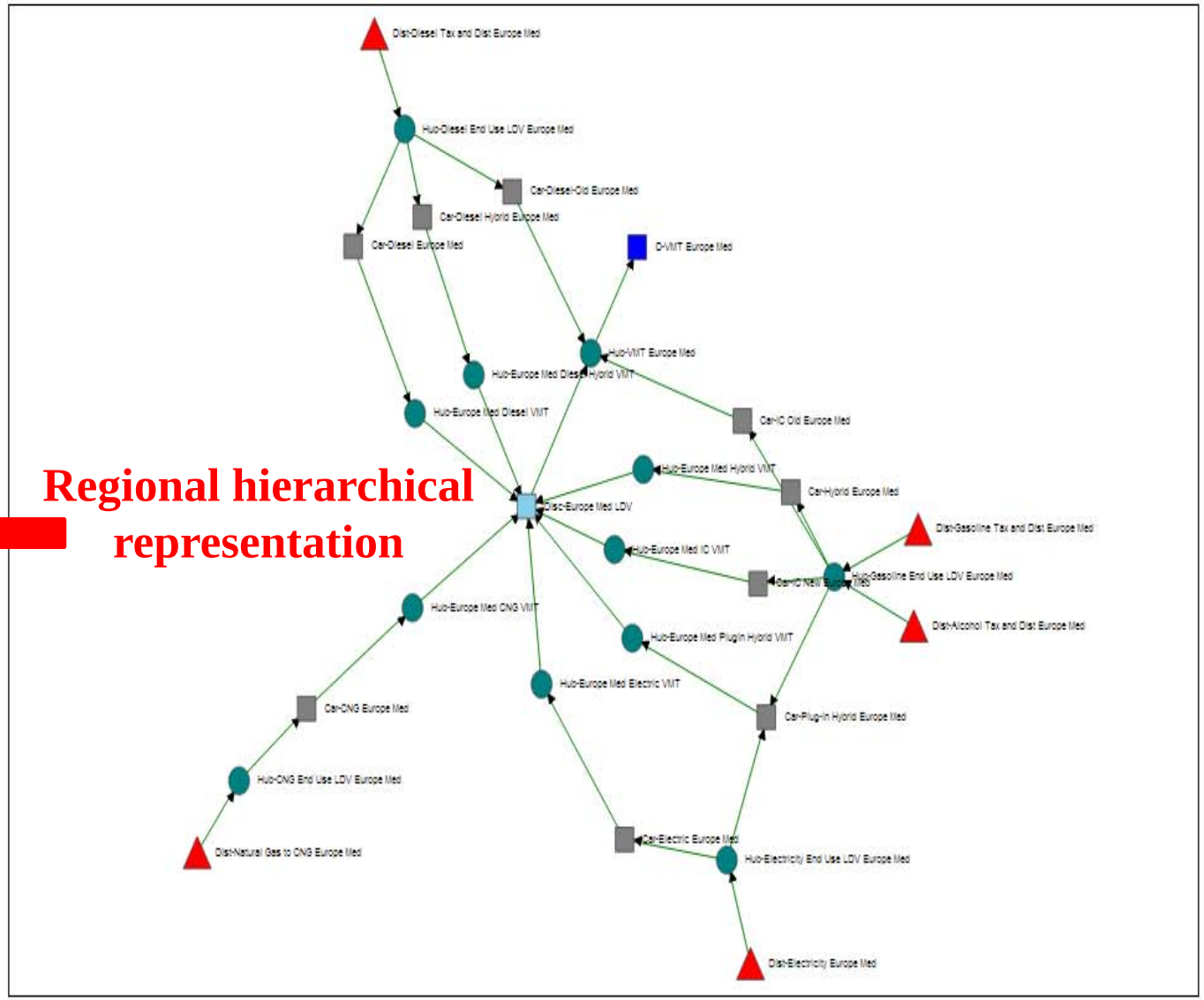
Apps | Tess | Home | Wedding | Job Search | Food and Drinks | Econ | Accueil | Tour du M... | Wai Sie Ng and Rich... | Caleb and Natalie ~ ... | Trusted Doctors in S... | Other bookmarks

Model Tree

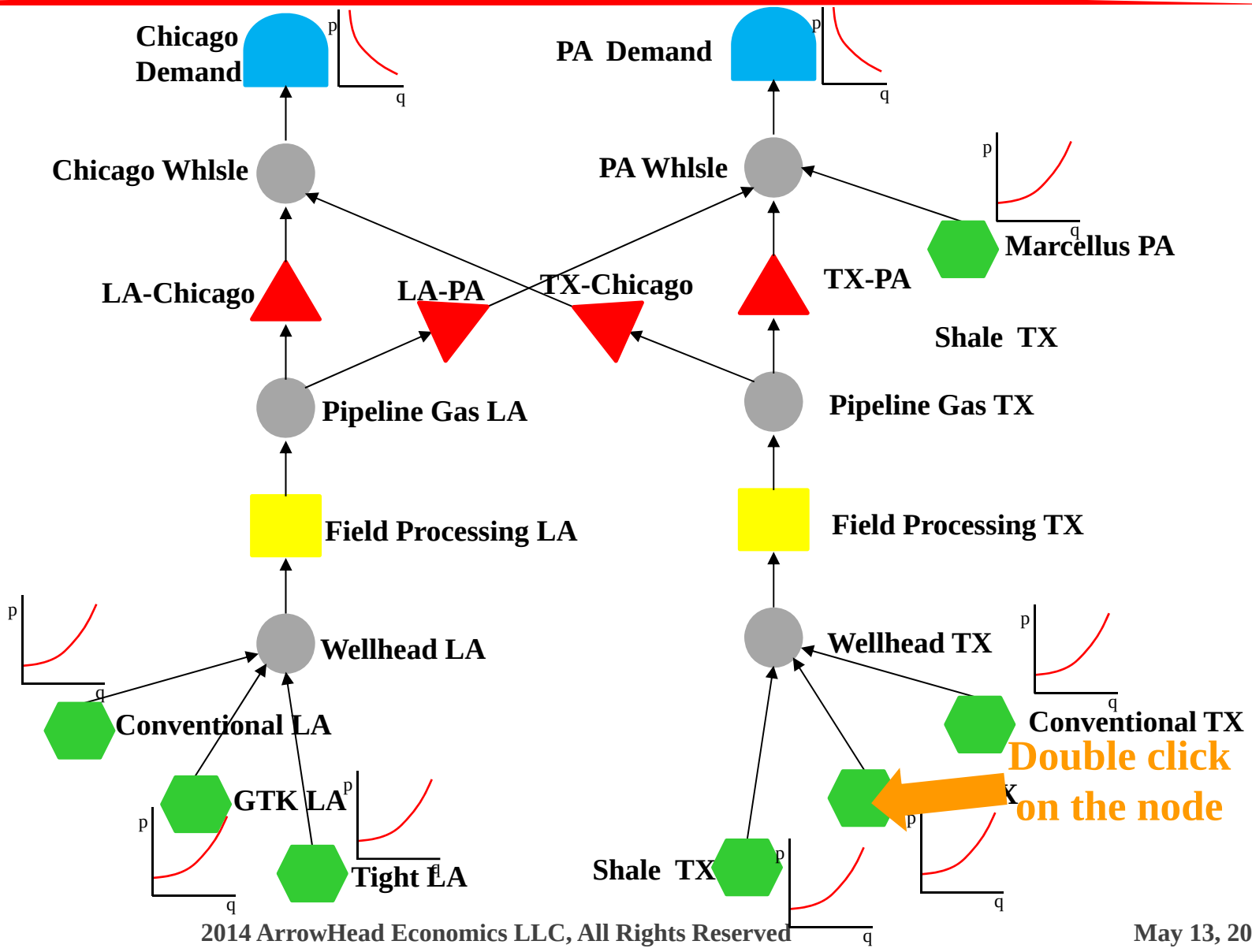
- Root
  - WOM
    - zFuel
    - _Notes
    - Oil
      - OPEC Quota
      - Africa
      - Asia
      - CIS
      - Europe
        - DG-Europe
          - D-Europe Mediterranean
            - DD-Europe Mediterranean
            - DLDV-Europe Mediterranean
          - D-Europe NW
          - D-Europe Eastern
        - RG-Europe
        - SG-Europe
        - TG-Europe
      - N Amer
      - zCO2
      - Lat Amer
      - M East

Regional hierarchical representation

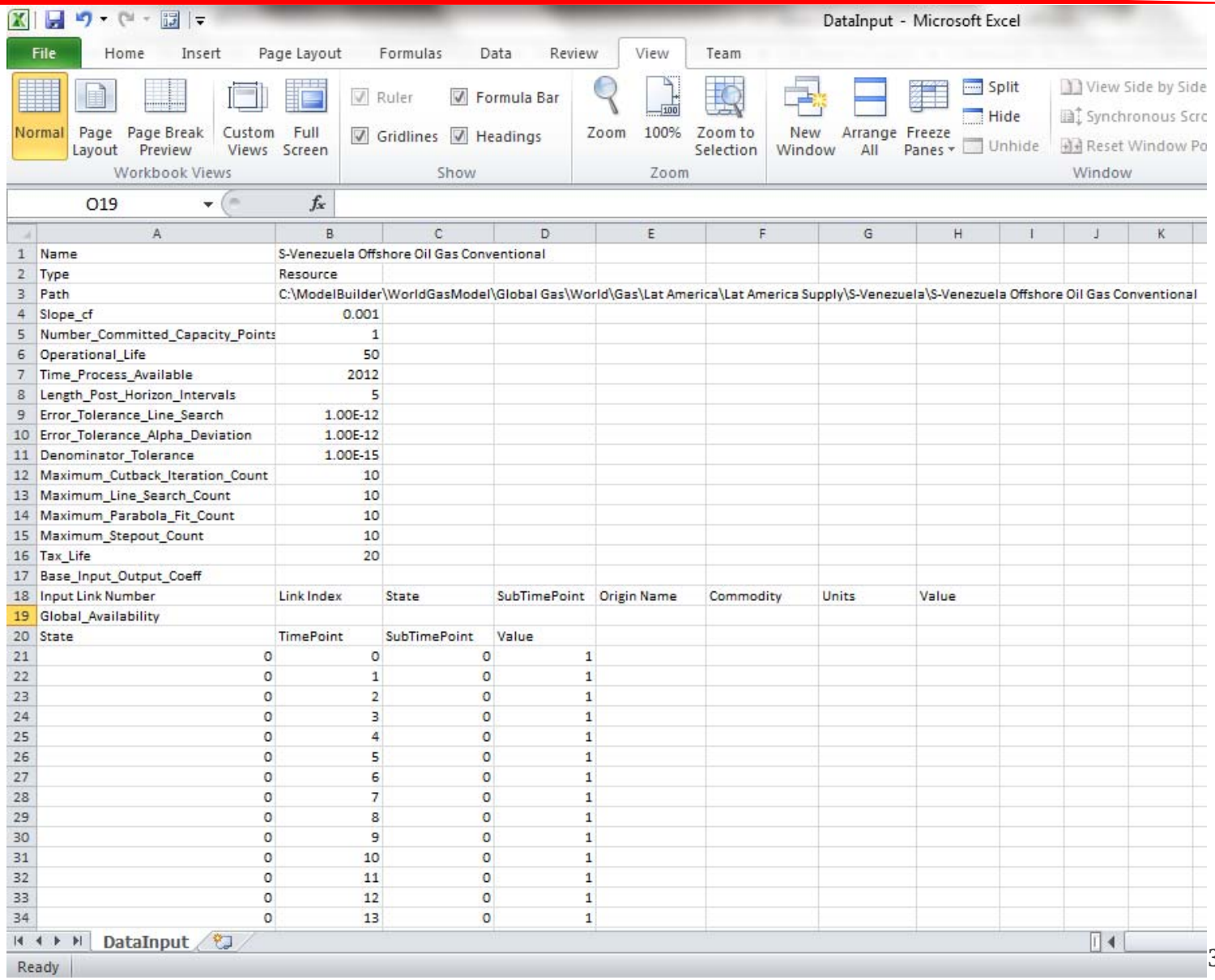
Network Diagram - DLDV-Europe Mediterranean



Easy and Intuitive Data Entry



Up Comes ALL the Data for That Node within Excel



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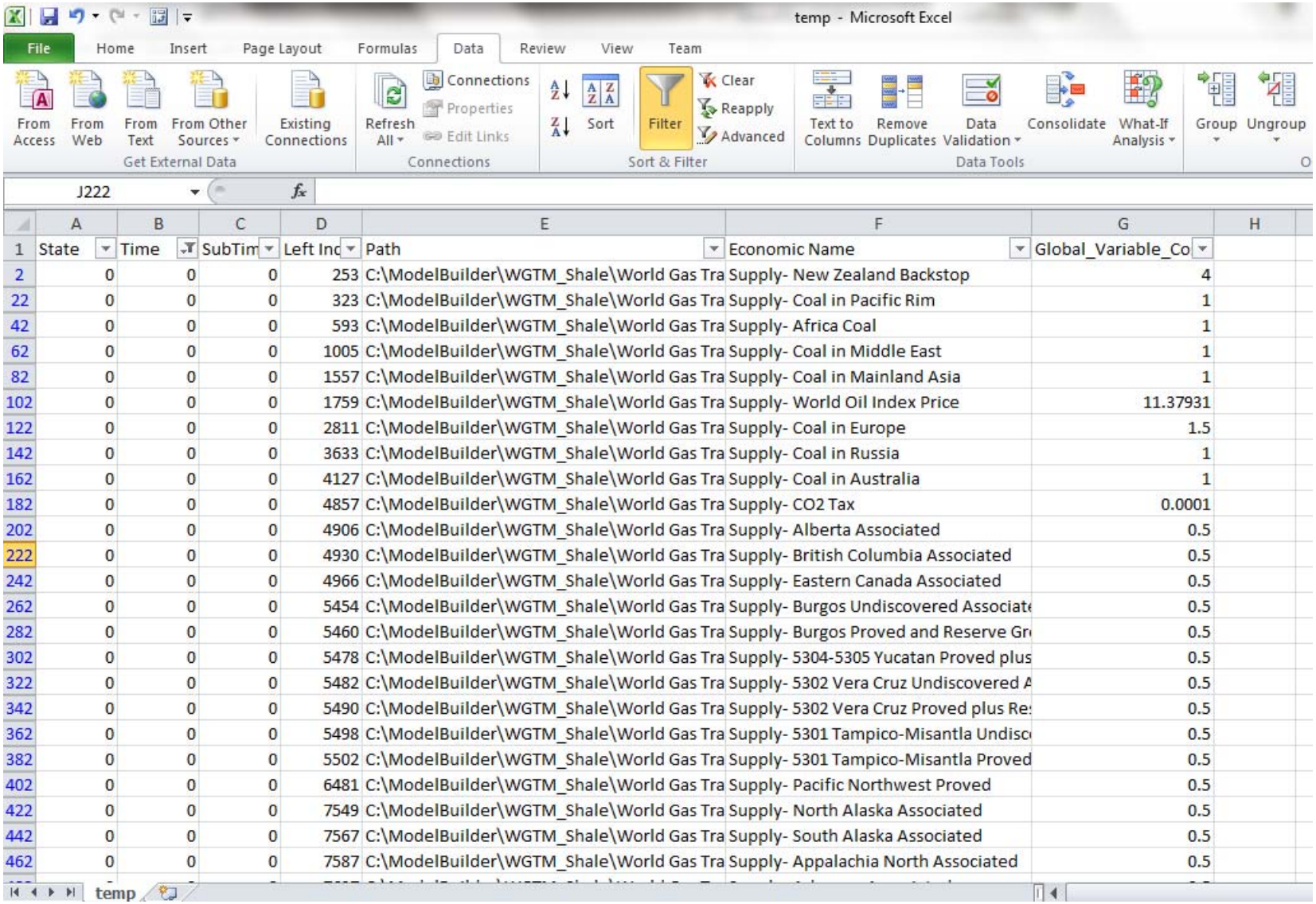
2	Type	Resource									
3	Path	C:\ModelBuilder\WorldGasModel\Global Gas\World\Gas\Lat America\Lat America Supply\S-Venezuela\S-Venezuela Offshore Oil Gas Conventional									
4	Slope_cf	0.001									
5	Number_Committed_Capacity_Points	1									
6	Operational_Life	50									
7	Time_Process_Available	2012									
8	Length_Post_Horizon_Intervals	5									
9	Error_Tolerance_Line_Search	1.00E-12									
10	Error_Tolerance_Alpha_Deviation	1.00E-12									
11	Denominator_Tolerance	1.00E-15									
12	Maximum_Cutback_Iteration_Count	10									
13	Maximum_Line_Search_Count	10									
14	Maximum_Parabola_Fit_Count	10									
15	Maximum_Stepout_Count	10									
16	Tax_Life	20									
17	Base_Input_Output_Coeff										
18	Input Link Number	Link Index	State	SubTimePoint	Origin Name	Commodity	Units	Value			
19	Global_Availability										
20	State	TimePoint	SubTimePoint	Value							
21	0	0	0	1							
22	0	1	0	1							
23	0	2	0	1							
24	0	3	0	1							
25	0	4	0	1							
26	0	5	0	1							
27	0	6	0	1							
28	0	7	0	1							
29	0	8	0	1							
30	0	9	0	1							
31	0	10	0	1							
32	0	11	0	1							
33	0	12	0	1							
34	0	13	0	1							

Pivot the Same Data Element for All Nodes in the Model



	A	B	C	D	E	F	G	H
1	State	Time	SubTim	Left Inc	Path	Economic Name	Global_Variable_Co	
2	0	0	0	253	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- New Zealand Backstop	4	
22	0	0	0	323	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Coal in Pacific Rim	1	
42	0	0	0	593	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Africa Coal	1	
62	0	0	0	1005	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Coal in Middle East	1	
82	0	0	0	1557	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Coal in Mainland Asia	1	
102	0	0	0	1759	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- World Oil Index Price	11.37931	
122	0	0	0	2811	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Coal in Europe	1.5	
142	0	0	0	3633	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Coal in Russia	1	
162	0	0	0	4127	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Coal in Australia	1	
182	0	0	0	4857	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- CO2 Tax	0.0001	
202	0	0	0	4906	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Alberta Associated	0.5	
222	0	0	0	4930	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- British Columbia Associated	0.5	
242	0	0	0	4966	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Eastern Canada Associated	0.5	
262	0	0	0	5454	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Burgos Undiscovered Associate	0.5	
282	0	0	0	5460	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Burgos Proved and Reserve Gr	0.5	
302	0	0	0	5478	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- 5304-5305 Yucatan Proved plus	0.5	
322	0	0	0	5482	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- 5302 Vera Cruz Undiscovered A	0.5	
342	0	0	0	5490	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- 5302 Vera Cruz Proved plus Re	0.5	
362	0	0	0	5498	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- 5301 Tampico-Misantla Undisc	0.5	
382	0	0	0	5502	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- 5301 Tampico-Misantla Proved	0.5	
402	0	0	0	6481	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Pacific Northwest Proved	0.5	
422	0	0	0	7549	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- North Alaska Associated	0.5	
442	0	0	0	7567	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- South Alaska Associated	0.5	
462	0	0	0	7587	C:\ModelBuilder\WGTM_Shale\World Gas Tra	Supply- Appalachia North Associated	0.5	

