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WHAT STARTS HERE CHANGES THE WORLD

Matching Environmental and Economic Performance of CCUS systems:

an approach to a decision-making methodology for sustainable development

Focus in CCUS Power Plant for CO2-EOR

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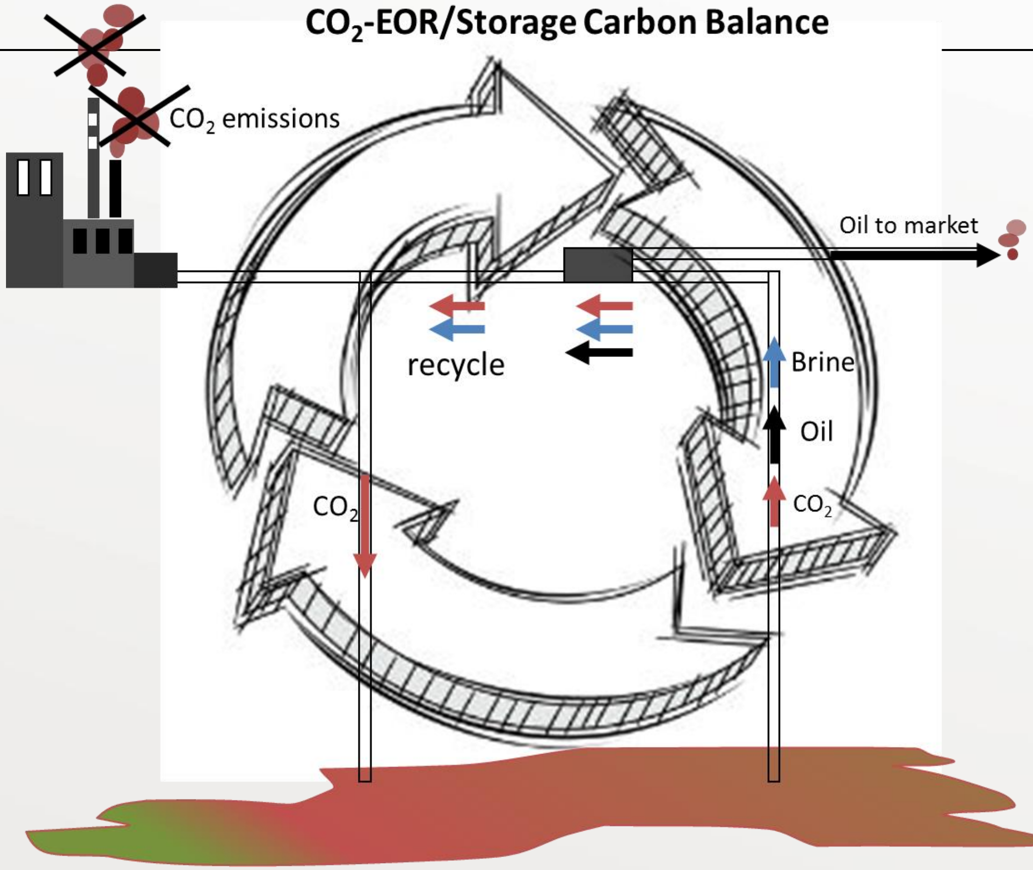
Content:

- Brief overview
- System Characterization
  - CCUS in Electric Power generation
  - CO2-EOR
  - Business Models
- Decision Making (methodological Approach)
  - Common practices
  - Integrated Framework
- Methodological proposal
- Conclusions

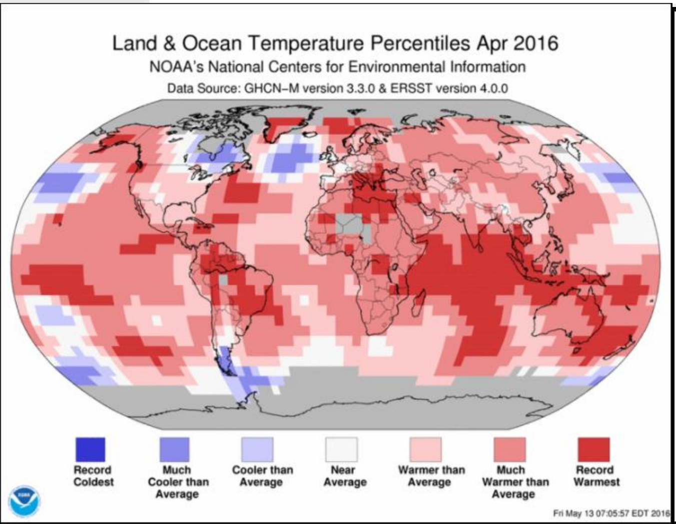
Main Objectives:

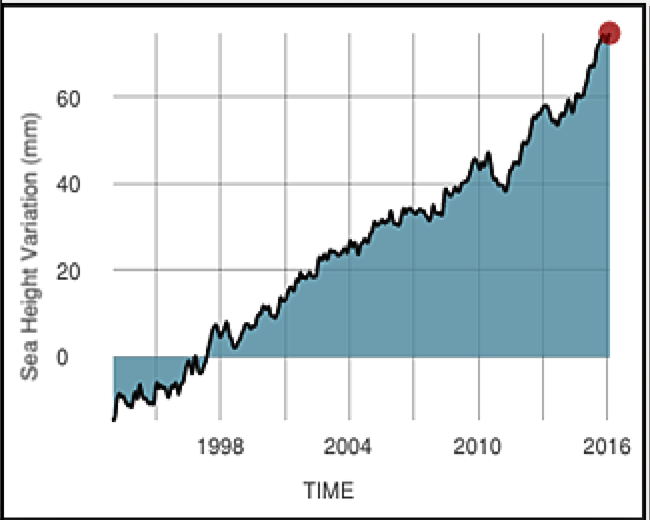
- Identify and frame critical aspects of the CCUS Electric Power for CO2- EOR.
- A quick review of the integrated assessment methodology for decision-making in complex systems
- Develop a first approach to a broad decision-making framework for CCUS Electric Power for CO2- EOR systems



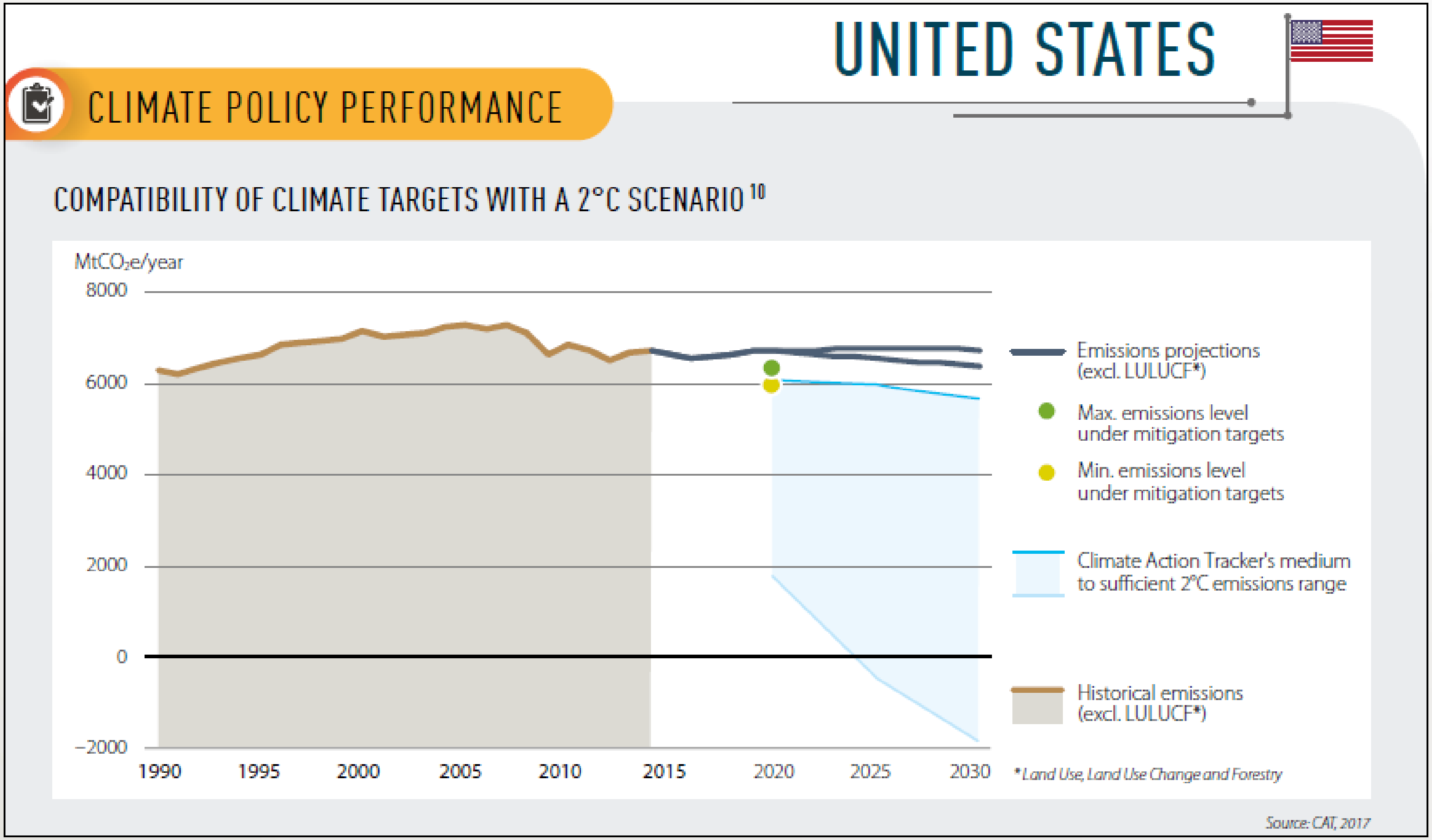
Brief overview

- Climate Change is real, it is occurring NOW!
- Anthropogenic prominent role.
- Paris Agreement
- The Goal was set (UNFCCC & IPCC): -2°C