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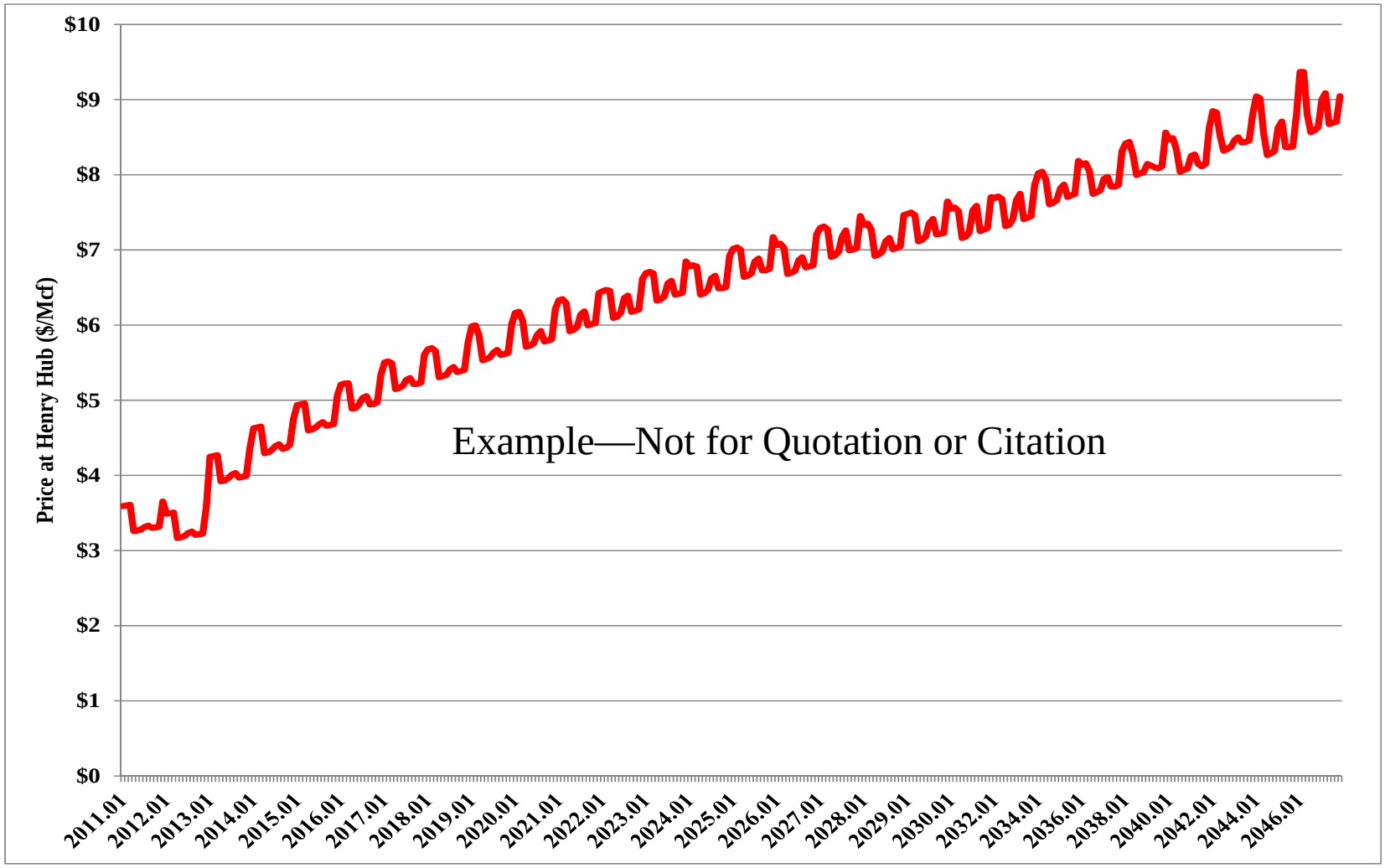
The Picture of the Model IS the Model

Reporter

- Fully automated, organized extraction of outputs.
- For each model sector,
  - Outbound prices and quantities
  - Inbound prices and quantities
- For aggregates of model sectors
  - Outbound prices and quantities
  - Inbound prices and quantities
- Input and output prices and quantities for a given node type (e.g., supply, demand)
- Reporter is easy and general and dumps into Excel for pivot table operation.

NYMEX Price (from the NYMEX Link)



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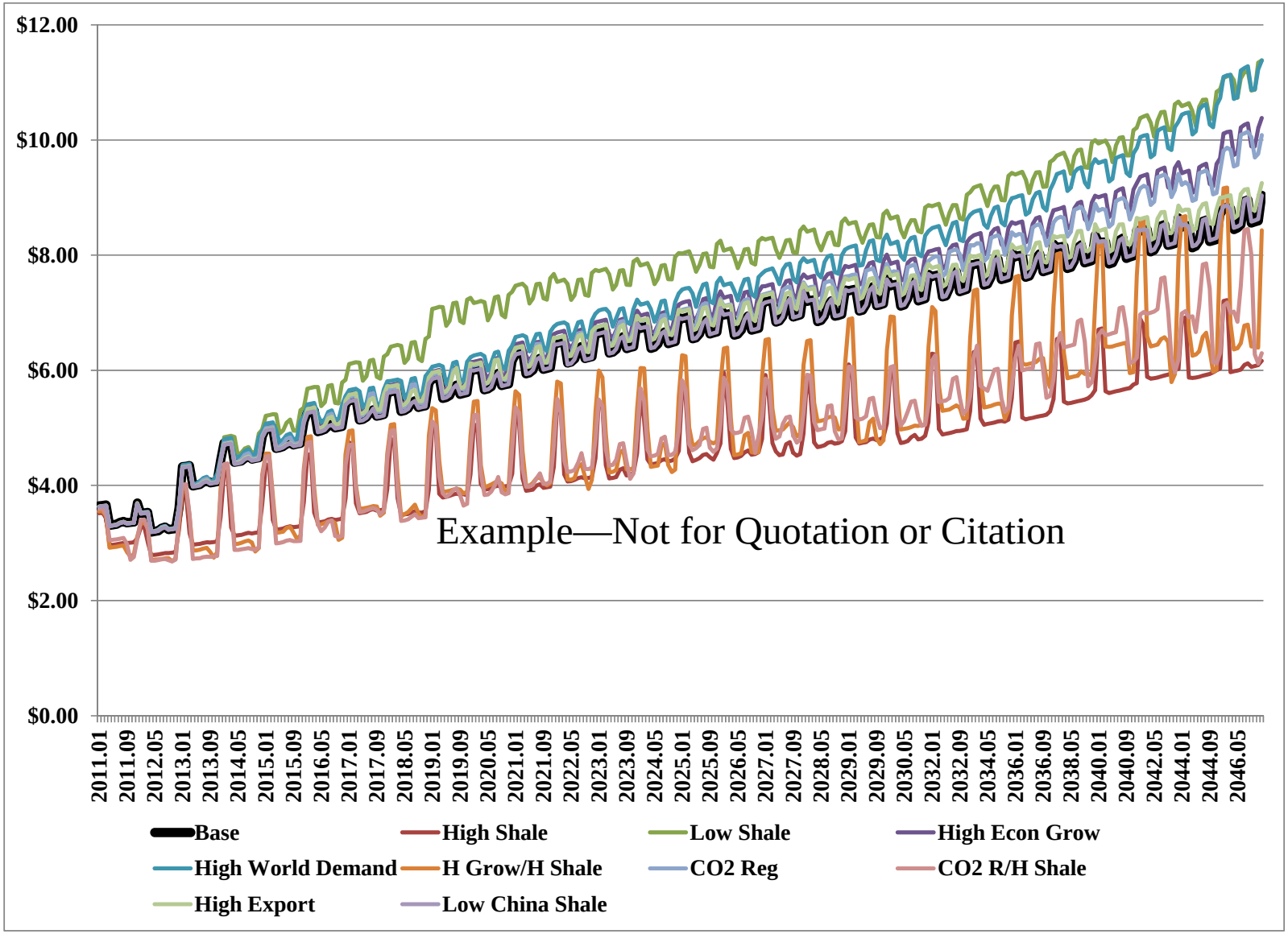
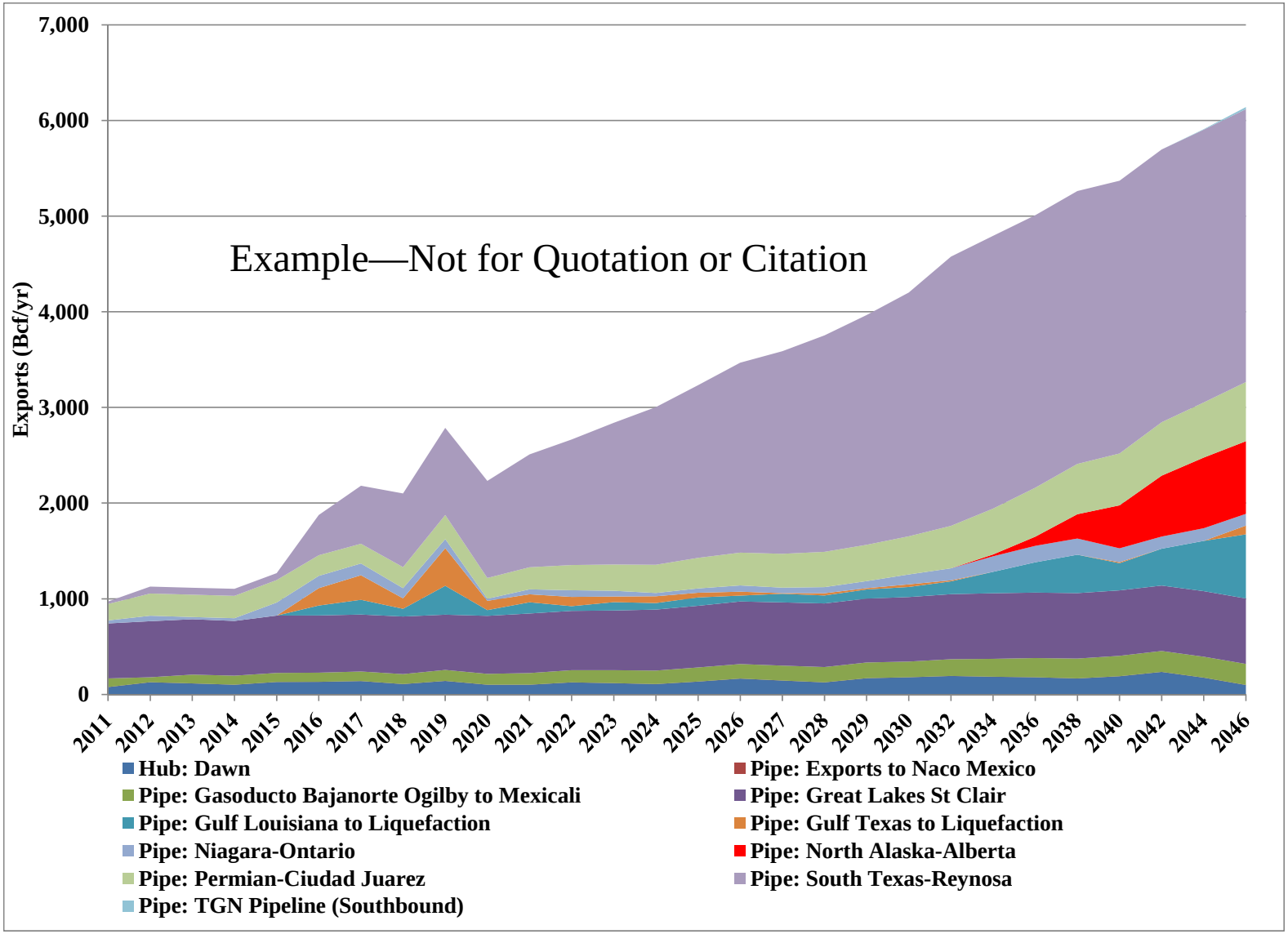
Report Writer Collects Link Clicks and Plots--Prices



Report Writer Collects Volume Clicks and Plots--Volumes



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Every Node Is a Separate Agent (This Is Real "Secret Sauce")

- The right methodology—most market modeling approaches are not "agent based models," and no one doubts that the real world is agent based
  - ***Profit seeking entities who pursue self interest independently of but in competition with other agents (e.g., profit maximizing individual firms rather than aggregate cost minimization, the latter of which is preposterous on its face).***
  - Zero arbitrage over space and time. It cannot be possible to change any agent's decisions over time or over space and beat the market solution.
  - "Clearing" of all markets, meaning that price is the variable that rations and eliminates shortages and excesses everywhere ("Walrasian equilibrium")
  - Market imperfections (e.g., monopoly, oligopoly, market power) that can be represented using constraints, restraints, and alternative market structure assumptions.

What I Would NOT Do

- Write one single complementarity or inequality condition!
- Write one single objective function!
- Write one single “constraint!”
- Adopt the slightest semblance of global welfare maximization or optimization or complementarity!
- Use any line-by-line 1960s vintage data entry like GAMS.
  - Write any VB to port stuff into arcane 1960s vintage command lines.
- Gather one piece of data (yet).

World Gas Model

- What serious analyst could offer a stand-alone North American, European, or Asian model?
  - Regions are indisputably and increasingly interconnected across the rest of the world
  - What is the long run marginal cost of LNG?
  - How silly is it for modelers to "inject" LNG or overland pipe onto the boundary of a continent or to export it from the boundary of a continent and argue that such injections/withdrawals represent the incentives and profits of LNG or pipeline suppliers?
  - We don't want to make unguided, egregious approximations like this.

We Don't Let Btus or Barrels Sail Off the End of the Earth Without Determining Their Effect on Price (and Quantity)

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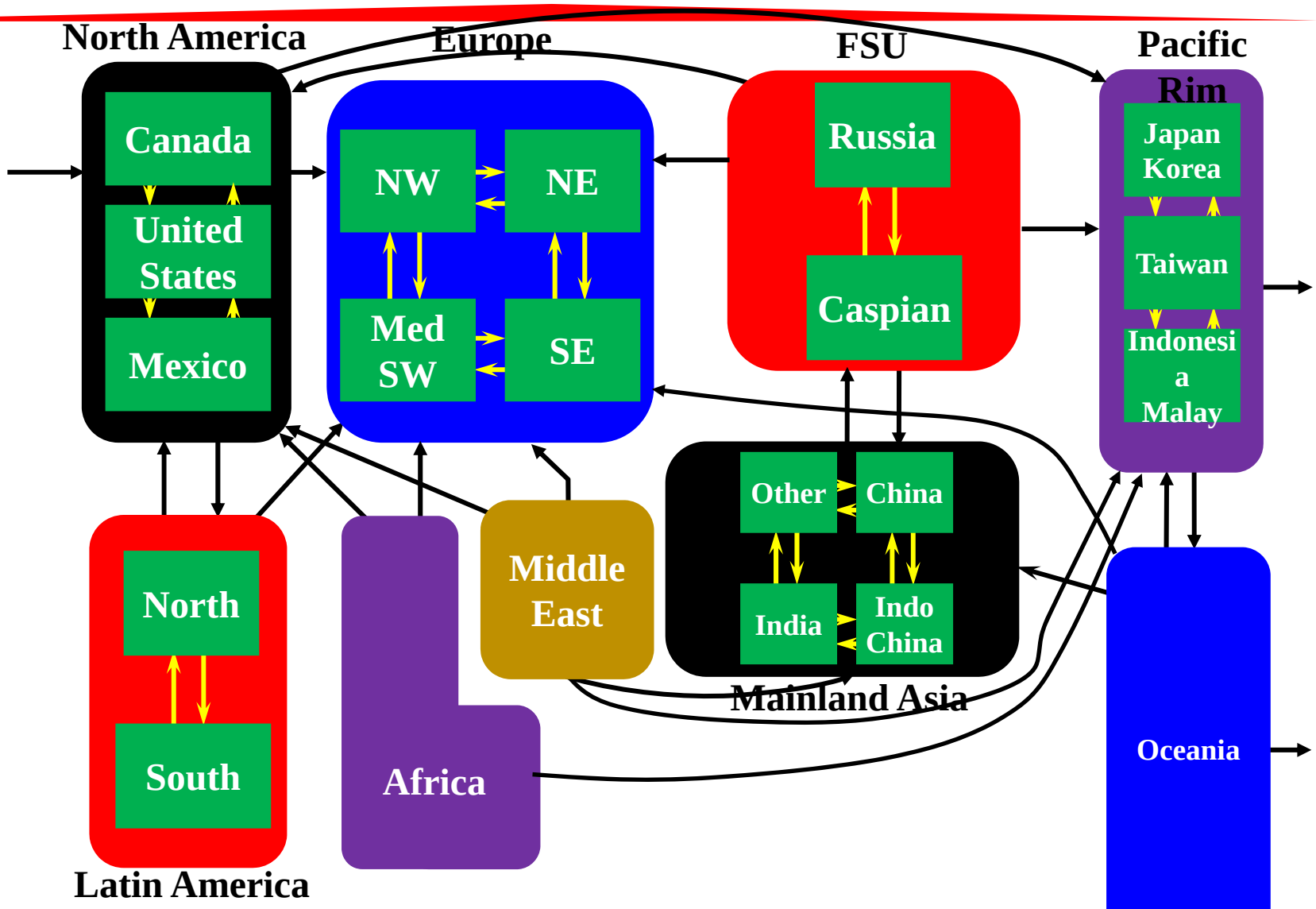
Out Comes and Even Bigger Piece of Butcher Paper for Each Region of the World

- I would draw for every region of the world
  - Existing and prospective supply nodes where the supply is
  - Existing and prospective gathering and field processing where gathering and field processing are
  - Coproduction of NGL where appropriate
  - The commodities and units associated with every link (e.g., bcfd, Tcf/yr, MMbbld, tons/yr)
  - Existing and prospective pipelines leaving supply regions
  - Pipeline junction points (e.g., Tuscola, Illinois)
  - Existing and prospective LNG import facilities
  - Existing and prospective LNG export facilities
  - Existing and prospective, segmented gas demand (residential, commercial, industrial, transportation, electric generation, refining)
  - Existing and prospective LNG shipping routes, categorized by ship size/draft
- I'd have out the pencil and eraser and draw every existing and prospective supply chain from source rock to burnertip.
- **I would never to what OR people do—write "equations"**
- I would structure the problem in the the detail required.

We Interconnected All the Regions to Form the ArrowHead Global Gas Model



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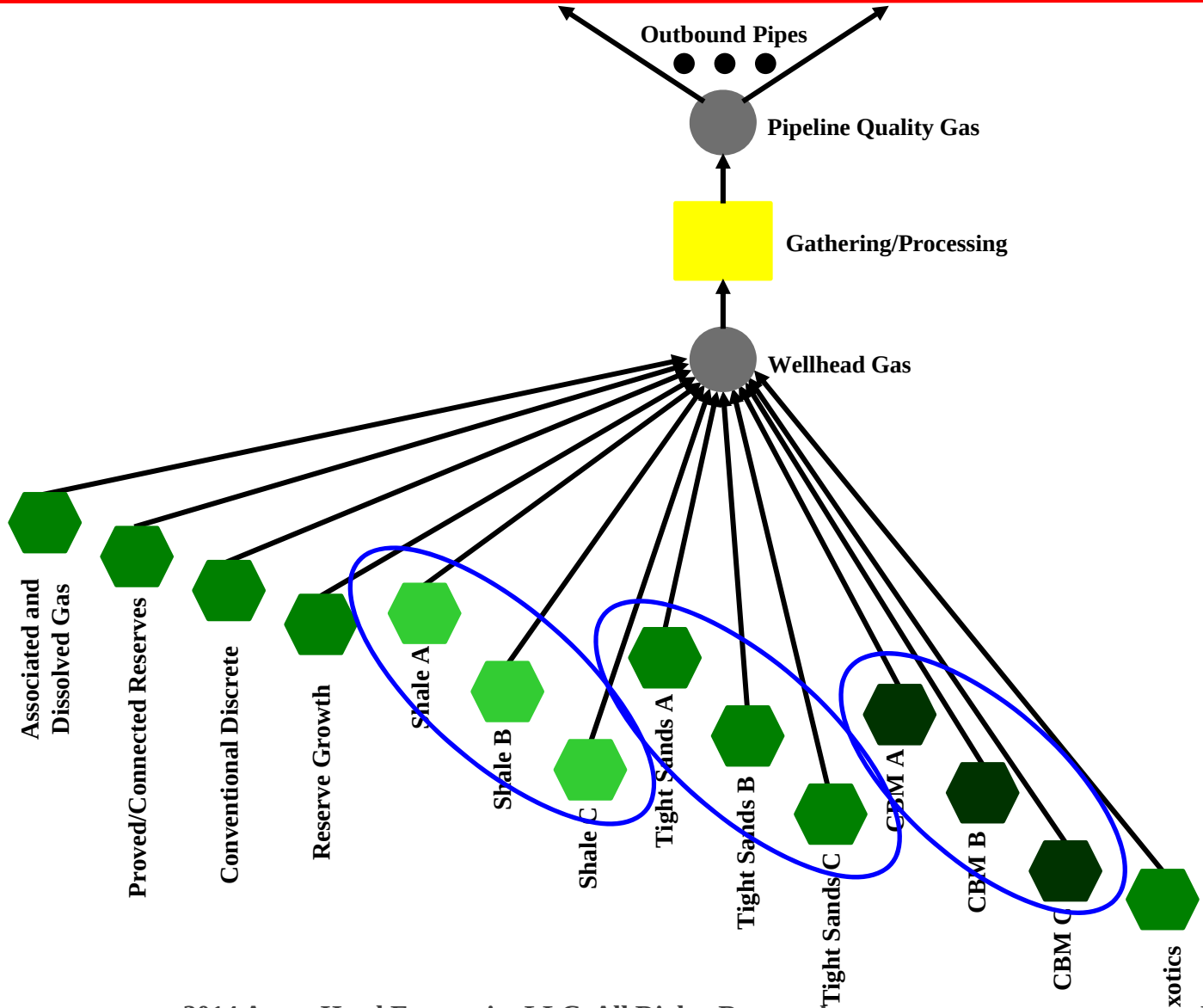
Origin of AGGM

- Originally a Decision Focus Incorporated (DFI) multiclient (Exxon, Mobil, Shell, Texaco, Chevron, Fina, Total, Elf Aquitane, Enron, Arco, California Energy Commission, BP, Canadian Energy Research Institute, Unocal, TransCanada,…) project initiated in 1990.
- We didn't approach EIA to be a sponsor
- It morphed into a European Gas multiclient with about 30 additional clients.
- Oil-gas-power companies have been using it internally and confidentially for 25 years since the inception
- Rice University licensed it and our software and built their Rice-Baker model within our erstwhile system (MarketBuilder that Nesbitt built) recently sold to another company.
  - The Rice-Baker model is a MarketBuilder model
- Adam Sieminski's erstwhile company used it successfully in their London office.

Detailed Supply Disaggregation of Every Exiting and Prospective Supply Region in the World



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The Different Types of Gas Are Distinguished in Every Existing and Prospective Basin

- Proved and connected reserves.
- Production of associated and dissolved gas.
- Conventional gas in discrete deposits.
- Growth of reserves in existing fields.
- Coal bed methane.
- Gas in fractured shales.
- Gas in tight sandstones.
- “Exotics” such as hydrates.
- Coal gasification with methanation.

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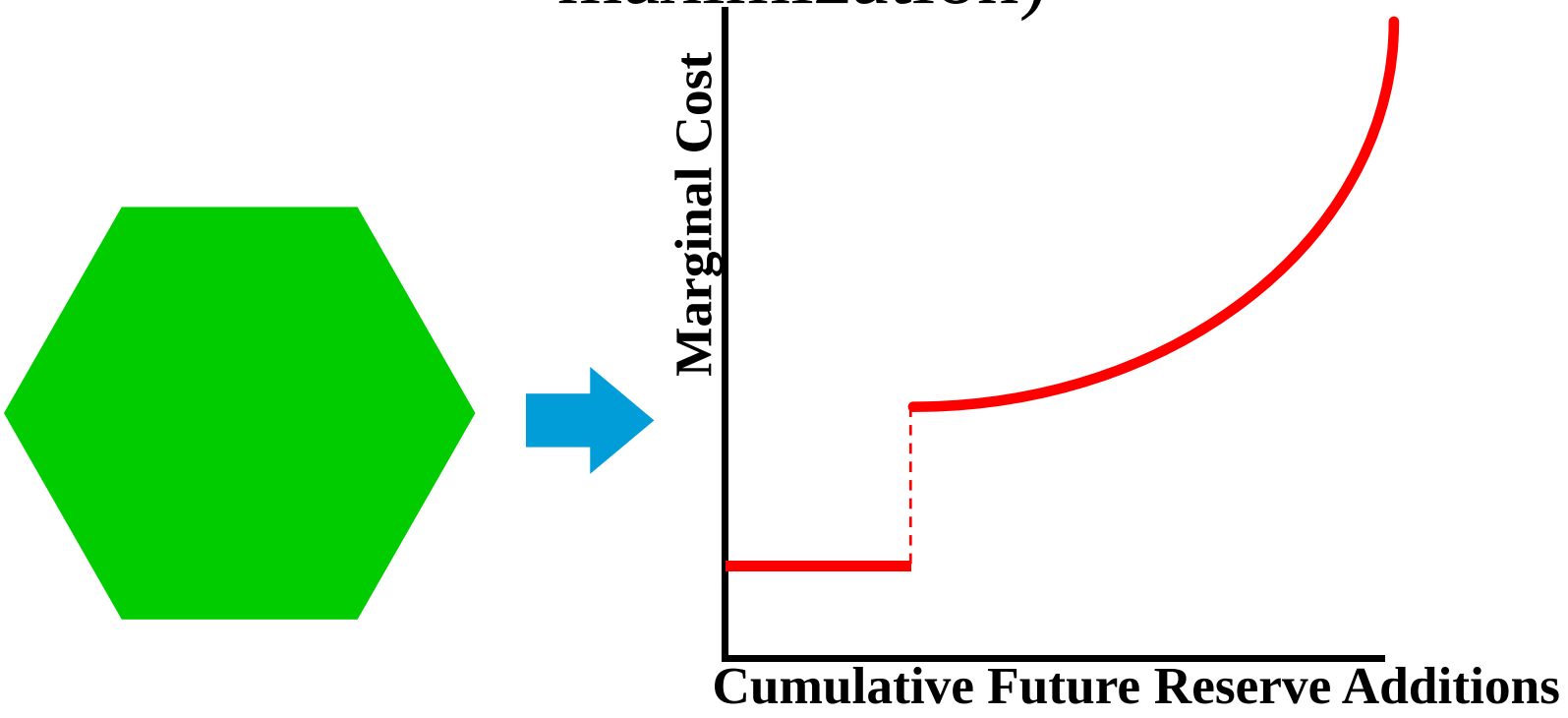
How Does a Supply Equation Work?

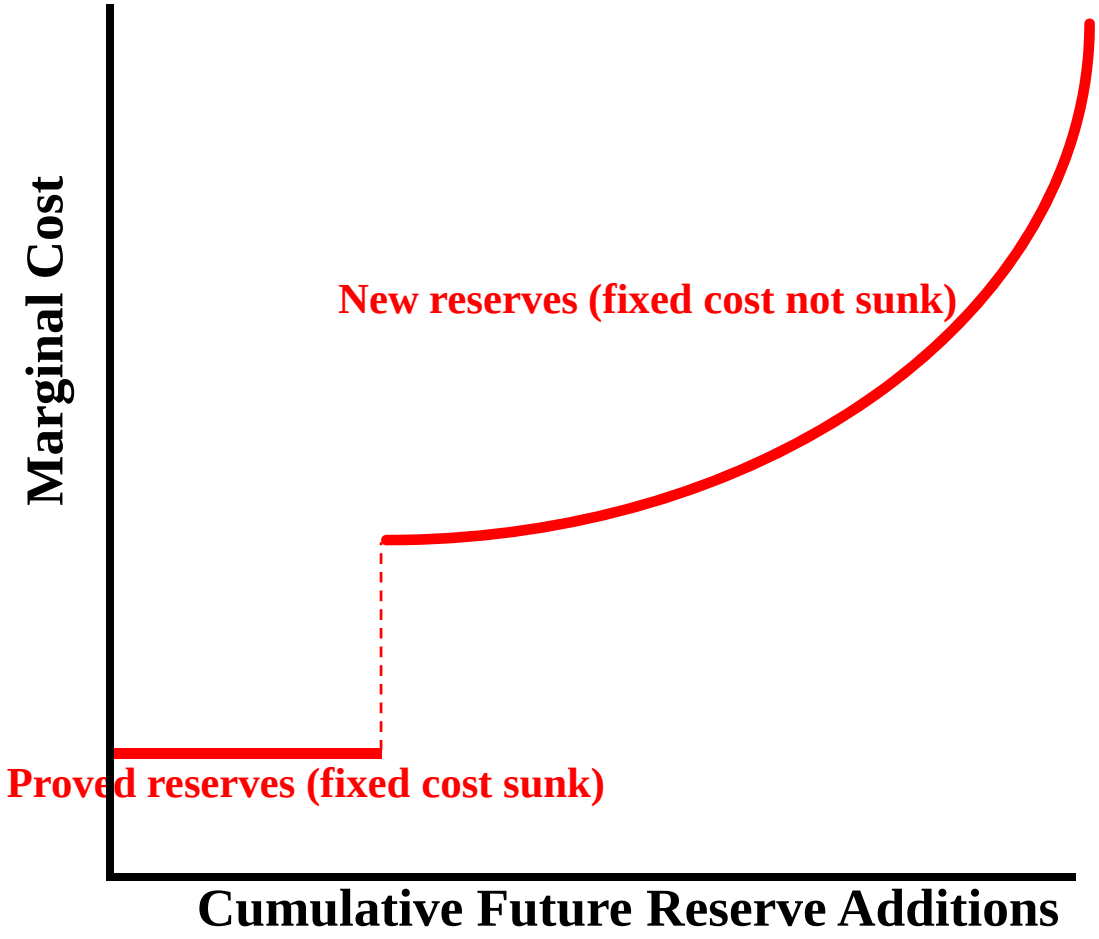
Natural Gas Primary Resource Supply

Every hexagon holds an individual regional or basinal gas supply curve and a representation of how producers behave to produce it (profit maximization)



Every Increment in Every Basin Has a Long Run Marginal Cost Curve

The resource data is comprehensive and unique



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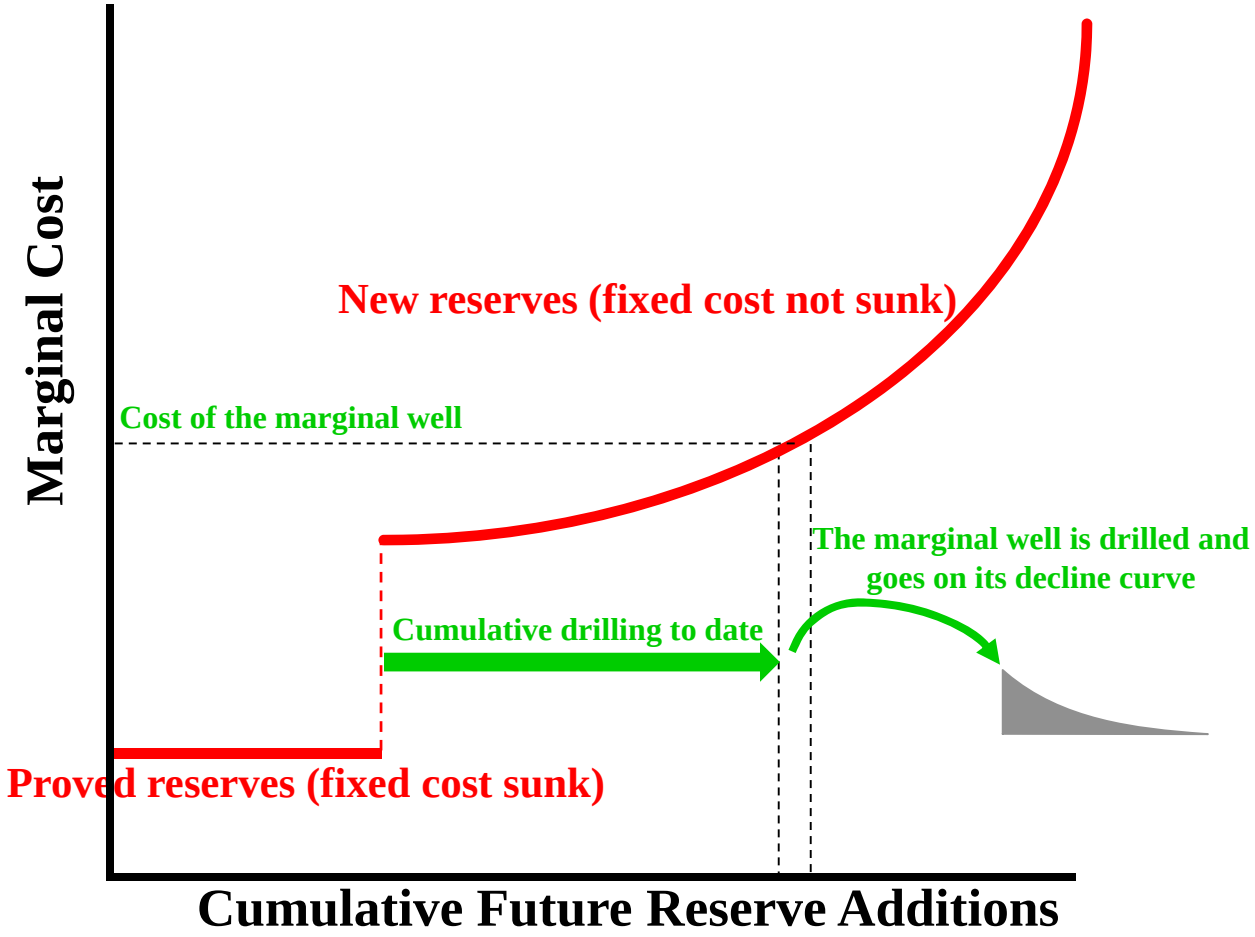
Drilling Proceeds Along the Horizontal Axis, Proving Reserves and Raising Costs As It Goes



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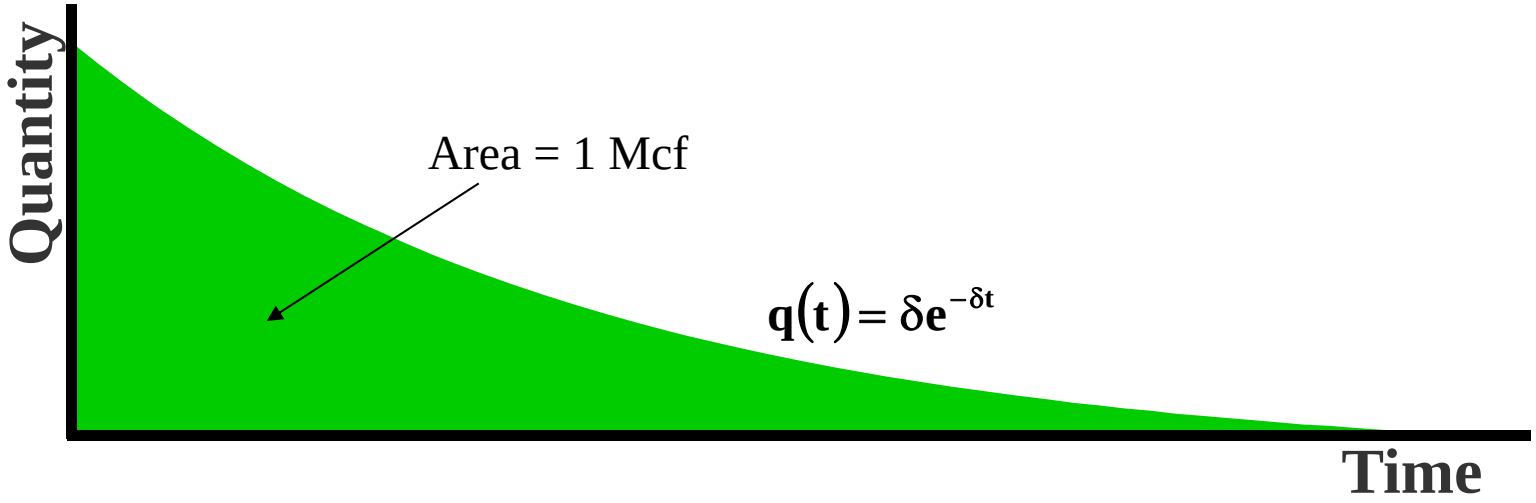
Each Facility Declines As a Function of Cumulative Production

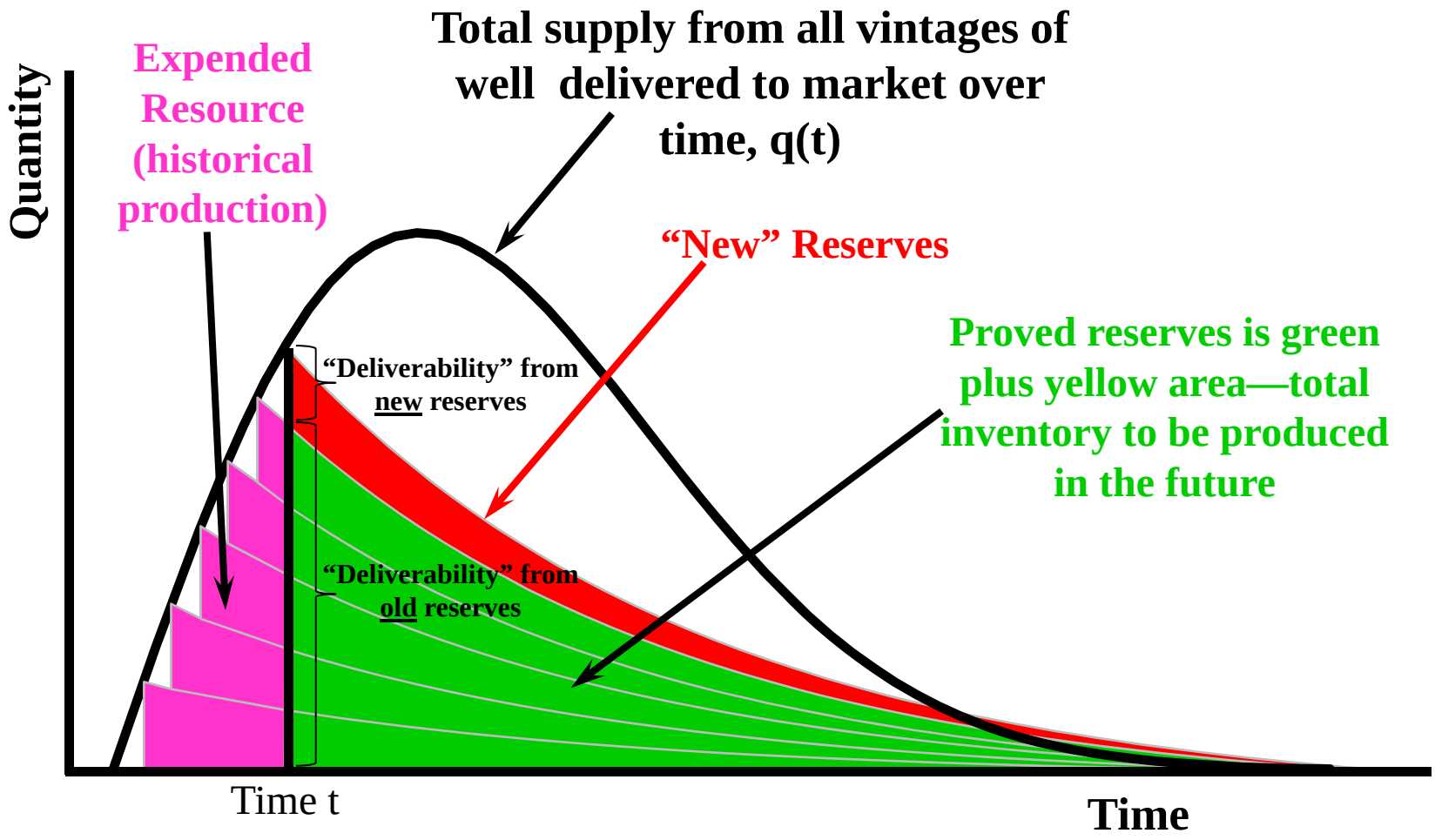
- Exponential decline often assumed



- AGGM uses any normalized decline curve; we are not limited to exponentials.