BROWN TO GREEN: THE G20 TRANSITION TO A LOW-CARBON ECONOMY | 2017 by Climate Transparency



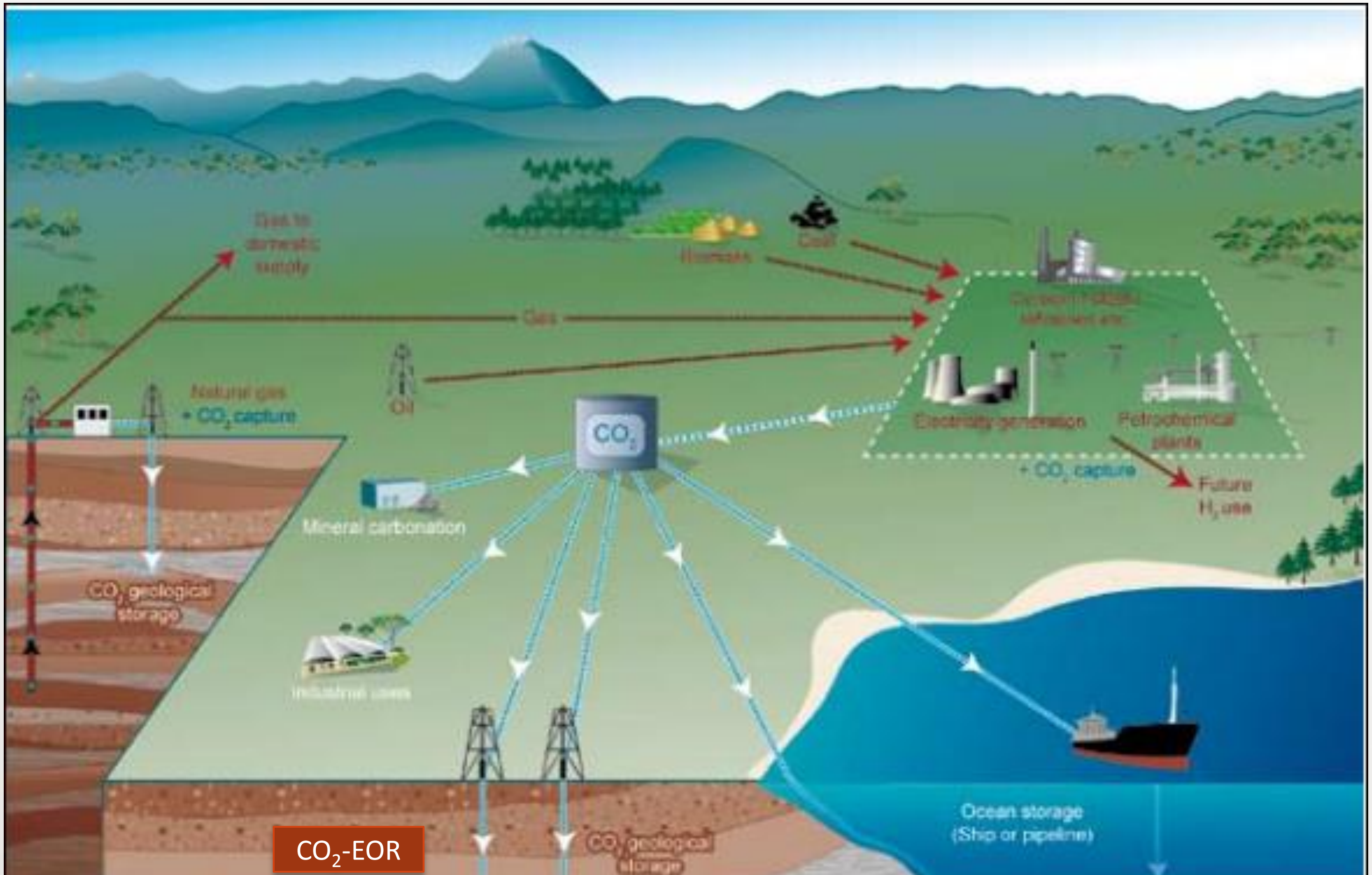
Brief overview

- Means Energy de-carbonization:
  - Transportation electrification
  - Phase-out large number of coal-fired Power Plants by 2030
  - Significantly share growth of renewables (+70%)
  - Carbon Capture, Utilization and Sequestration (CCUS)
  - Side demand energy efficiency.

- Simultaneous implementation of these technologies
- CCUS should be a priority [IPCC, 2013]
- All the Global Climate Change models necessarily include CCUS

Brief overview

What is CCUS?



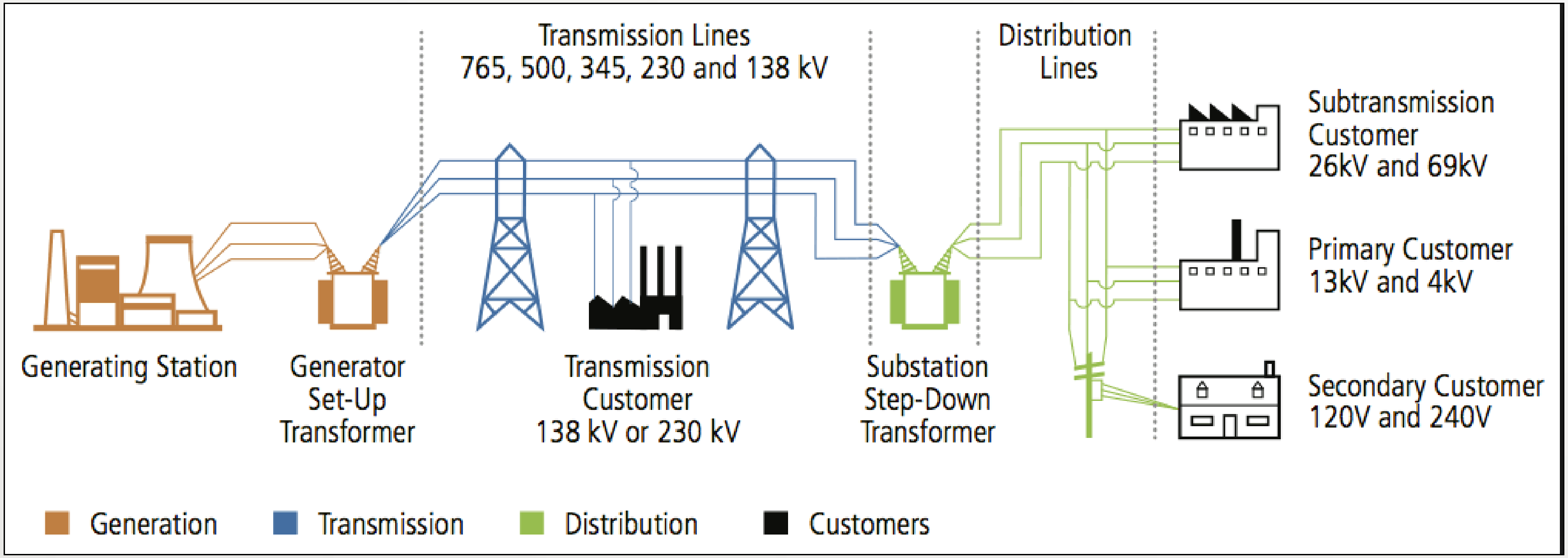
From: CCS, IPCC,2005)

System Characterization

Electric Power Sector

- Strategical High Value Sector
- High Capital Intensive
- Integrated and interconnected system
- Major changes in markets pressure the system to its operable limits
- Planning is becoming increasingly complex