ArrowHead Produces Gas Just Like a Real World Producer

Wellhead deliverability is modeled from fundamentals



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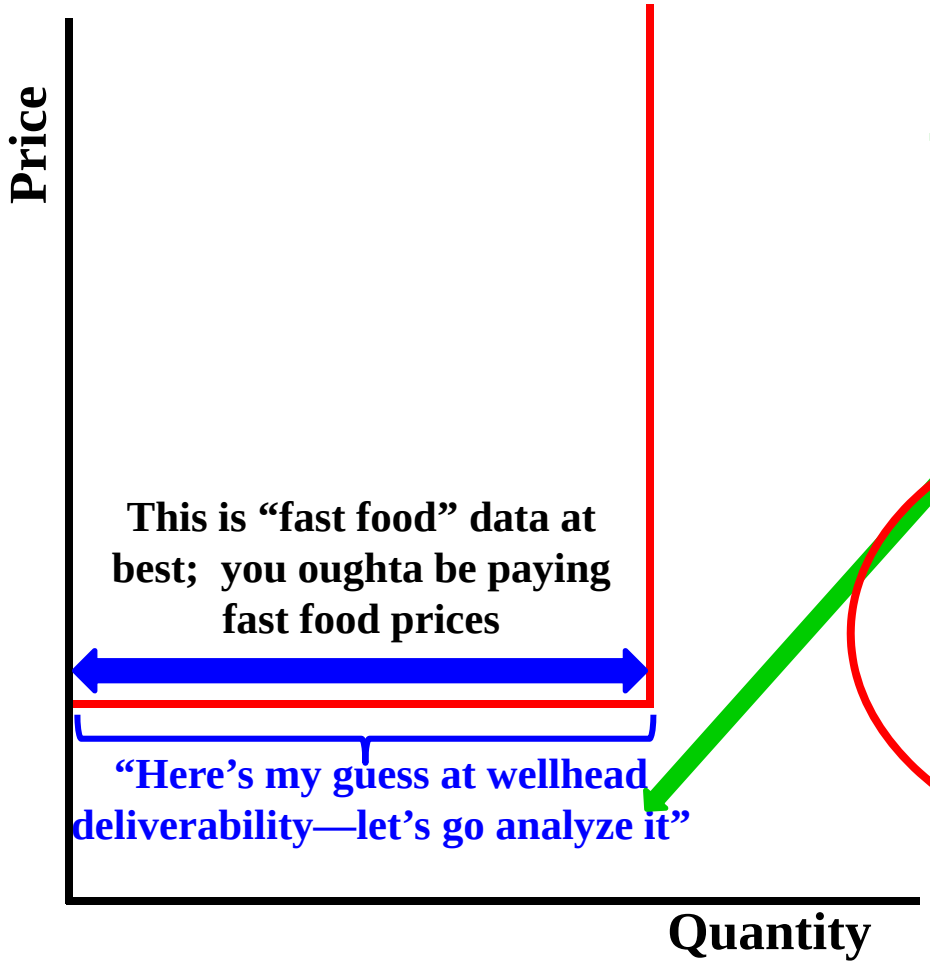
Other Gas Models (LP) Exogenously "Estimate" Wellhead Deliverability (Over Time)

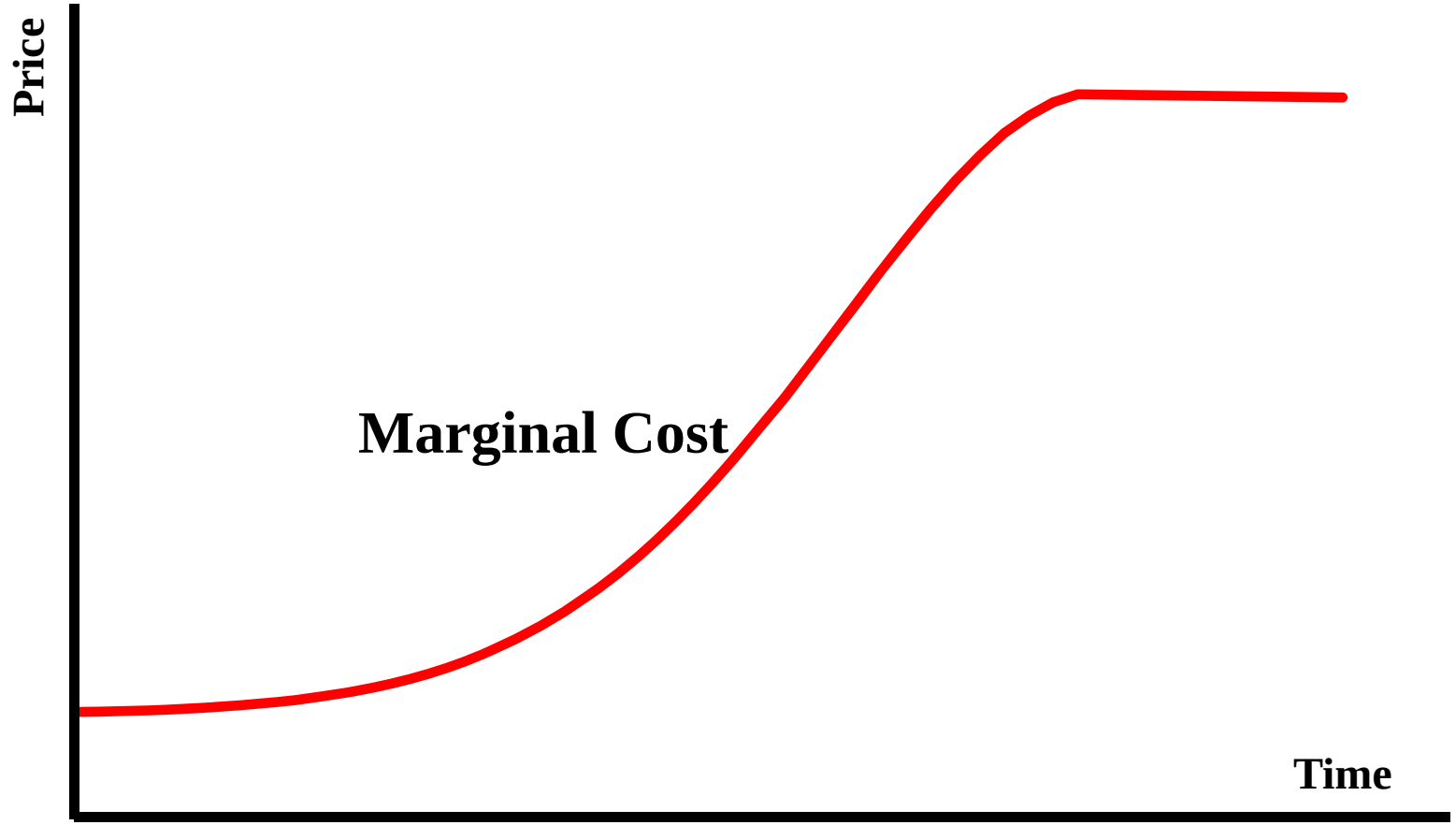


This crucial piece of data to an LP model is totally **ARBITRARY**, **SUBJECTIVE**, **EXTERNALLY INPUT**, and **NOT RESOURCE BASED**.

The hardest piece of data in their model is ASSUMED, not modeled from resource or economic fundamentals.

Those models are totally nonpredictive as a result

Step 3: The Schedule of Cumulative Reserve Additions Implies a Marginal Cost Schedule Like This



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Step 5: Hand This Price Over to the Demand Side

- See if you get demand equal to the production level you started with in Step 1.
  - If so, supply and demand are balanced
  - If no, use the new demand and go to Step 1 again.

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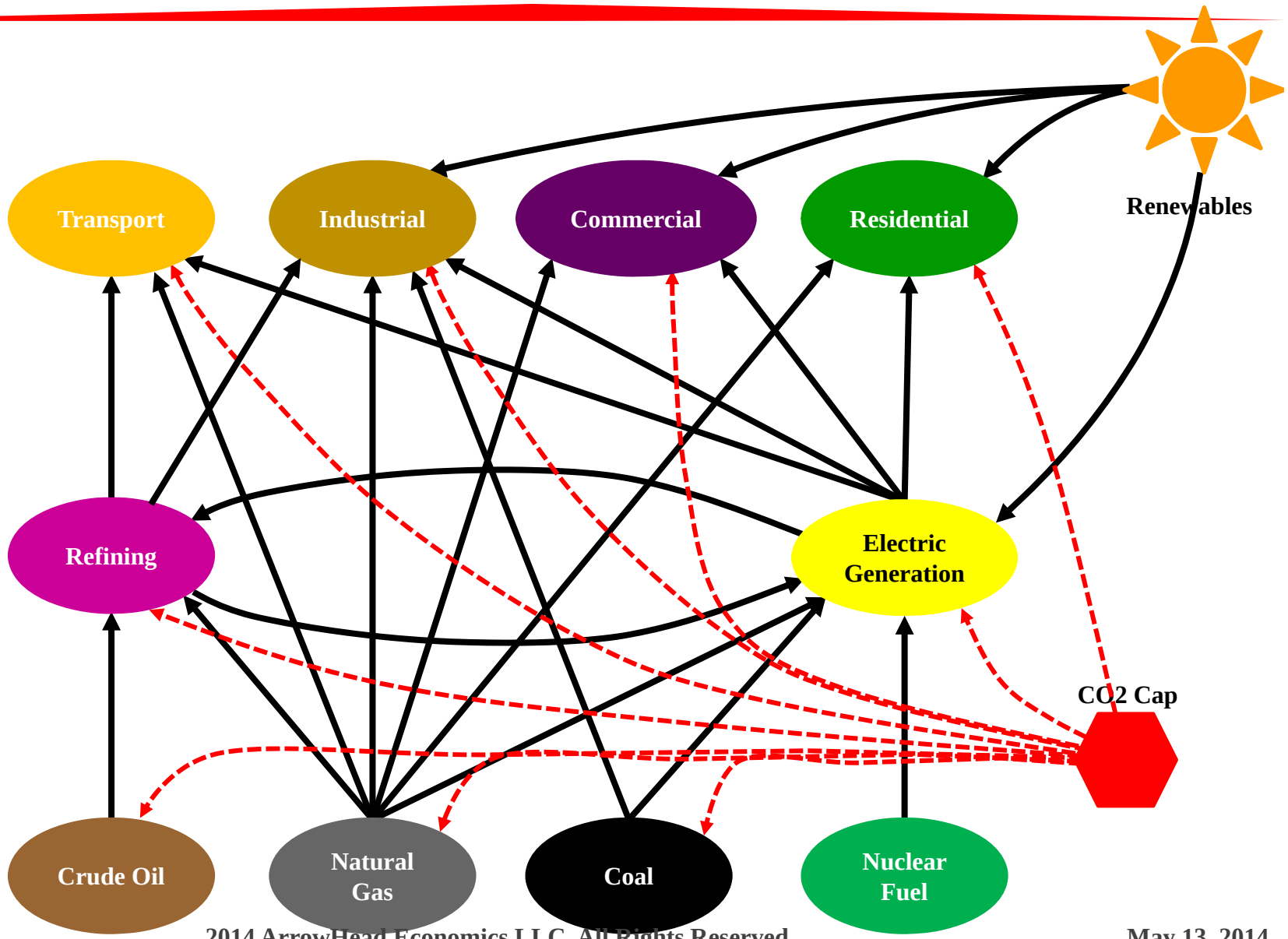
Demand Is Sectoral, Regional, and Sophisticated Around the World

The Energy System Is Inextricably Interconnected



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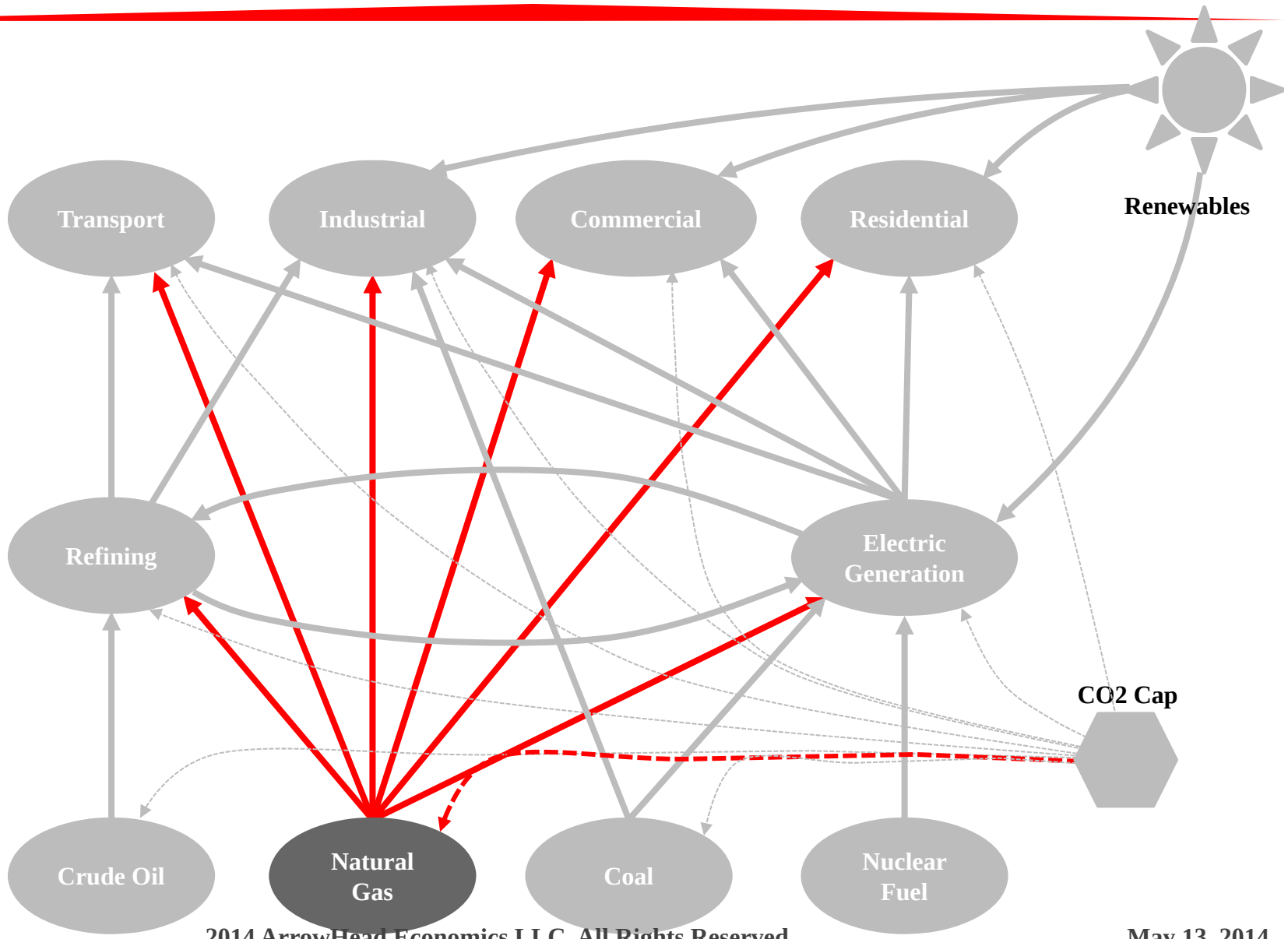
Natural Gas Is More Intertwined Than Anything



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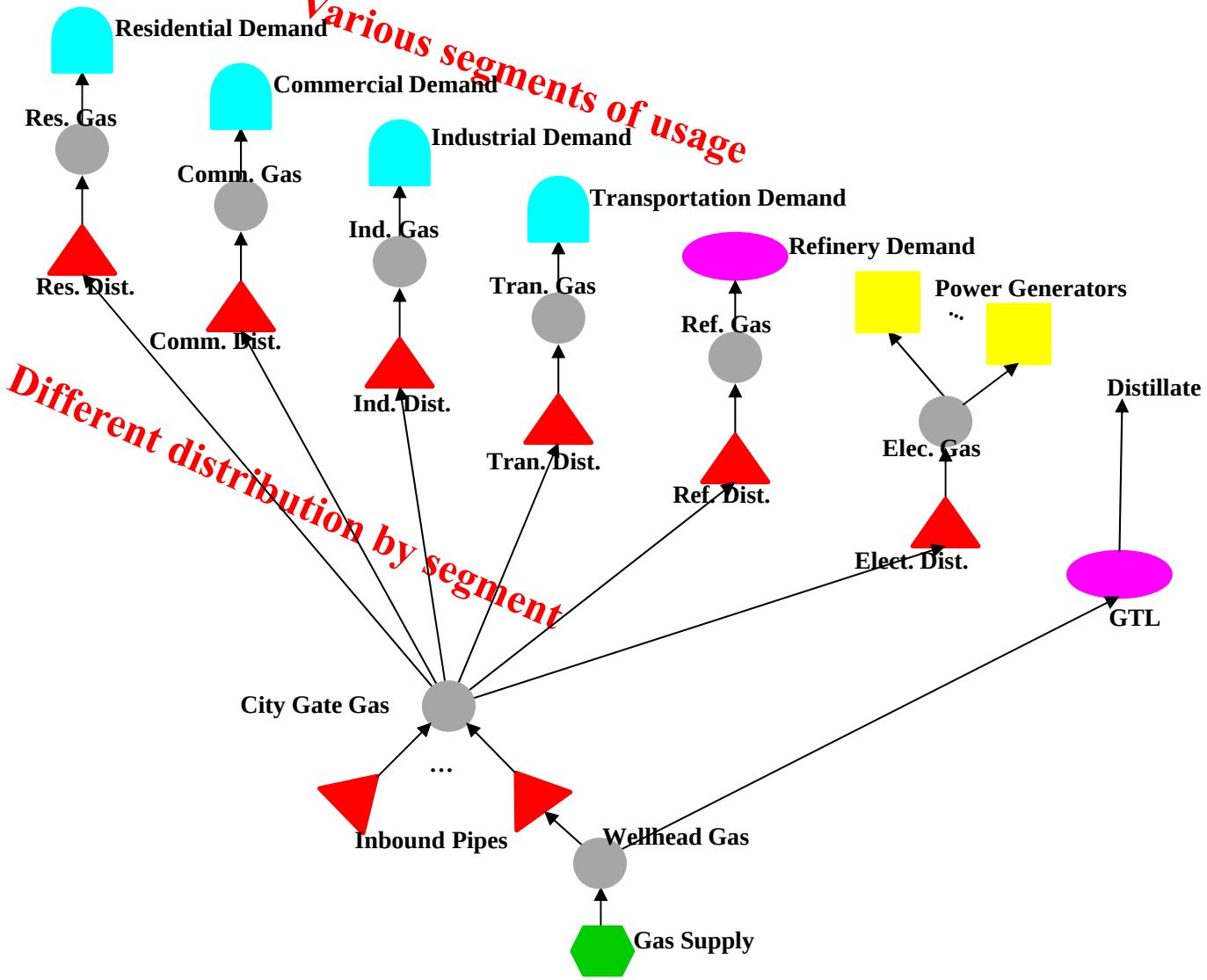
Gas Demand Modeling Has to Be Extensively Sectoralized

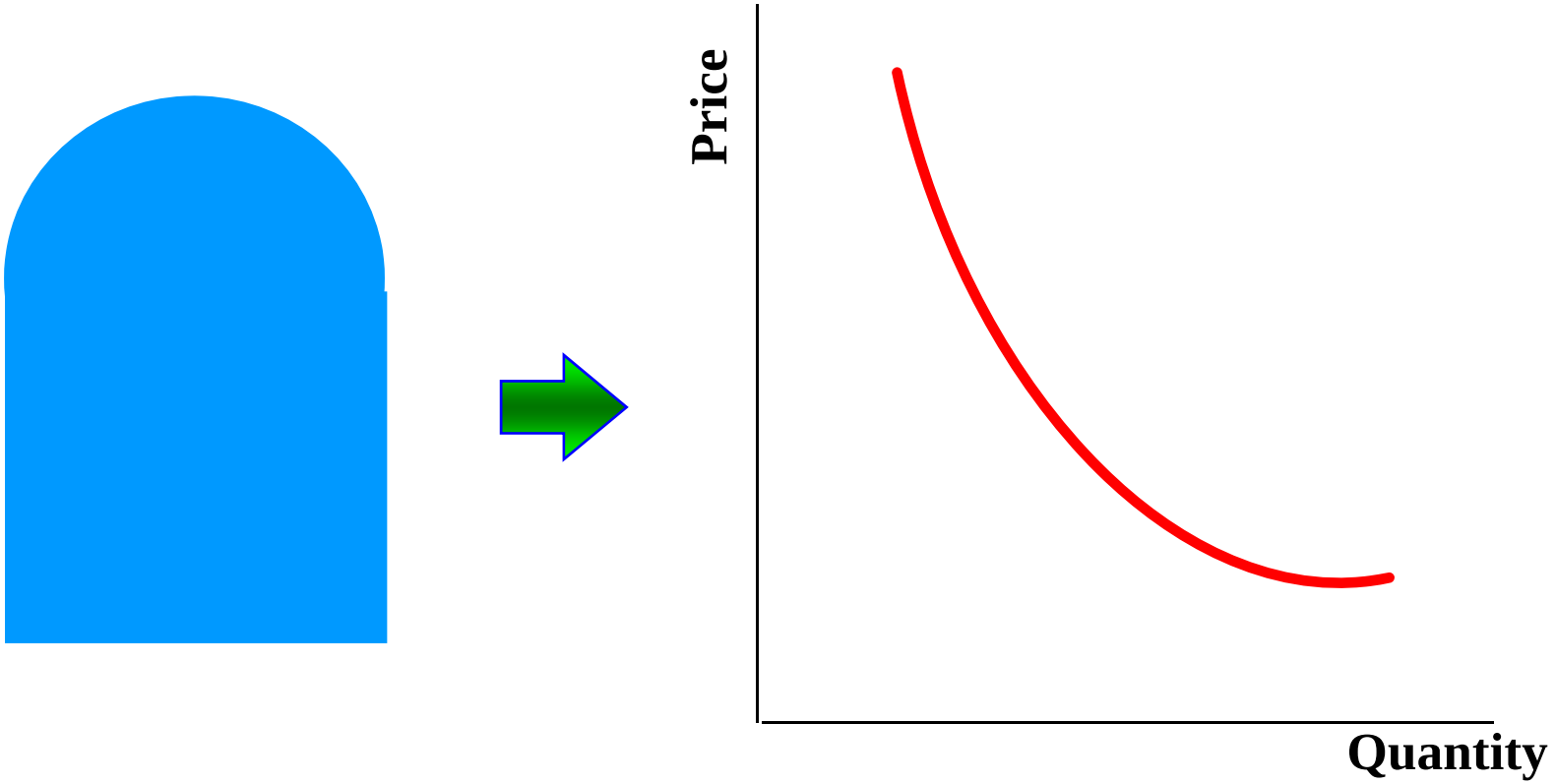
- Residential
- Commercial
- Industrial (perhaps disaggregated)
- Transportation
- Refineries
- Electricity generation

Gas Demand in Every Region Is Sectorized in ArrowHead

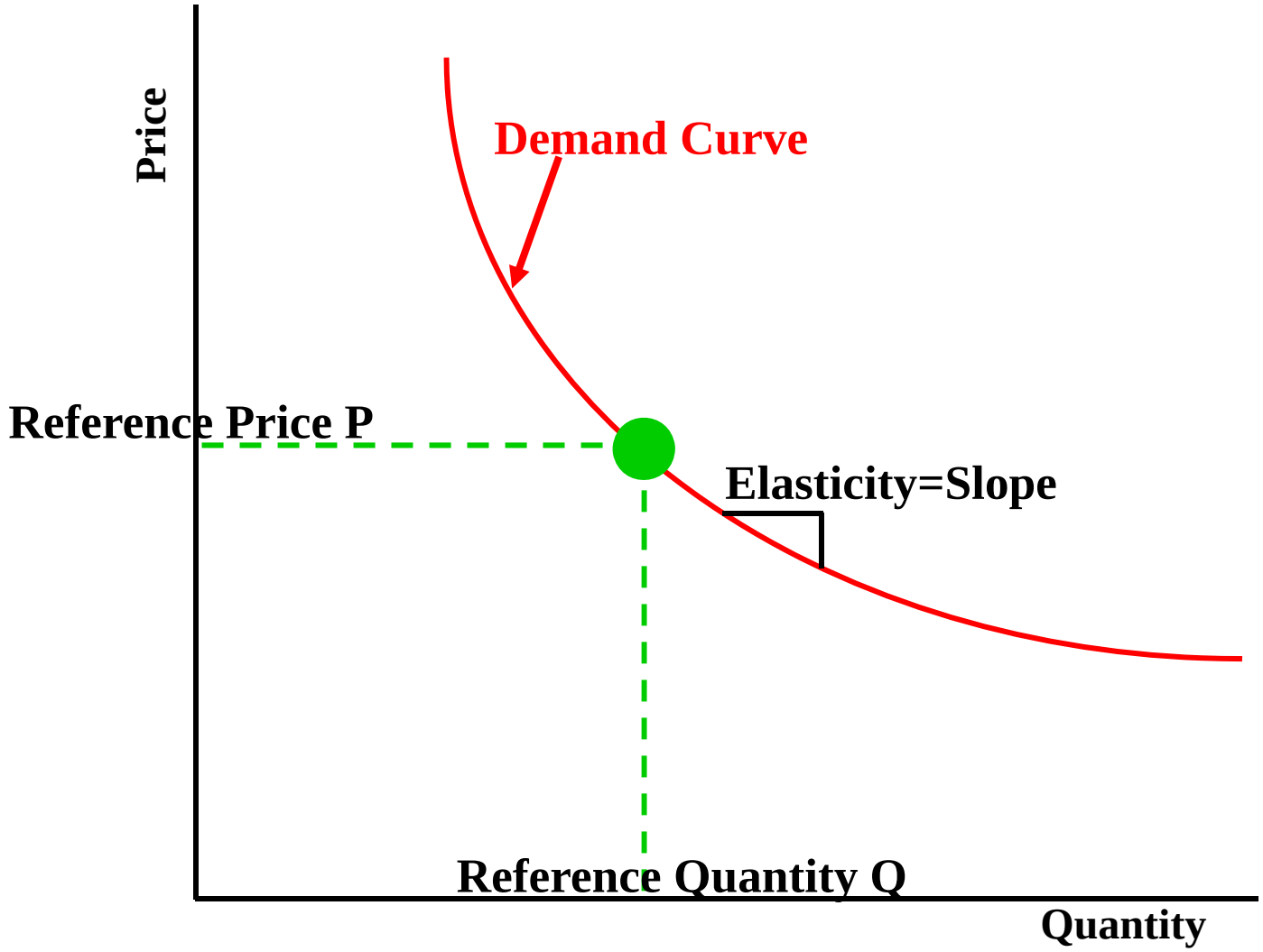


There Is a Demand Tombstone for Every Refined Product in Every Region

- Each demand tombstone holds a complete nonlinear demand curve



A Convenient Representation of Nonlinear Demand Curves—A Reference Point and a Slope (Elasticity)



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A Simple Reference Point Demand Curve

$$\frac{q(t)}{Q(t)} = \left[\frac{p(t)}{P(t)}\right]^{\varepsilon}$$

- Inputs
  - Q(t)=reference quantity at time t
  - P(t) = reference price at time t
  - ε = price elasticity of demand (negative)
  - p(t) = actual price at time t
- Outputs
  - q(t)= actual quantity at time t

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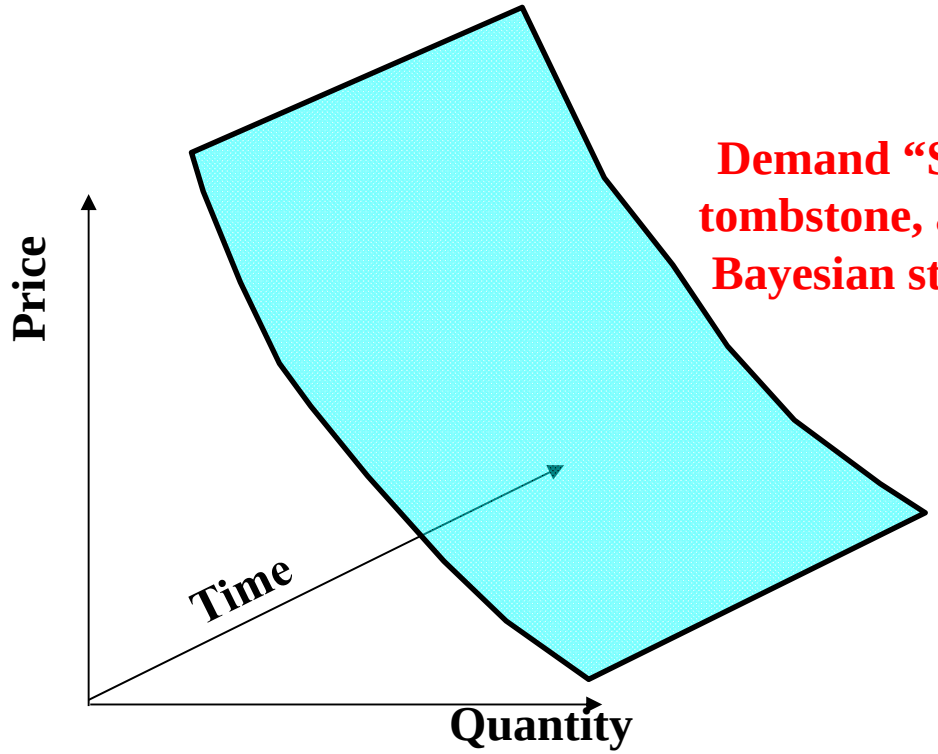
We Need to Be Much More General Than This

- Elements of demand
  - HISTORICAL product consumption schedule q(t) during the past number of years allows us to model lagged adjustment
  - Product price p(t) during past and present years
  - Gross Domestic Product (income) for the country in which the product demand occurs gdp(t)
  - Population for the country in which the product demand occurs pop(t)
- We want product consumption to be a function of these four parameters—lagged consumption, price, GDP, and population

We Assume Reference Quantity, Price, GDP, and Pop—VERY General



Demand "Sheet" is in every tombstone, all analyzed using Bayesian statistical methods

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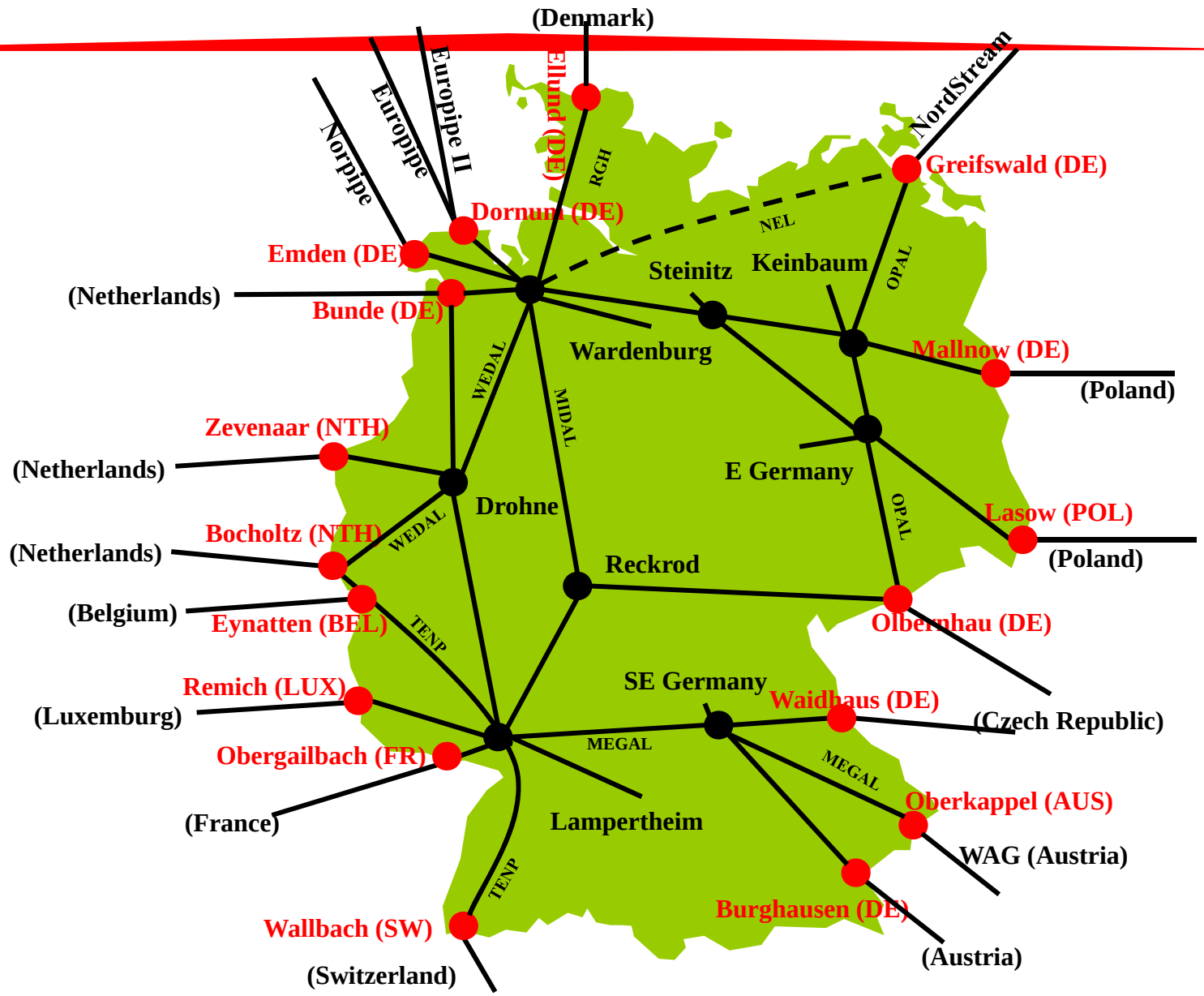
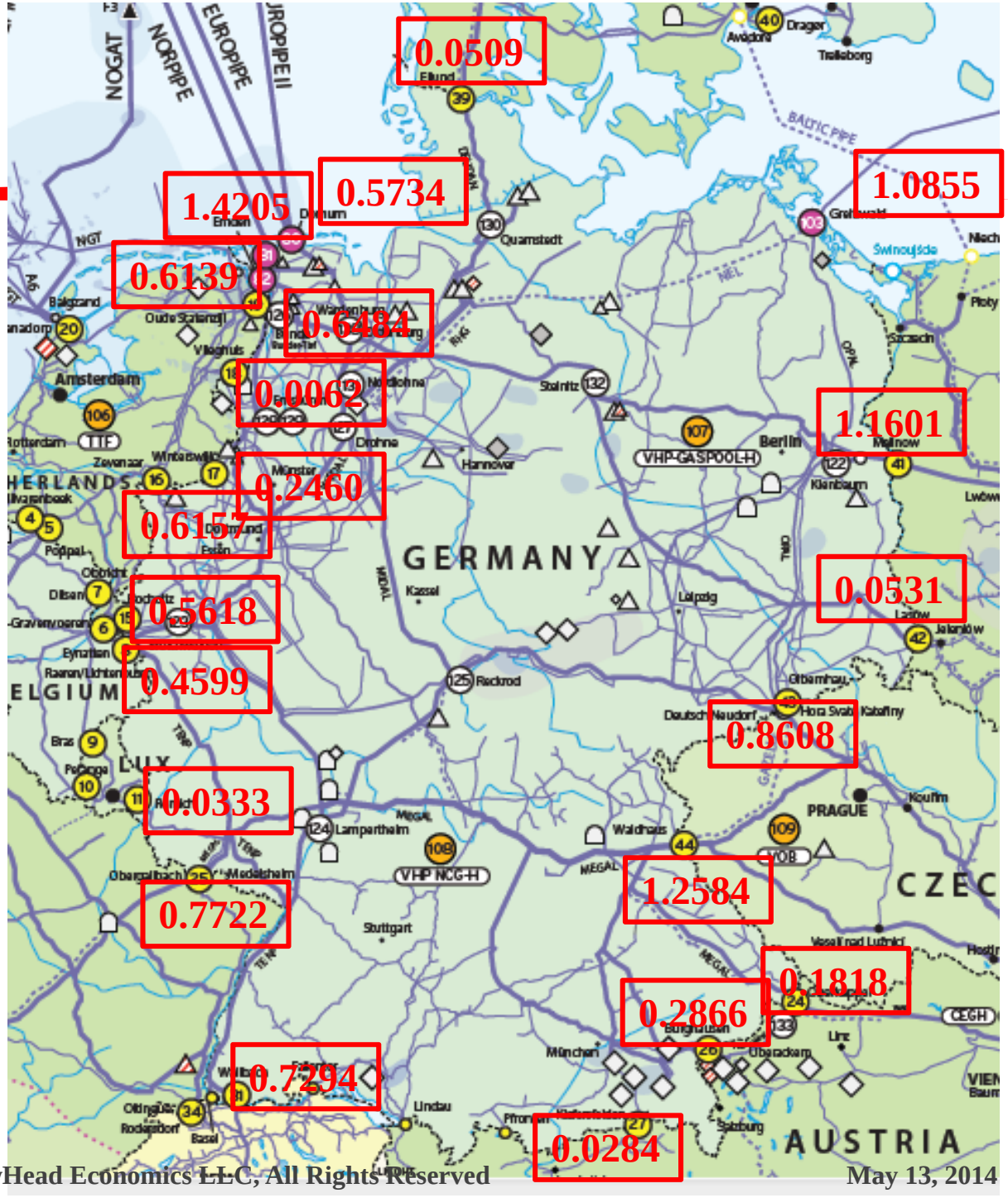
3. Transportation Connects Regions and Sectors Around the World

Germany (Border-Pipe-Demand Map)



Germany



Transportation

- Transportation maps for every country in the world
- All outbound destinations from every supply region.
  - All upstream infrastructure (e.g., gathering and field processing)
  - All costs and losses on every pipe or tanker.
- All inbound sources in every demand region.
  - Contracted sources
  - Spot/competitive sources
  - All costs and losses on every pipe or tanker