Figure from: DOE - Quadrennial Energy Review



System Characterization

CCUS in Electric Power Sector

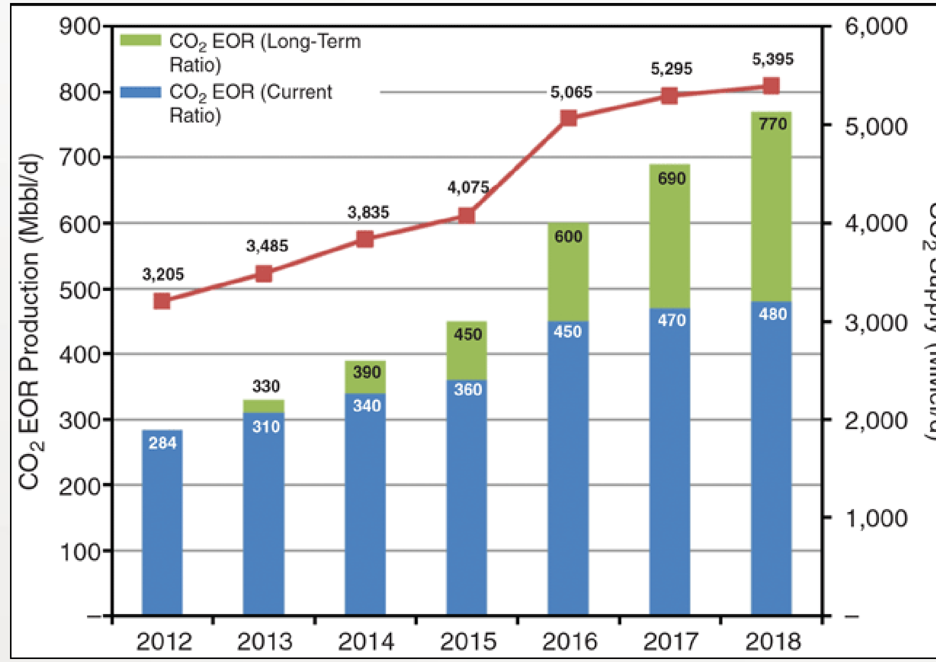
- CCUS is a key factor in least-cost transitions to a low-carbon electricity system in 2050
- The scale of Power Plants force thinking their integration to a CCUS system
- Capture technology is expensive and energy intense
- Energy penalties reduce competitiveness
- Low energy prices, low demand growth, more renewals share and others limits investments on CO2 capture
- Power Sector CO2 supply require long term demand

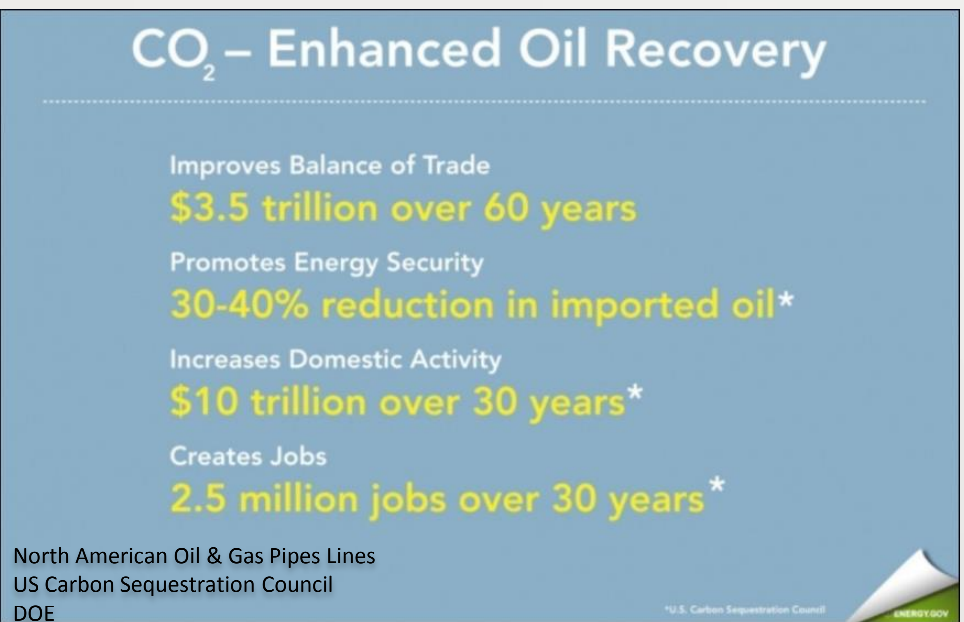
System Characterization

CO2-EOR

- Promissory CCUS technology
- Mature process. Tertiary Recovery
- Additional 4-15% of OIP (Mezler, 2012)

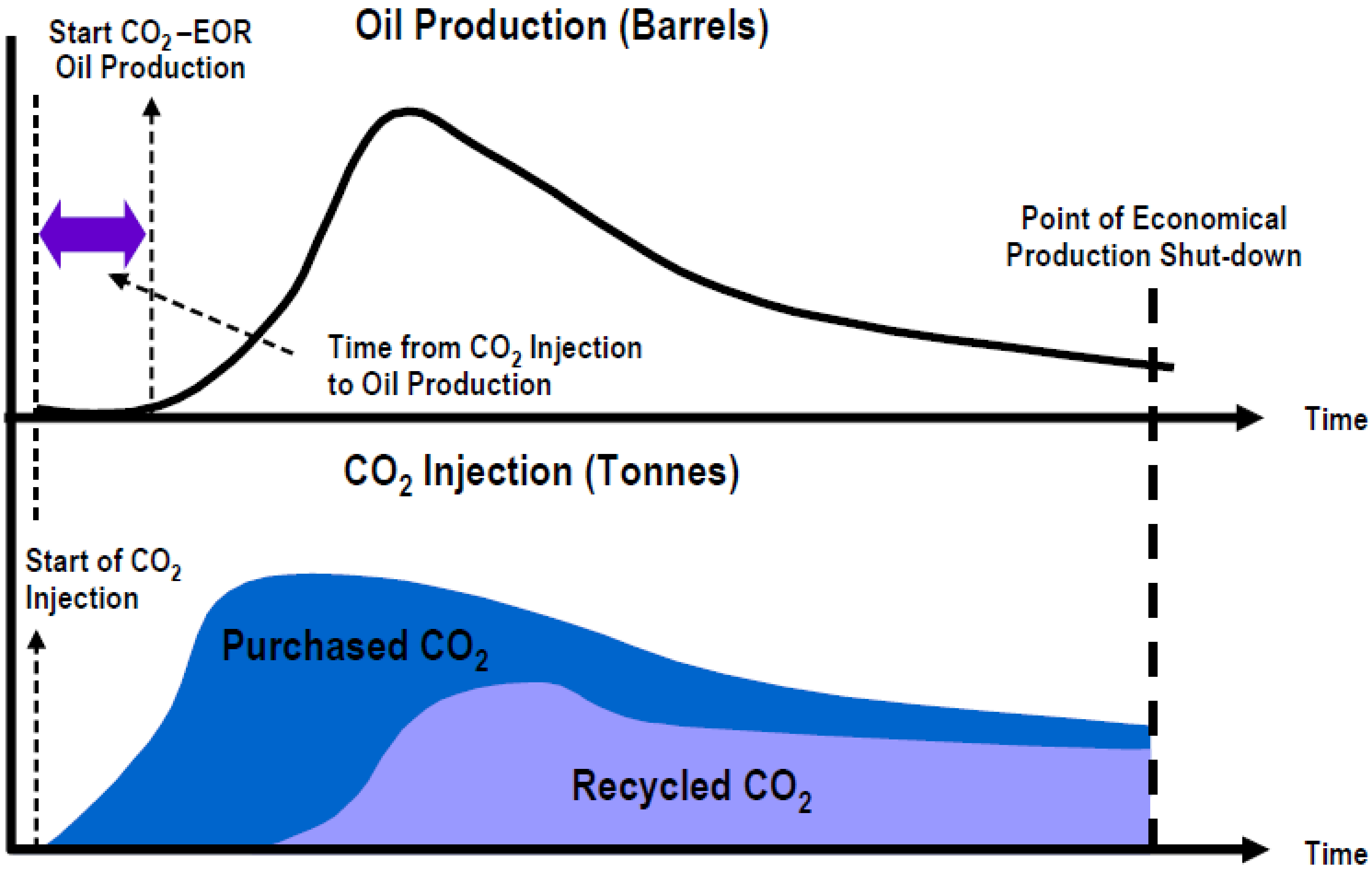
American Oil & Gas Reporter





North American Oil & Gas Pipes Lines
US Carbon Sequestration Council
DOE

- CO2-EOR potential requires expanded access to CO2 sources
- Historically Oil Optimization
- Next Generation Tecnologies improves oil production and CO2 storage capacity