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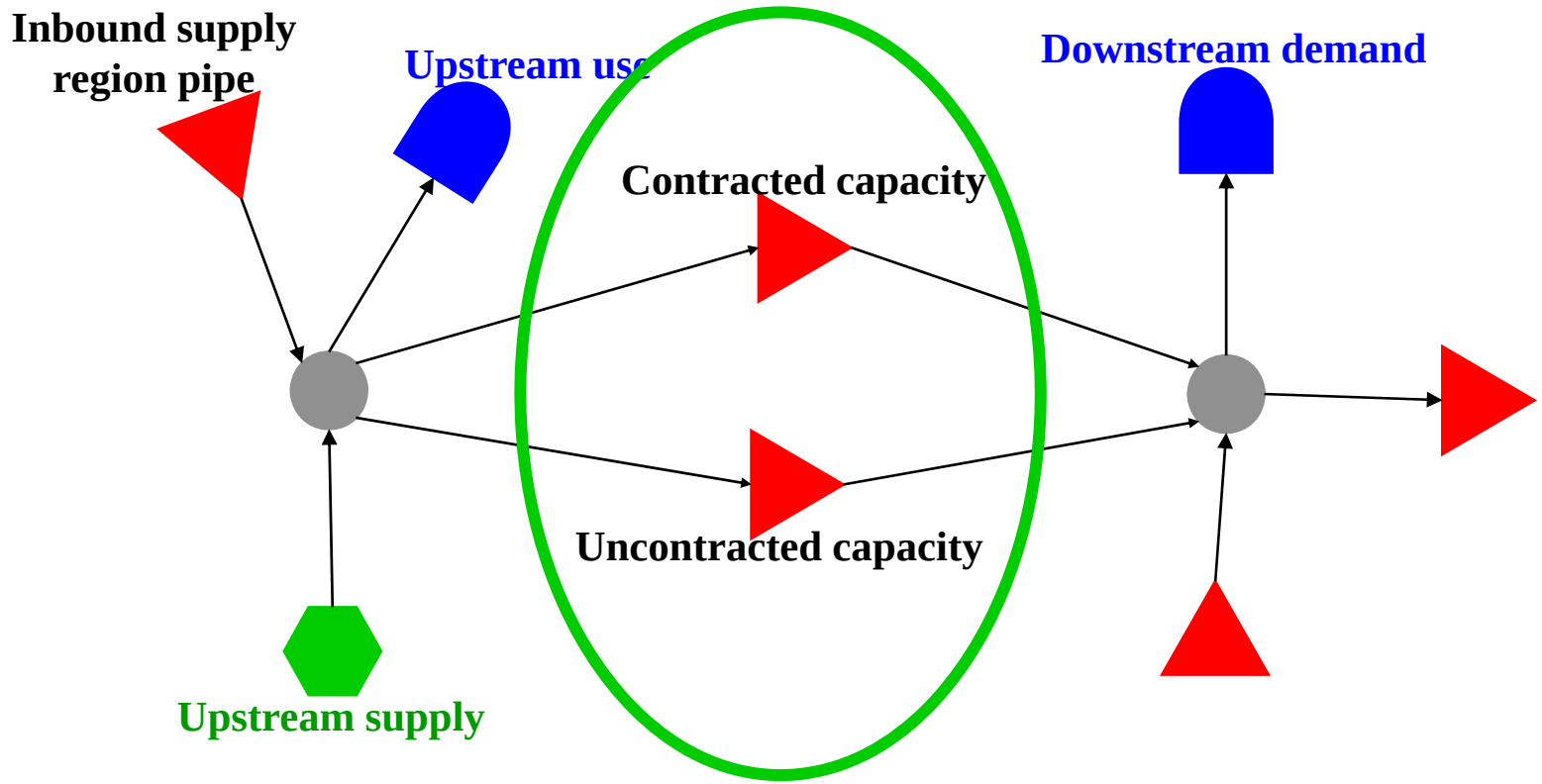
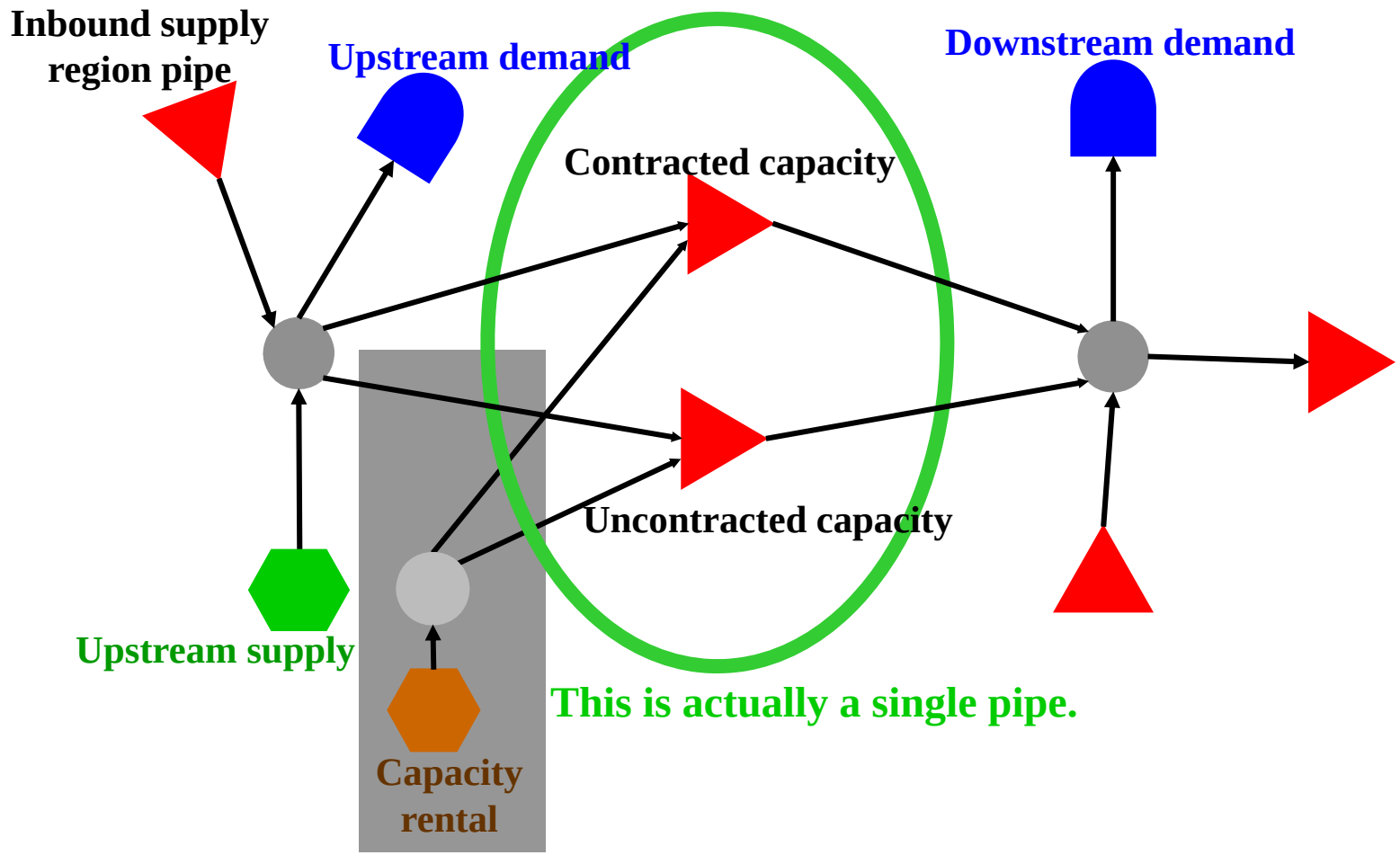
Contract Versus Spot Gas

AGGM Distinguishes Contracted and Uncontracted Transport Capacity

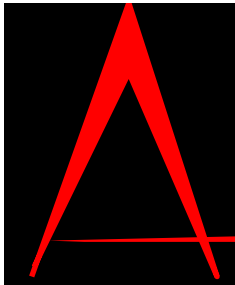


AGGM Limits Sum of Contracted and Uncontracted Transport



Uplift Overcontracted Gas to the Spot Market

- If a market is temporarily or permanently overcontracted, the receiver
  - Uploads the excess to the local spot market
  - Transports the excess from the local spot market to its best available (in terms of price) use
  - Disposes it in that contestable market
  - Takes the price hit between the contracted price and the spot price.



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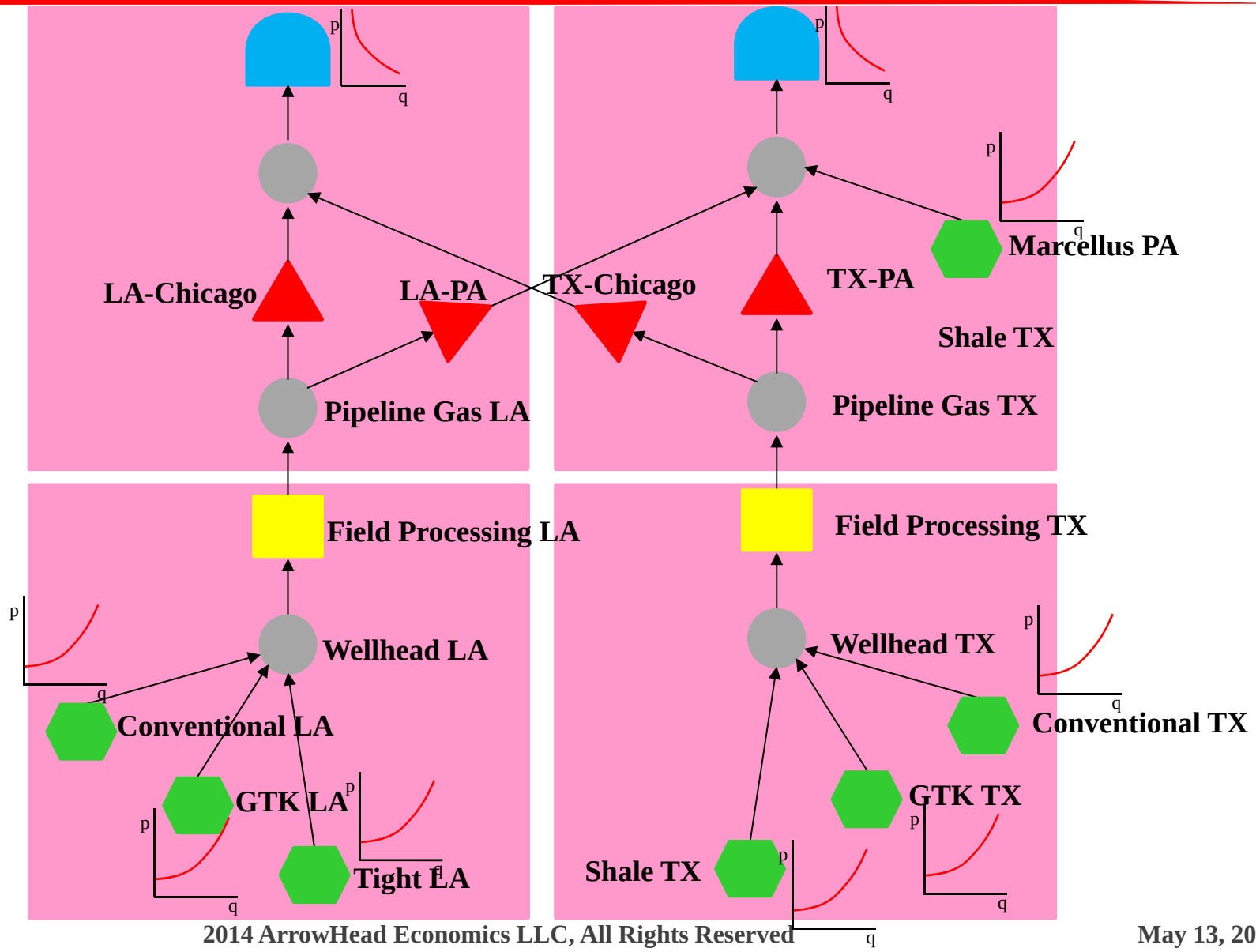
Parallel Computing

Fixed Point Algorithms Are Fully Parallelizeable

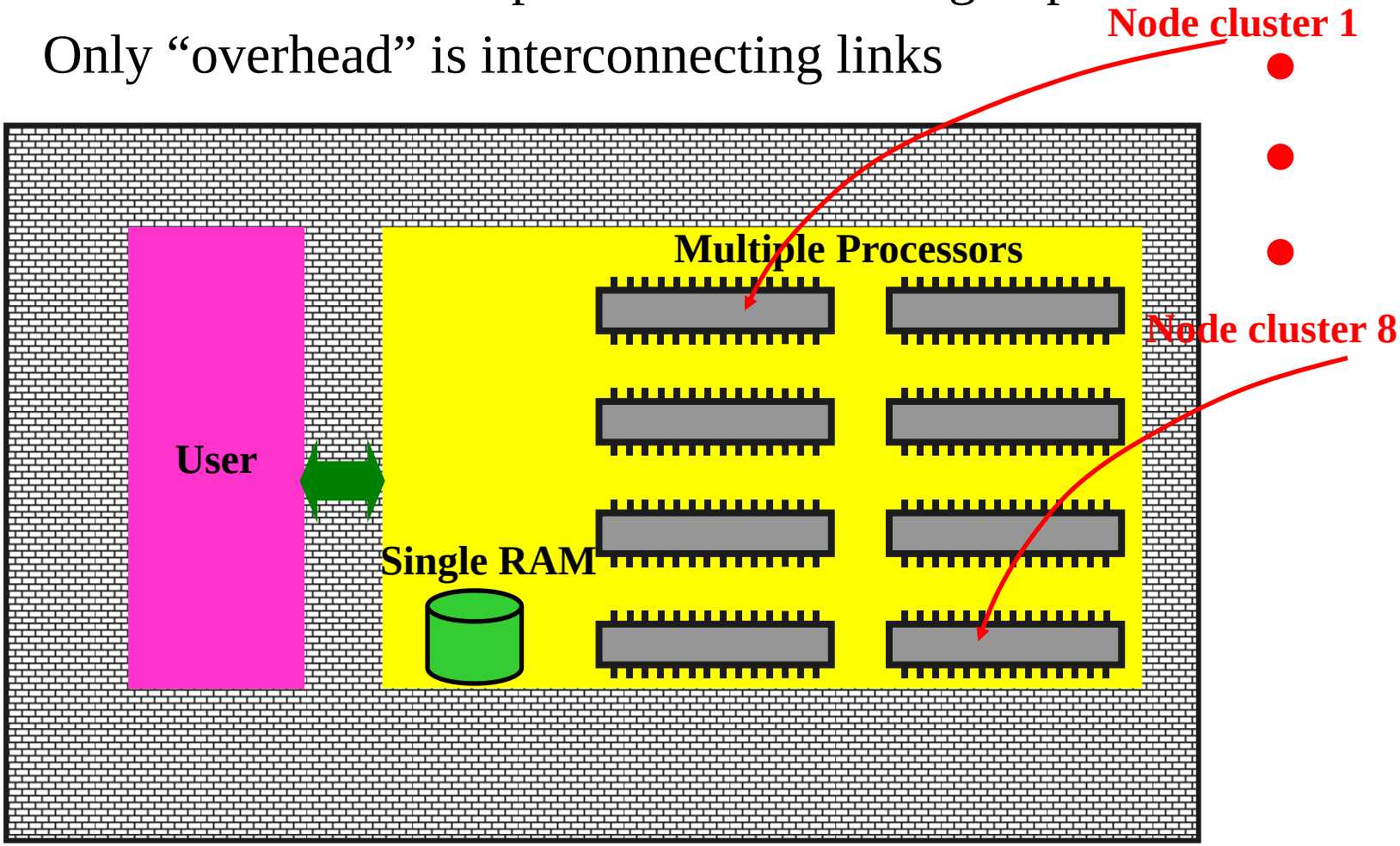
- Serial algorithms are NOT (LP, NLP, complemetarity, Genetic, Neural Networks)
- Anything written in a nonmodern language like GAMS has little hope of parallelizing.
- They are not algorithmically parallelizable because the algorithms are inherently serial.
- “If Jack takes 3 hours to mow the lawn and Jim takes 2 hours to mow the lawn, how long will it take them to mow the lawn if they work together.”

Parallelizeable Algorithm (Assign Groups of Nodes to "Threads")



MarketBuilder and ArrowHead Are Fully Parallelized

- 8 processors
- 1/8 of nodes on each processor all running in parallel
- Only “overhead” is interconnecting links



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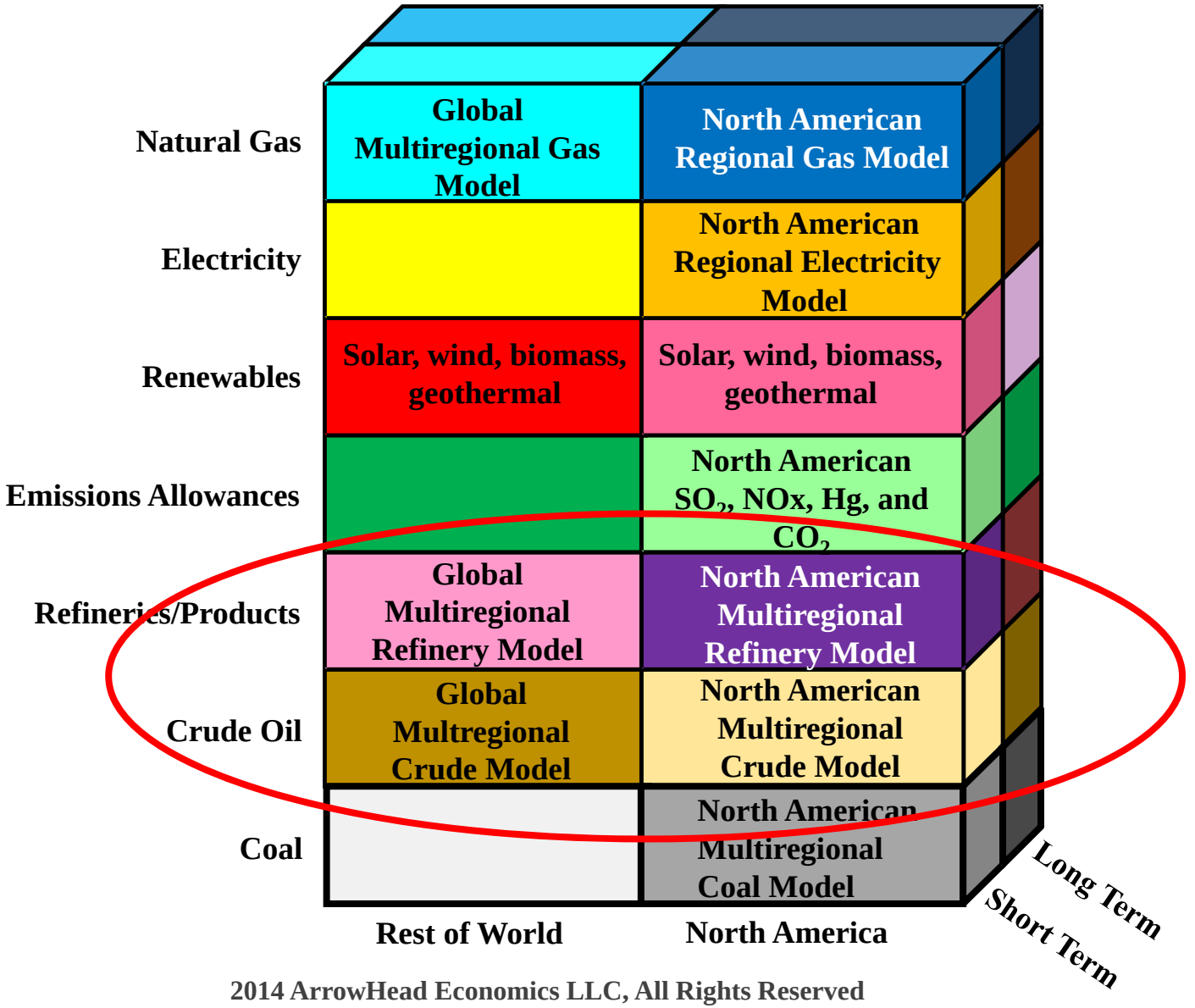
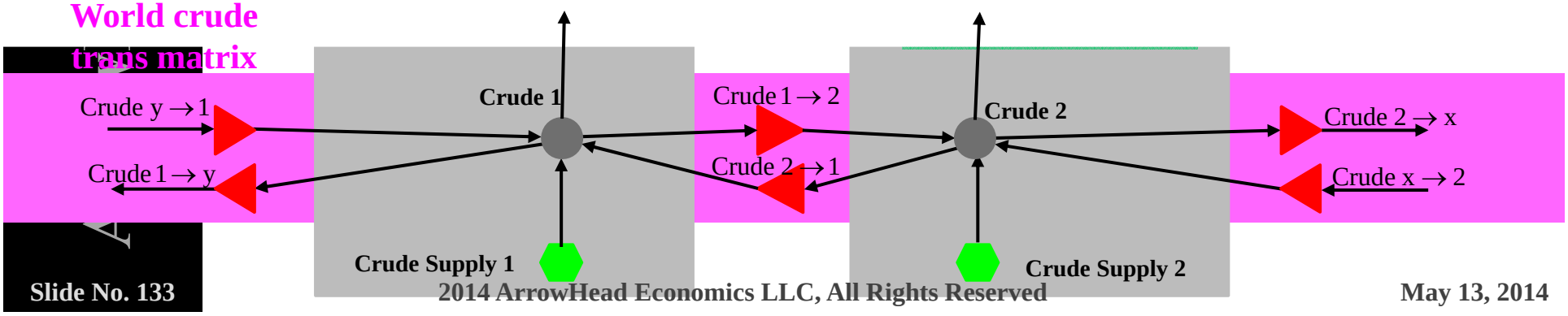
World Oil Model

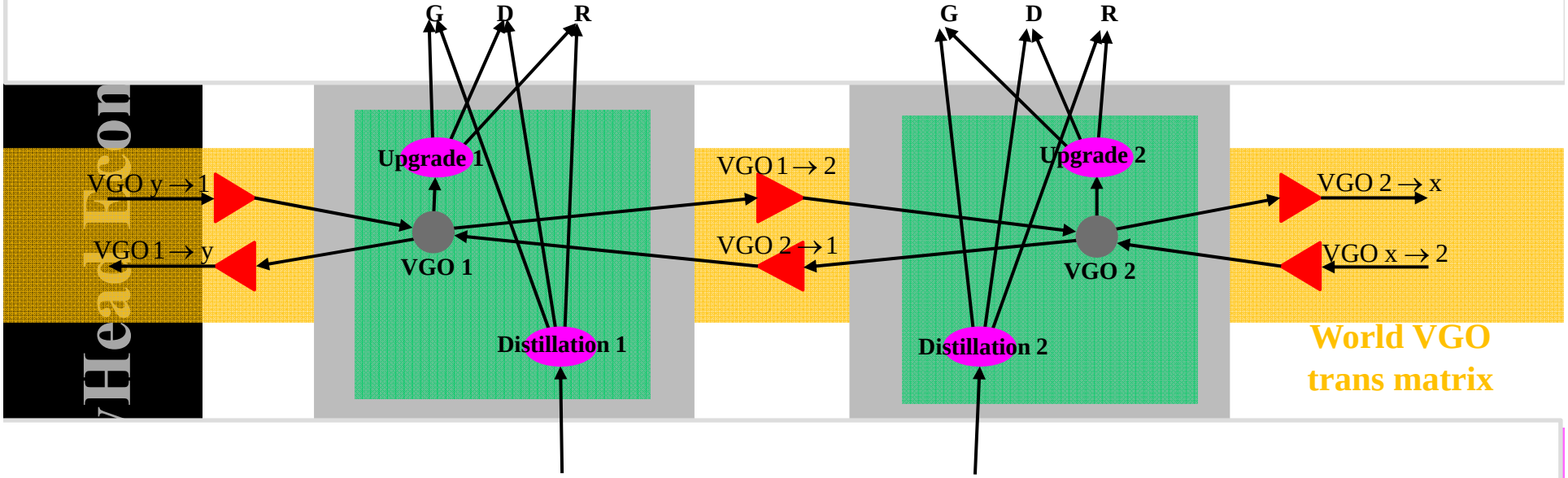
We Have a Complete Suite

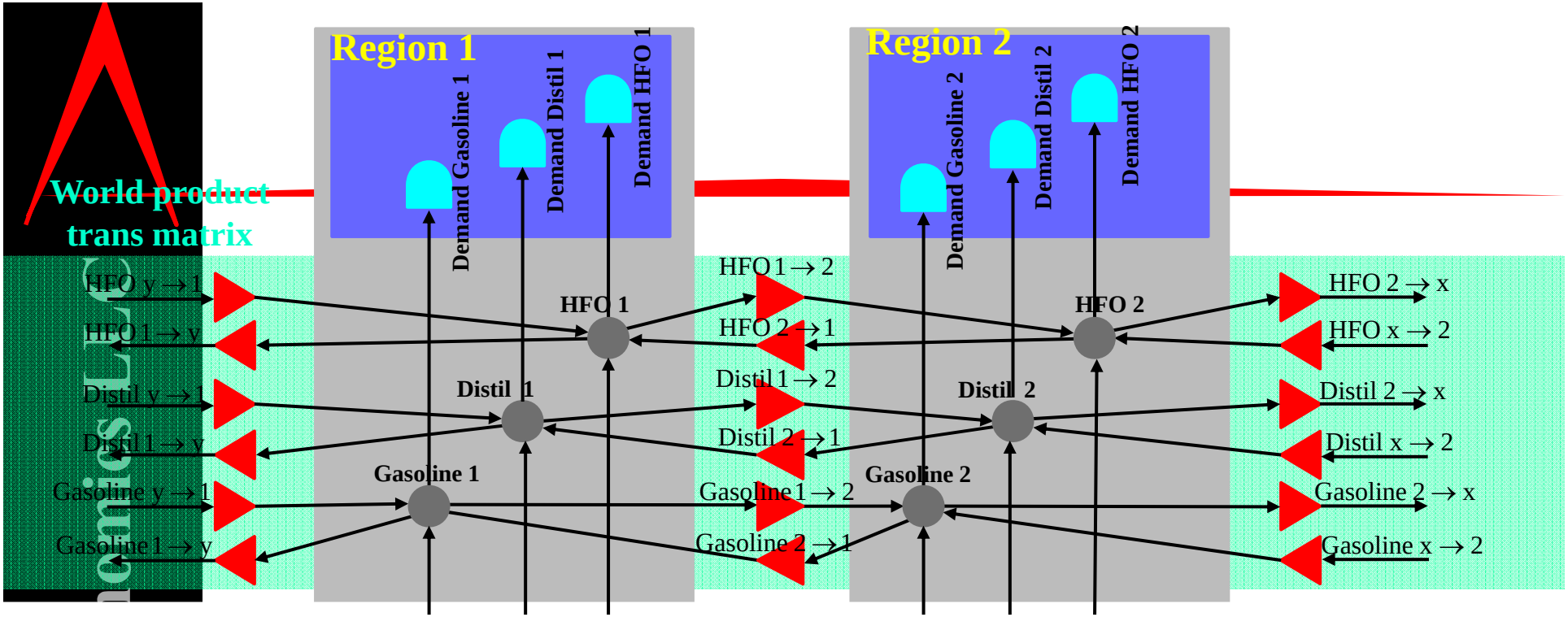


Full Regional Supply and Crude Transportation Model Worldwide

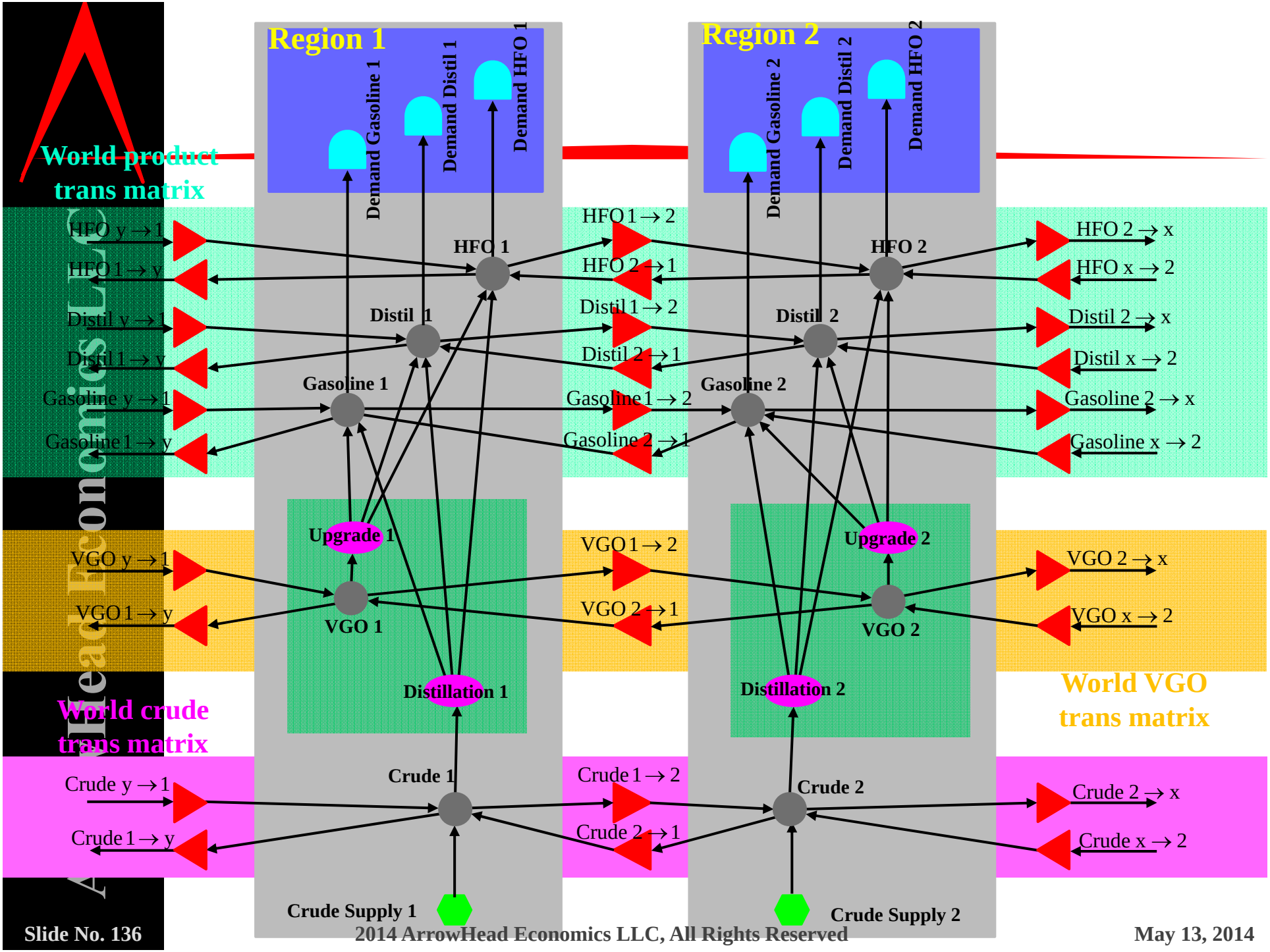


Full Regional Refining and VGO Transportation Model Worldwide





Full Regional Product Transportation and Consumption



Regionality

- 30+ refinery regions
- ~100 supply regions
- 30+ consumption regions

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Temporality

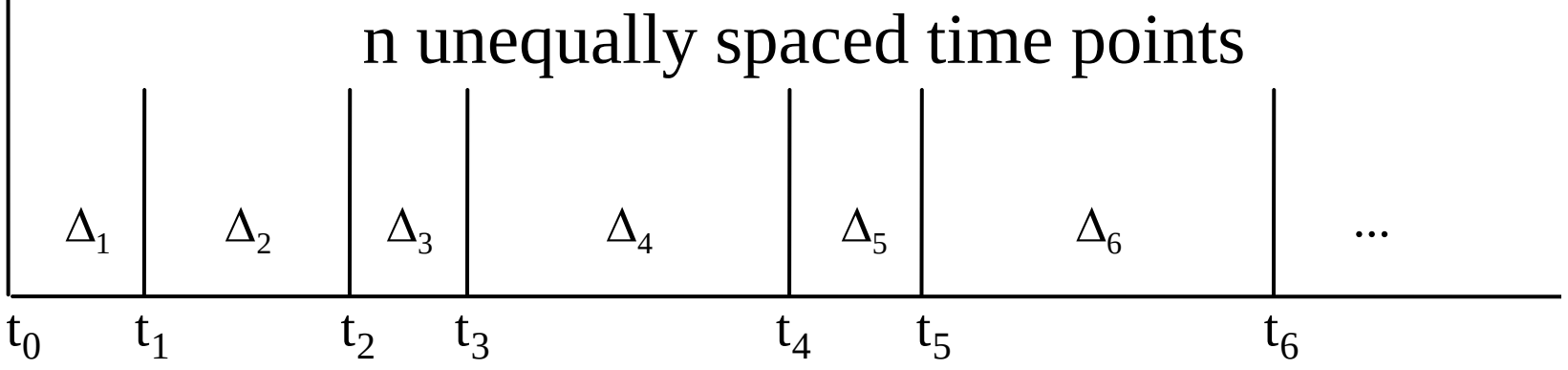
Timeline in ArrowHead

- The model solution is based on a timeline
- The modeler specifies the number of time points and the spacing between them
- Equilibrium is calculated for each and every time point and subtime points simultaneously
- All time points and subtime points are fundamentally interconnected and interrelated
  - The equilibrium is not static
  - The equilibrium is not serial
  - The equilibrium is jointly intertemporal, i.e., simultaneous and interconnected for every time and subtime point.

Equally or Unequally Spaced Time Points of Any Length

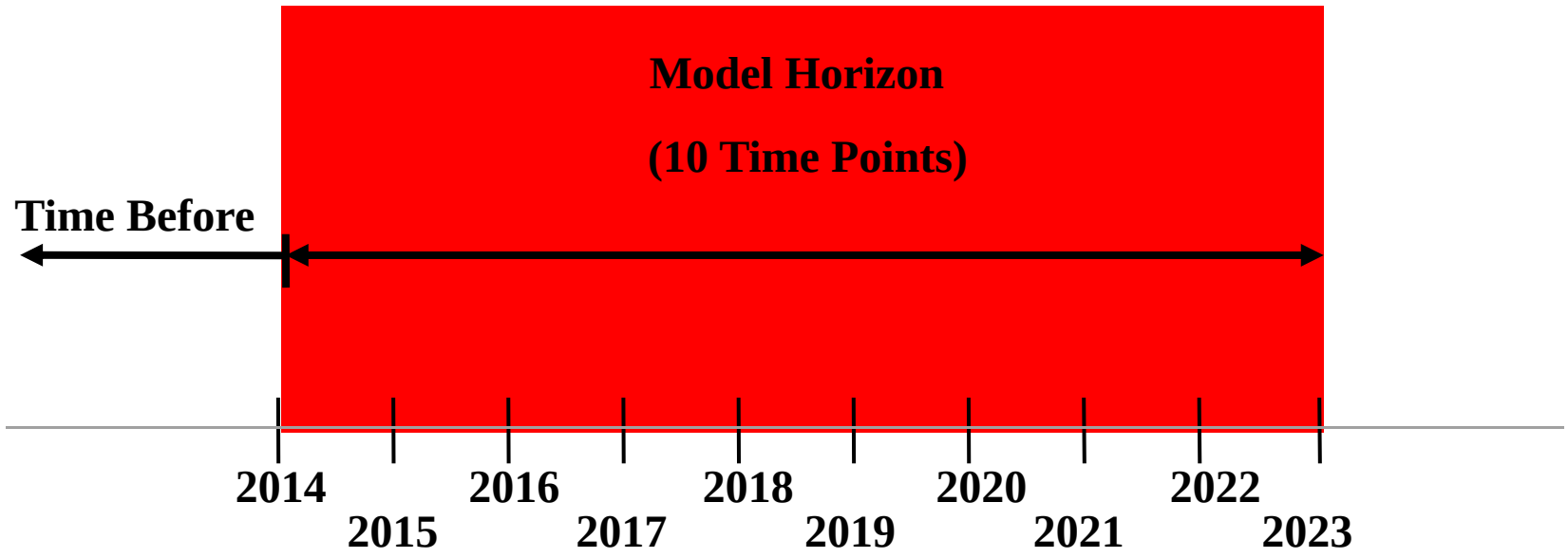
- Hourly-daily-weekly-monthly-annual
- This is actually quite hard
  - That is why you never see other modelers do it.
  - It is needed BECAUSE of vintaging.

Model Horizon



It Is a Vintage Model, So You Need Times Before, During, and After Model Horizon

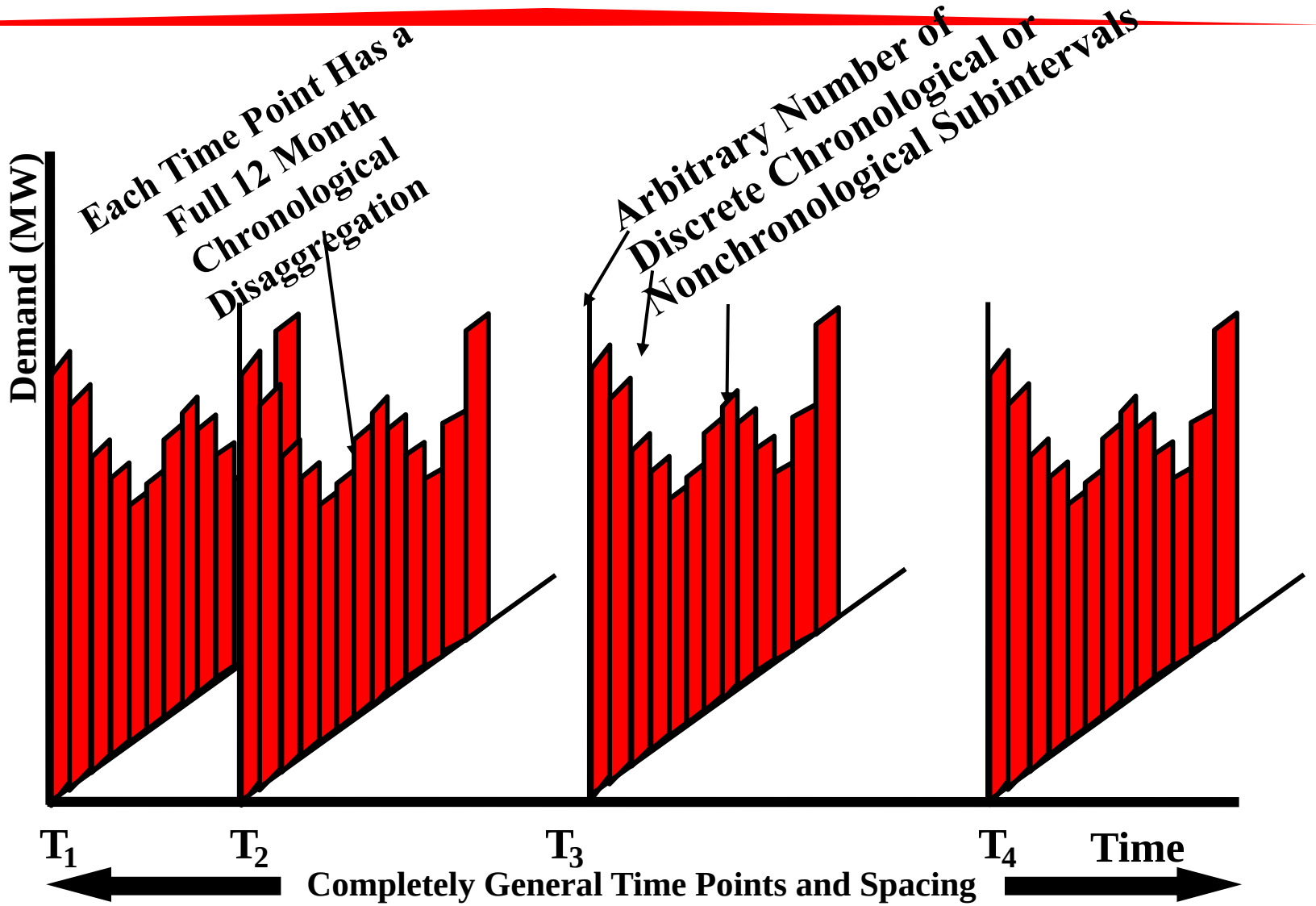
- Times before MATTER. We will discuss times within and thereafter move to times before



Timeline Insights

- There will always be n time points and n-1 time intervals.
- The user defines time points, not time intervals
- The time intervals are implicit from the user defined time points.
- There is assumed to be a “histogram” of demand at each timepoint
  - Seasonal gas storage
  - Power plant load following by hour
- The histogram is divided into “subtimes”

Chronological Multi-Annual Monthly Model



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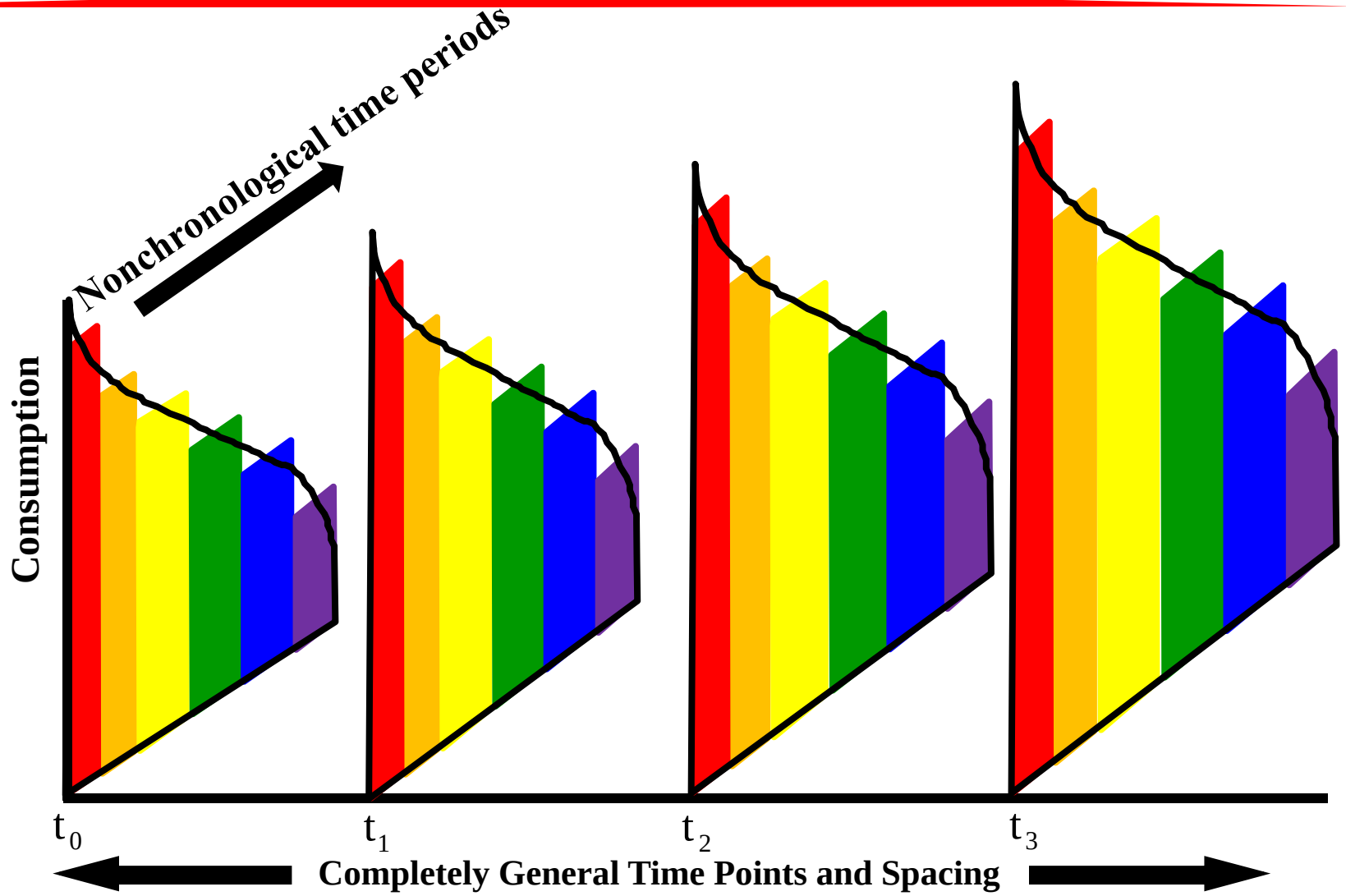
Hybrid Chronological/Nonchronological if Desired