Source: Bellona, 2005

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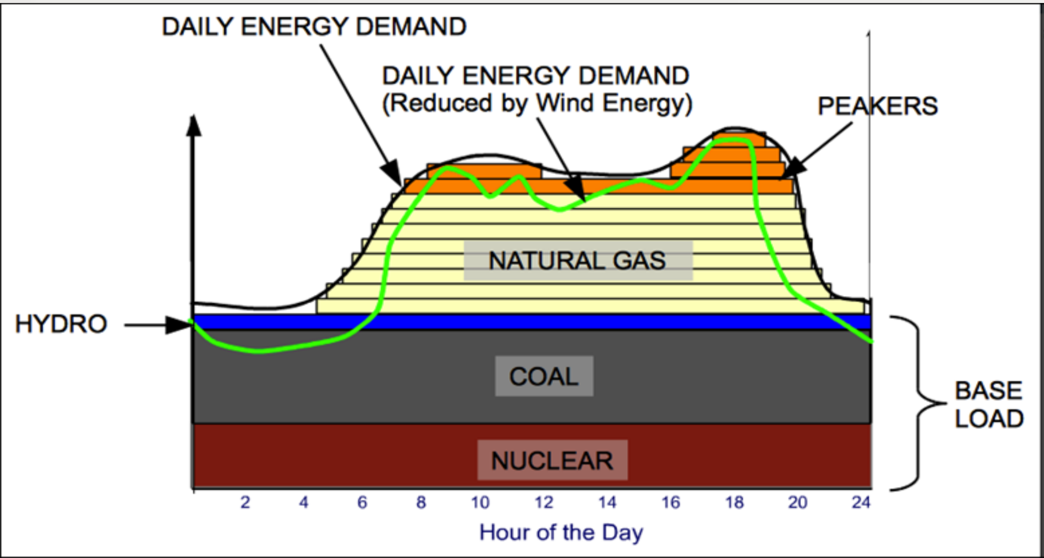
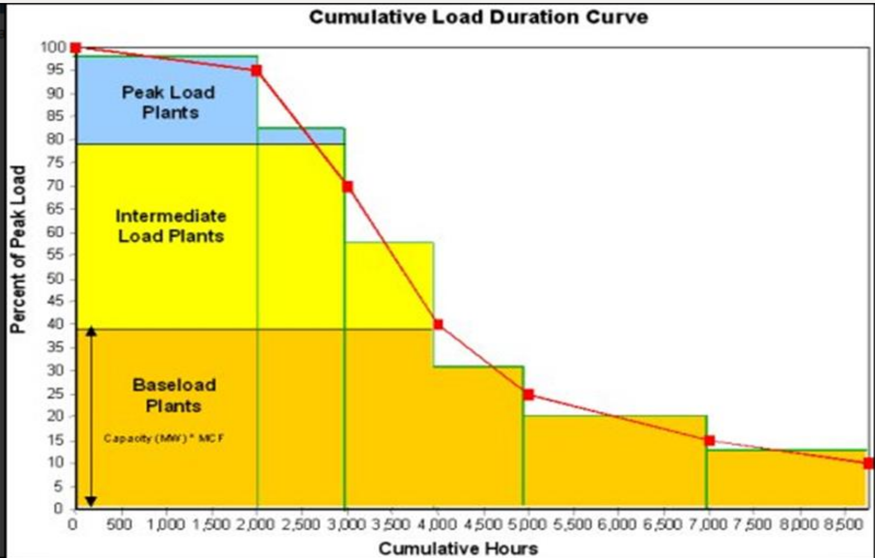
Business Models

- CO2-EOR: activity dominated by independents
- Predominant CO2 source: Gas Processers and Fertilizer plants
- Operators look for Upstream integration building pipelines
- Two large independent companies control half of total CO2-EOR production and expanding
- Petranova, CCUS Coal firered Power Plant. New player build a downstream integration model.

MAIN DIFILCULTIES INTEGRATING THIS CCUS SYSTEM 1/2

- **Alignment of the industries sectors that integrate the CCUS system (economic performance)**
- Strategic sectors has high regulatory intervention that has to harmonized
- Product optimization and emission intensity
- CO2 emissions: externality vs commodity





MAIN DIFILCULTIES INTEGRATING THIS CCUS SYSTEM 2/2

- Assignment of the environmental responsibilities (the environmental performance -LCA)
- Different methodological approaches to emissions accounting and allocation processes.
- DOE-NETL recommends system expansion with displacement (Skone et al., 2016)
  - which product or process of the systems (up, middle, or downstream),
  - under which criteria (cost or emission efficiency, marginal or average), and
  - All or part of it?

Decision Making (methodological Approach)

- Common practices
  - two different methods are commonly known, not integrated for environmental and economic evaluation (LCA and LCC)
  - Different purpose different method and scope
  - From LCA-LCC to ELCC

From Norris, G, 2001

Tool/Method	LCA	LCC
Purpose	Compare relative environmental performance of alternative product systems for meeting the same end-use function, from a broad, societal perspective	Determine cost-effectiveness of alternative investments and business decisions, from the perspective of an economic decision maker such as a manufacturing firm or a consumer
Activities which are considered part of the 'Life Cycle'	All processes causally connected to the physical life cycle of the product; including the entire pre-usage supply chain; use and the processes supplying use; end-of-life and the processes supplying end-of-life steps	Activities causing direct costs or benefits to the decision maker during the economic life of the investment, as a result of the investment
Flows considered	Pollutants, resources, and inter-process flows of materials and energy	Cost and benefit monetary flows directly impacting decision maker
Units for tracking flows	Primarily mass and energy; occasionally volume, other physical units	Monetary units (e.g., dollars, euro, etc.)
Time treatment and scope	The timing of processes and their release or consumption flows is traditionally ignored; impact assessment may address a fixed time window of impacts (e.g., 100-year time horizon for assessing global warming potentials) but future impacts are generally not discounted	Timing is critical. Present valuing (discounting) of costs and benefits. Specific time horizon scope is adopted, and any costs or benefits occurring outside that scope are ignored

Decision Making (methodological Approach)

- Integrated Framework
  - The CCUS system for EOR integrates productive sectors of significant national relevance in terms of economy, security and environment
  - System optimization and appropriate cost-benefit assessment necessarily goes through an overview both cross-sector and public-private trade-off
  - Integrated Analysis for: Feed Stock, PowerPlant, CO2-EOR site, Refinery and Product combustion

Decision Making (methodological Approach)

- ***System Assessment***

- *Risk and Uncertainty Technology*
- *Planning and Projection*
  - *Technology Readiness Levels*
  - *Technology Roadmapping*
  - *Expert Elicitation*
  - *Experience Curve Analysis*

- *Analysis Tools and Metrics*
  - *Life-Cycle Assessment Overview*
    - *Greenhouse Gas Emissions*
    - *Other Emissions*
    - *Water Use*
    - *Land Use*
  - *Materials and Criticality*
  - *Reliability and Resilience*
  - *Other Metrics*

- ***System Assessment (cont..)***

- *Economics metrics*
  - *Levelized Cost of Energy*
  - *Life-Cycle Cost -LCC- (e.g PTLaser, TCAce)*
  - *Environmental Life-Cycle Cost -ELCC-*

- *Evaluation Tools*
  - *Options Space Analysis*
  - *Wedge Analysis*
  - *Integrated Assessment Models*
  - *Science of Human Decision Making*
  - *Real Options Valuation*

General Methodological Proposal

- ***System Assessment***

- *Risk and Uncertainty Technology*
  - *CO2-EOR site selection- Characterization and technology implementation*
  - *CCUS Power Plant*
  - *Vehicle efficiency*
- *Planning and Projection*
  - *Technology Readiness Levels*
  - *Technology Roadmapping*
  - *Expert Elicitation*
  - *Experience Curve Analysis*

- ***System Assessment (cont..)***

- *Analysis Tools and Metrics*
  - *Life-Cycle Assessment*
    - *GHG*
    - *Water Use*
    - *Land Use*
- *Economics metrics*
  - *Levelized Cost of Energy*
  - *LCC (e.g PTLaser, TCAce)*
  - *ELCC*
- *Evaluation Tools*
  - *Integrated Assessment Models*
  - *Real Options Valuation*

Key aspects of this proposal would be modeling the operation and investments of the Grid (e.g. ERCOT) system by minimizing the cost to meet the emission reduction goals

Conclusion

- CCUS in Power Plants for CO-EOR is a very complex cross-sector system that require be develop at the minimum economic and environmental cost

- The real value of CCUS can only be determined by an integrated analysis of economic and ecological performance

- The integrated assessment models require greater diffusion and validation that allows standardization and implementation in different levels of analysis. In particular for the making of private decisions

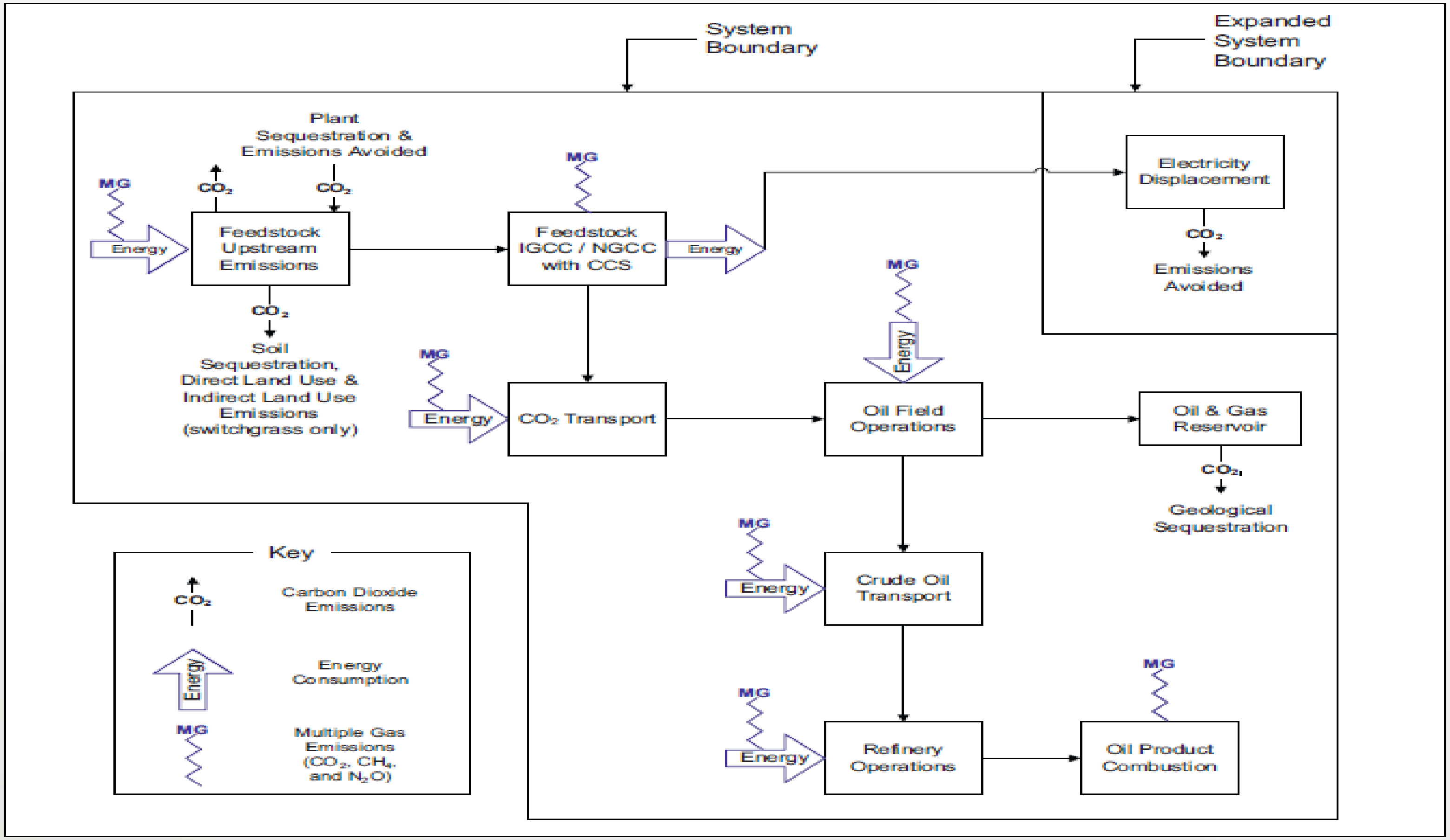
- Methodological proposal must be reviewed and refined in order to improve the decision making in the CCUS system

Questions?

It's a Complex Problem

LCA for CO_2-EOR have many path ways, products and sub products

Cradle-Grave Boundary

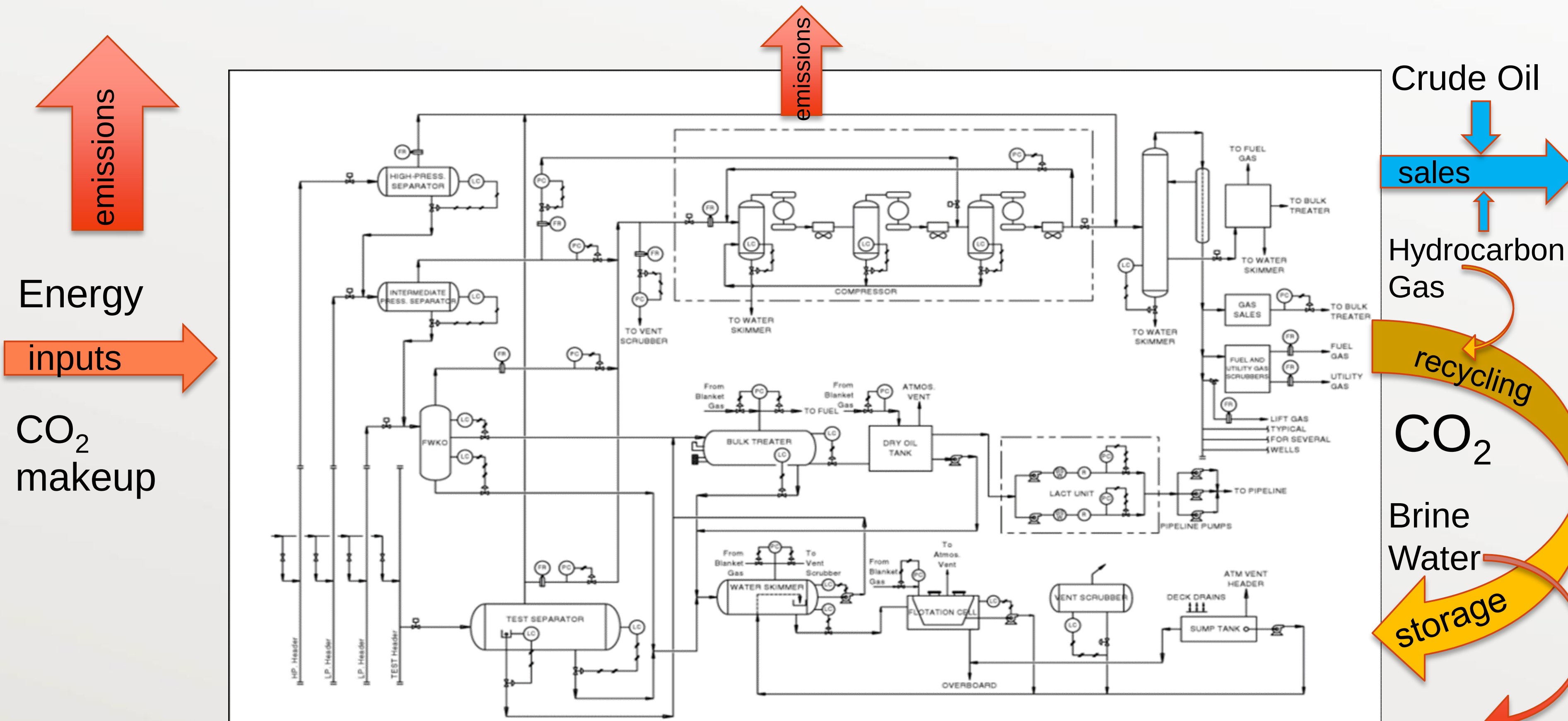


Jaramillio; et. Al., 2013, *Comparative LCI GHG emission in EOR Operations from diferents sources*

It's a Complex Problem

LCA for CO_2-EOR have many path ways, products and sub products

Gate-Gate Boundary



Jarrel, P.; et. all.(2002), *Practical aspects of CO2 flooding*

My contribution:

Central Objective: Create model to analyze the relation between **energy consumption**, oil production, CO2 injection, GHG emissions and sequestration oriented to achieve the NCNO classification for CO2-EOR Operations and energy efficiency recommendations.

Specific objective :

- Review the boundaries criteria
- Homogenize the functional units
- Clearly understand the CO2-EOR surface operations/emissions/energy efficiency
- Collaborate with other phases of the project
- Present advances of the model developed
- Help developing strategies that are conducive to achieving a NCNO classification.