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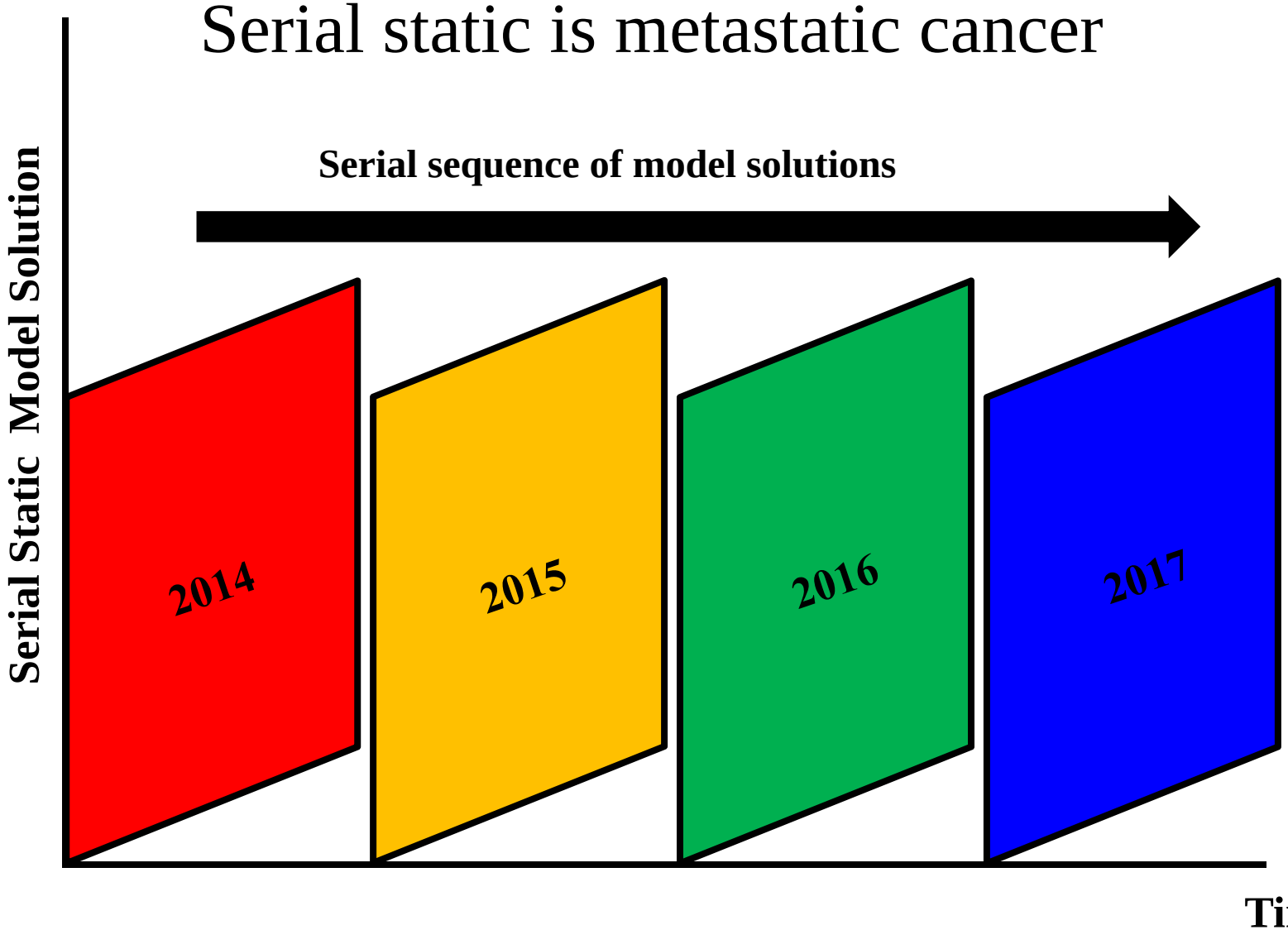
LP (and Other Models) Are "Serial Static"

Serial static is metastatic cancer



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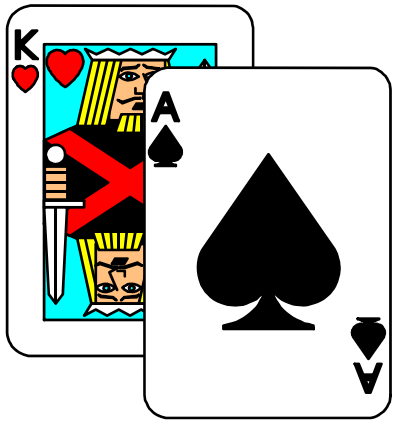
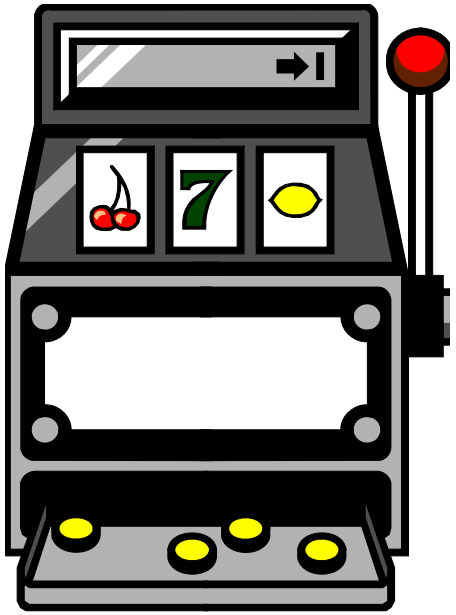
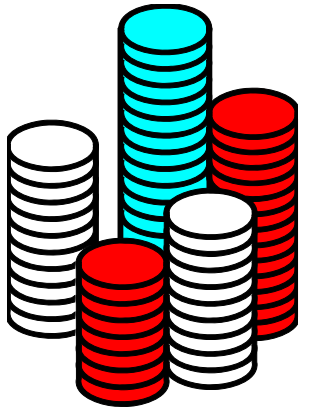
Various Timelines That Have Been Used

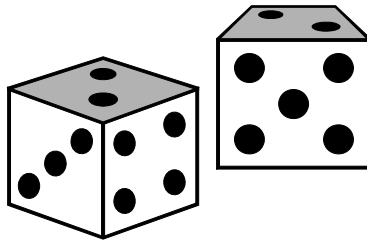
- Gas
  - Daily for 365 days forward (sale dome storage development)
  - Monthly for 36, 60, and 120 months forward
  - Multiannually 40 years forward with 12 monthly subtimes and skipped years
- Oil and refining
  - Multiannually 40 years forward with skipped years but without monthly granulation
- Electricity
  - Multiannually with skipped years for 20 years forward
    - 120 sub-annual subtimes
      - 12 months specifically enumerated
      - 10 tranches per month enumerated
  - Hourly for weeks, months, and a year forward

6. Endogenous Uncertainty









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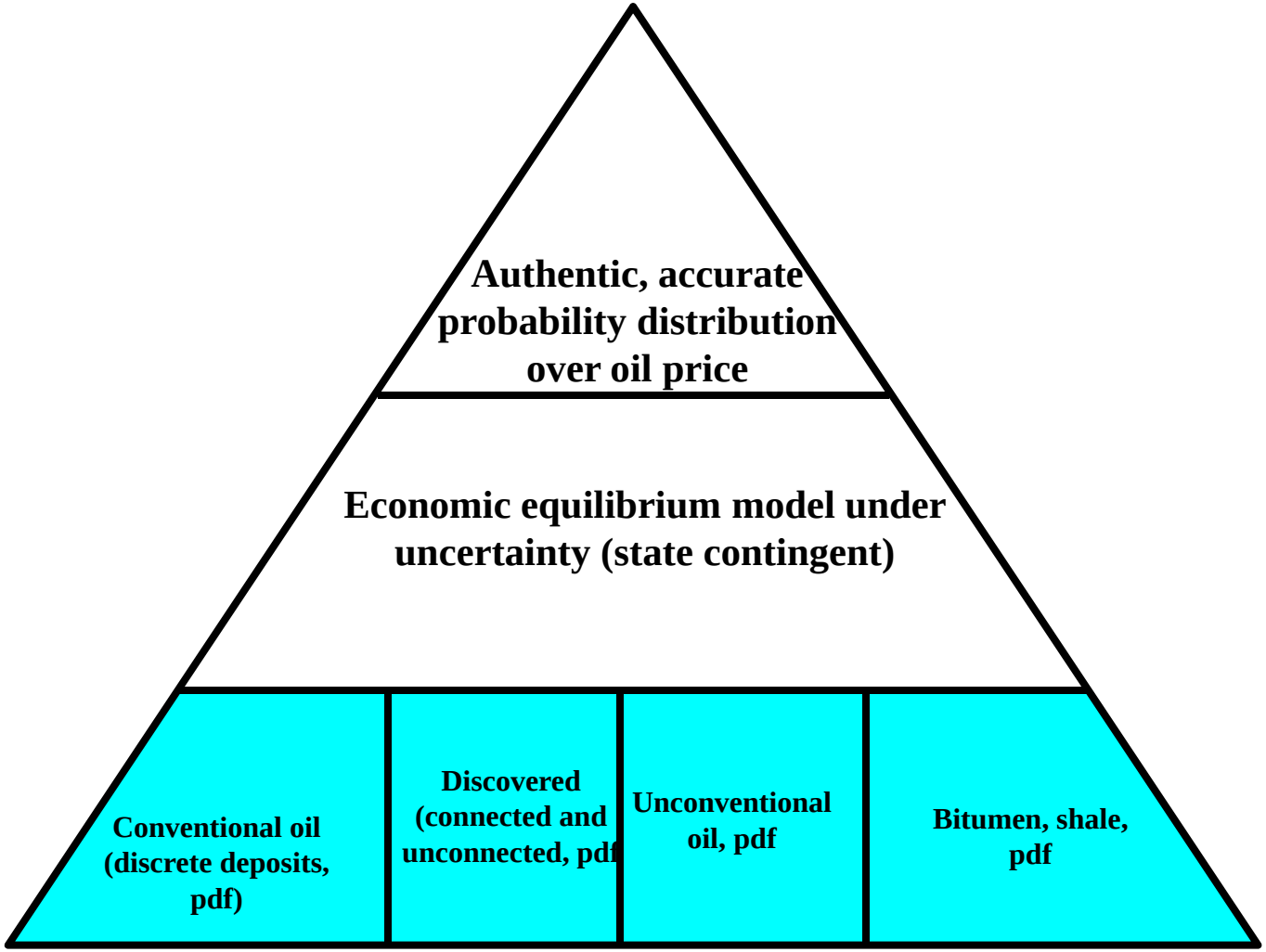
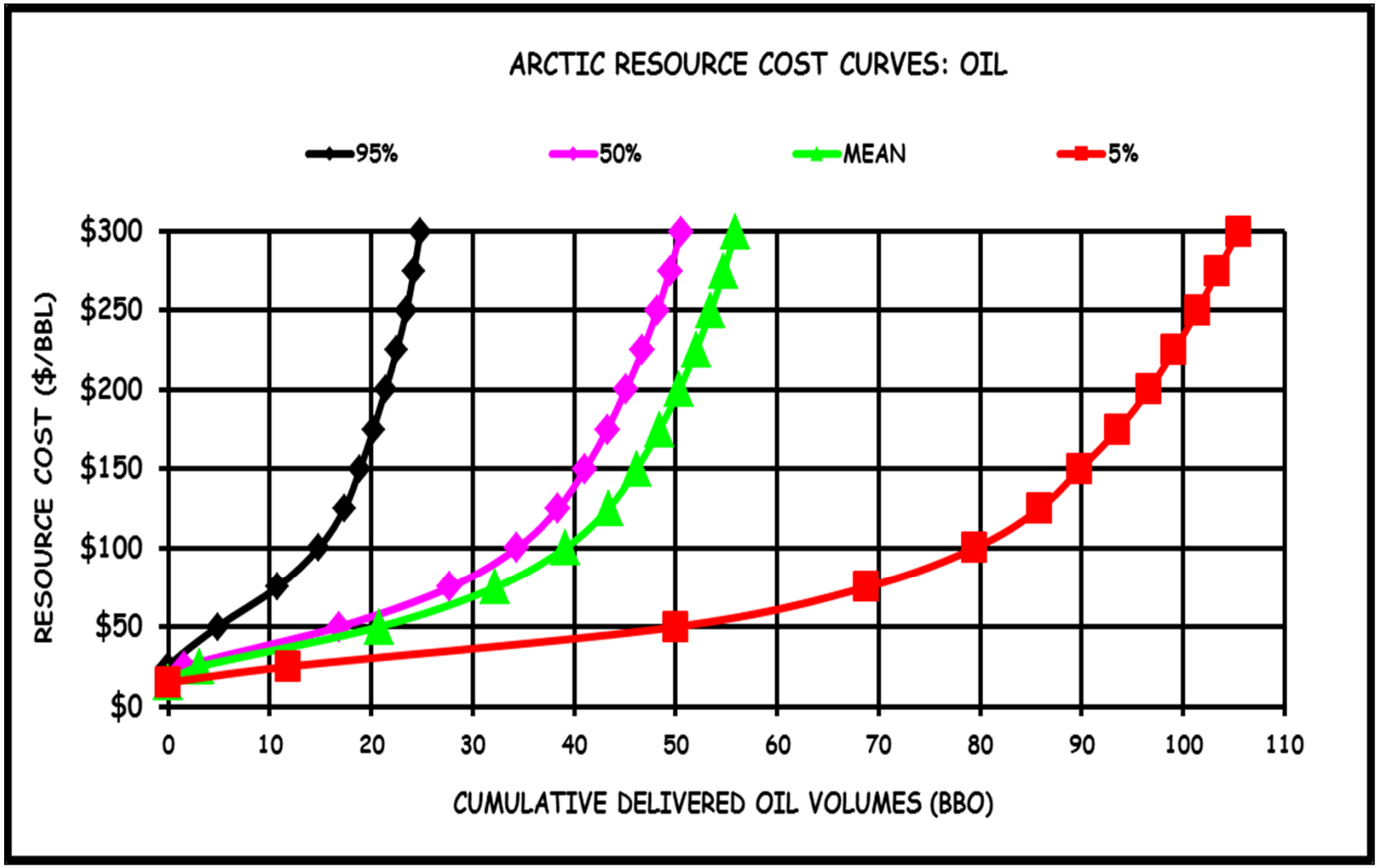
1. A Probabilistic North American and World Assessment of Undiscovered Oil and Gas

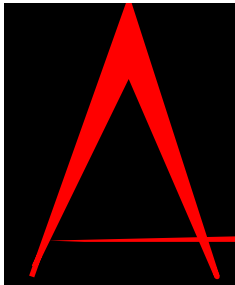
What People Need for Oil, Gas, and NGL Decision Making



Dr. Donald Gautier Has Done This (Arctic Resource Cost Curves)



From White and Gautier 2010



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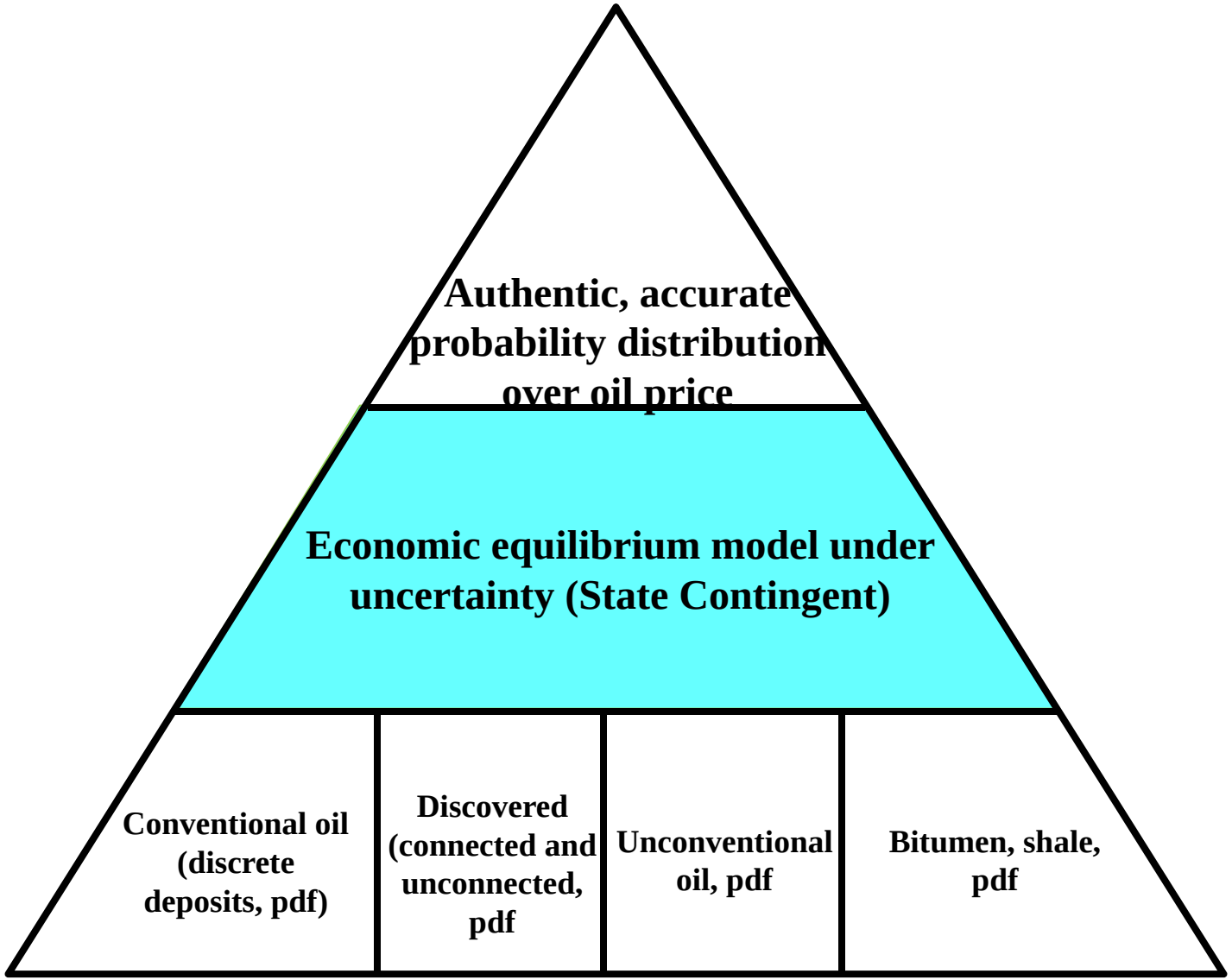
2. Economic Model with Endogenous Uncertainty

What Companies Need for Oil, Gas, and NGL Decision Making



Nesbitt and Calvez Have Prepared a Written Paper on This

- It will be delivered to EIA at the appropriate time.