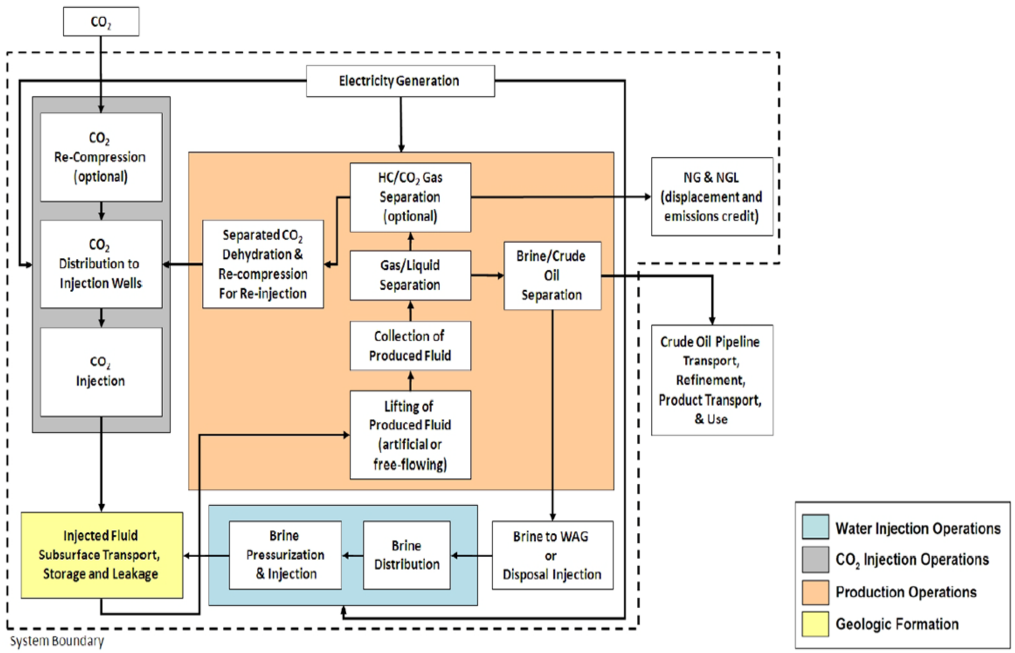
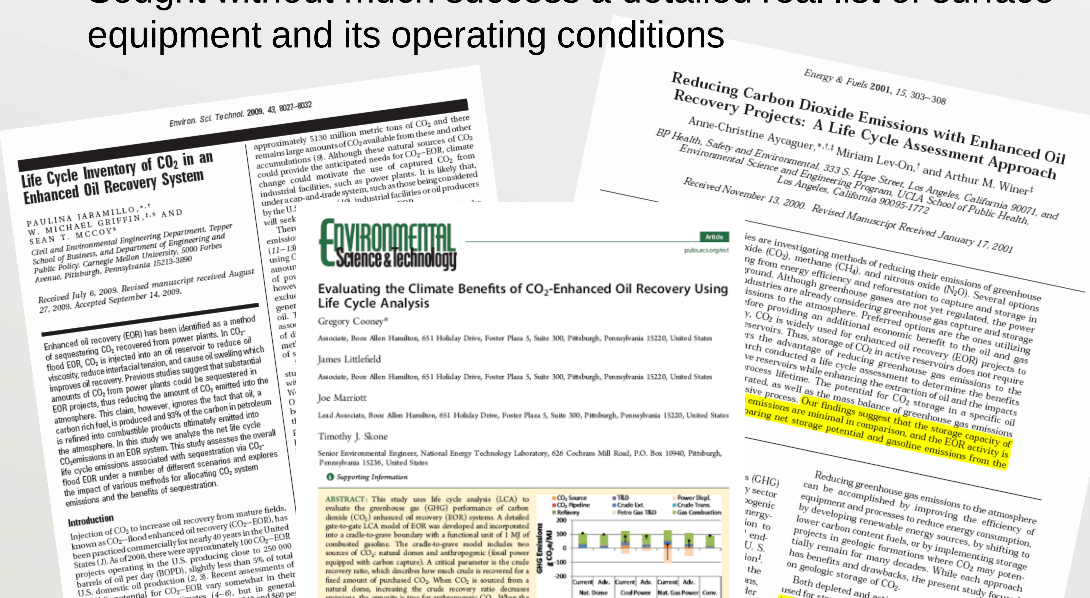


Figure 2-1 Simplified System Boundary for Operation Phase of "Gate-to-Gate" Life Cycle Assessment of CO_2-Based Enhanced Oil Recovery. Dotted line indicates study boundary.

Dilmore, Robert M. (DOE/NETL), 2010. *An Assessment of Gate-to-Gate Environmental Life Cycle Performance of Water-Alternating-Gas CO2-Enhanced Oil Recovery in the Permian Basin*, pp 206

Our Efforts

- ✓ Reviewed, process, classified and referred in the reports to DOE-NTEL large number of studies (60+)
- ✓ Selected the most consistent and commonly referred works
- ✓ Conversions and calculations
- ✓ Developed some schematics with all significant components for EOR and established the mass and/or energy flow between them
- ✓ Sought without much success a detailed real list of surface equipment and its operating conditions



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Example:

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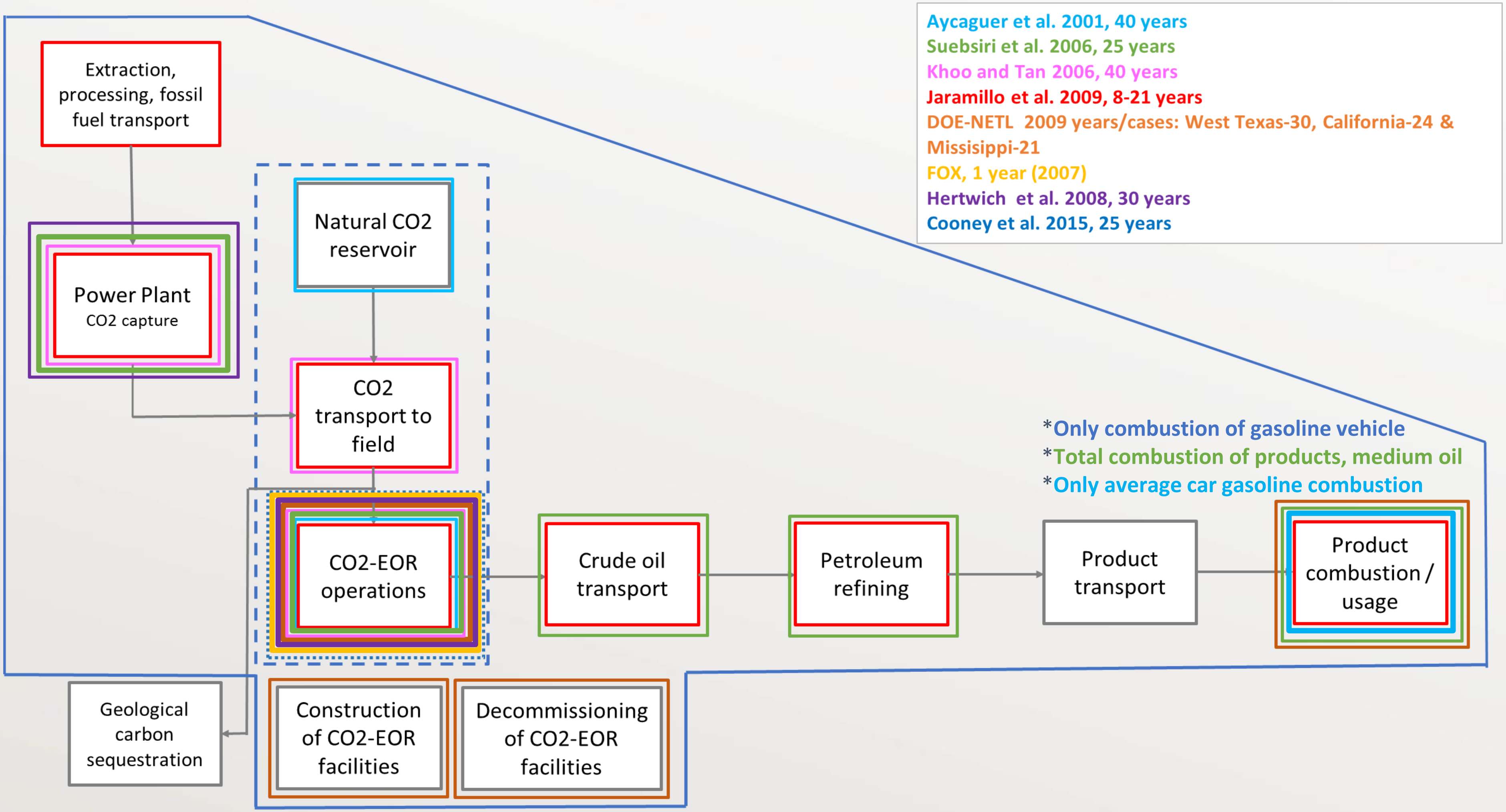
System boundaries of previous studies



Summary

- Goings-on:
  - ✓ Selected the system boundaries relevant to NCNO classification
  - ✓ Identification of critical CO_2 emission components within the EOR site
  - ✓ Homogenize the functional units to determinate the parameter in our study
  - ✓ Looking for Cranfield CO_2-EOR electricity consumption
- Next Tasks:

  In current Study
  - Build a model for energy consumption of the CO_2-EOR operation
  - Start scenario analysis
  - identify and analyze significant relationships between **energy consumption**, oil production, CO2 injection, GHG emissions and sequestration
  - Link results from numerical simulations with energy consumption model
  - Help developing the strategies to achieve the NCNO classification for CO2-EOR Operations and energy efficiency recommendations

Conclusions

- Carbon balance of CO_2-EOR is sensitive to the system boundary.
- In a gate-to-gate life cycle analysis, the electricity consumption (purchased and generated) is responsible for almost all the emissions associated with the EOR operation, particularly at the CO_2 separation and compression processes.
- Each CO_2-EOR facility is unique. Different facility dissing and operational strategies, different energy requirements, performance and GHG emissions
- Electricity consumption data is critical to allow appropriate correlation in mass/energy flows. Not have this would lead to assume generalizations with very high uncertainties.
- Carbon balance is sensitive to CO2 flood performance (CO2 utilization rates).
- A universal methodology for NCNO classification will certainly benefit CO_2-EOR operations as there might be an economic impact if potential future regulations provide value to the emissions and/or storage of CO_2.

Future Objectives:

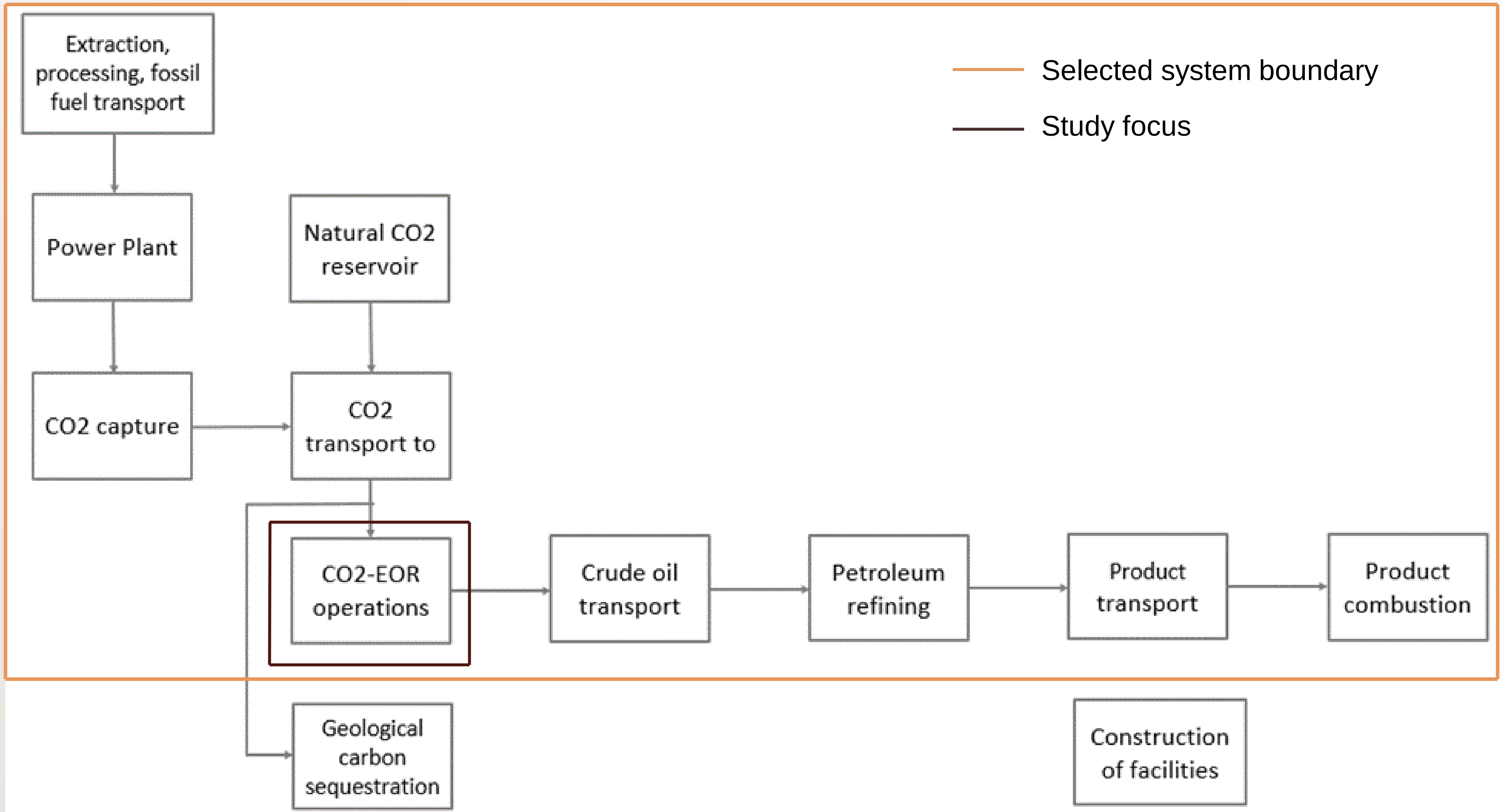
- Abstract that summarizes the conceptualization and first results of our model

- Draft conceptualization of a proposal for research:
  The economic Implications of:
    - CO2-EOR Operations with Classification NCNO (with VN)
    - Corrosion Behaviors in CO_2 Injection Wells (with AI)
    - Complement other studies

  Other topics of interest:
    - CCS Public acceptance (Japan)
    - CO_2 Pricing

- Start with contacts in L.A. Oil Companies managers, decision maker, academic and research institutions oriented to promote BEG research, cooperation and interchange interests. (goin-on)

Selection of system boundaries for NCNO classification: Cradle-to-Grave



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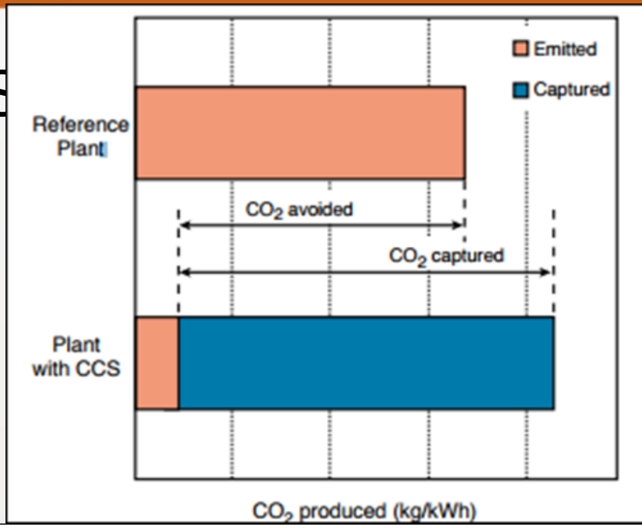
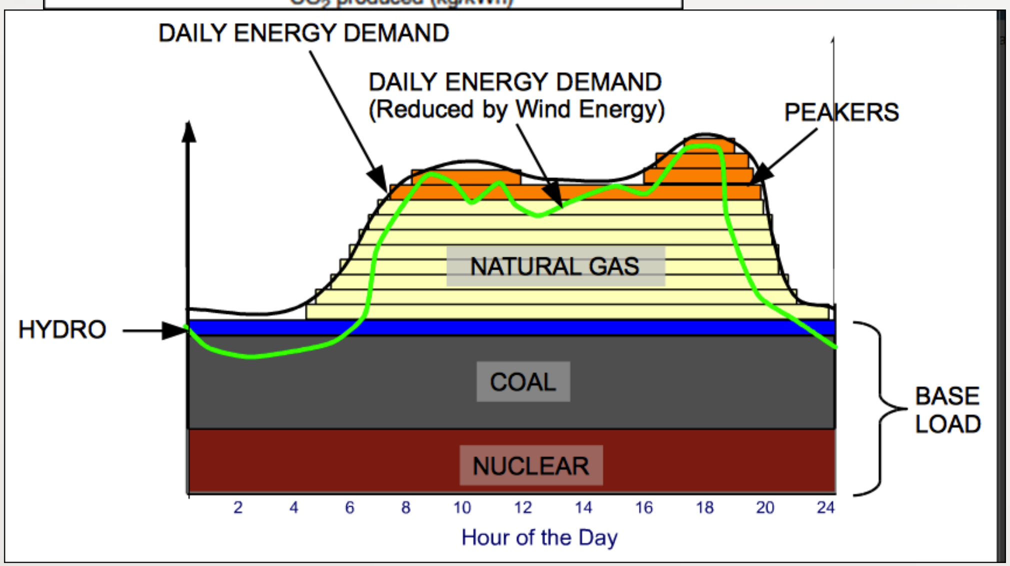
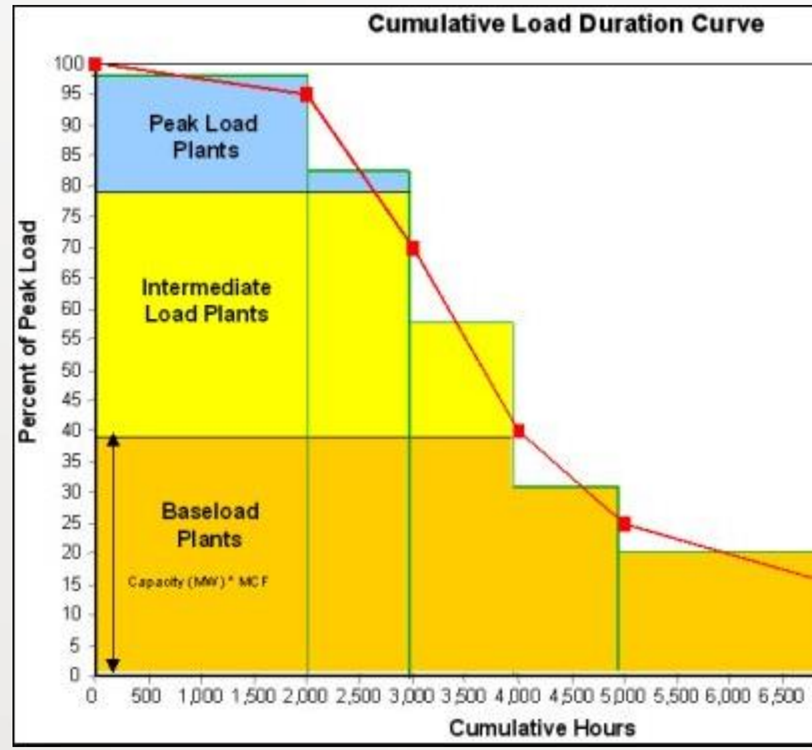
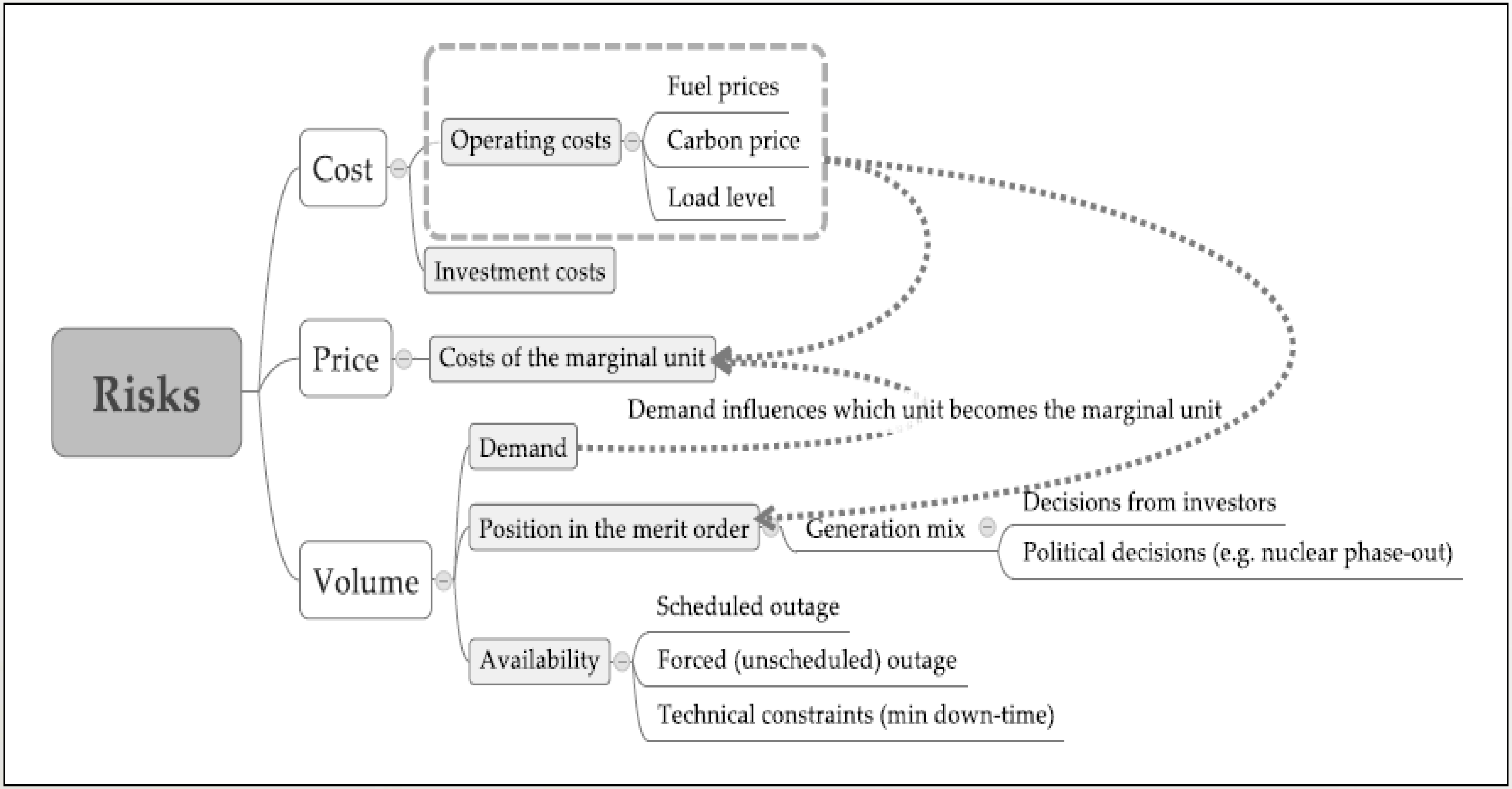
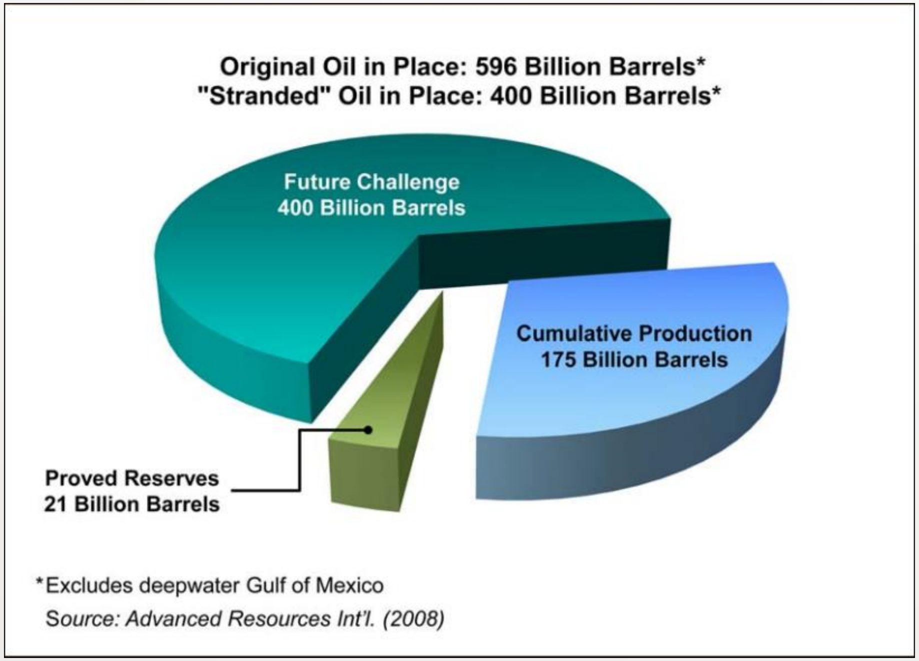

Emitted
Captured
Reference Plant
CO_2 avoided
CO_2 captured
Plant with CCS
CO_2 produced (kg/kWh)


DAILY ENERGY DEMAND
DAILY ENERGY DEMAND (Reduced by Wind Energy)
PEAKERS
NATURAL GAS
HYDRO
COAL
NUCLEAR
BASE LOAD
2 4 6 8 10 12 14 16 18 20 24
Hour of the Day

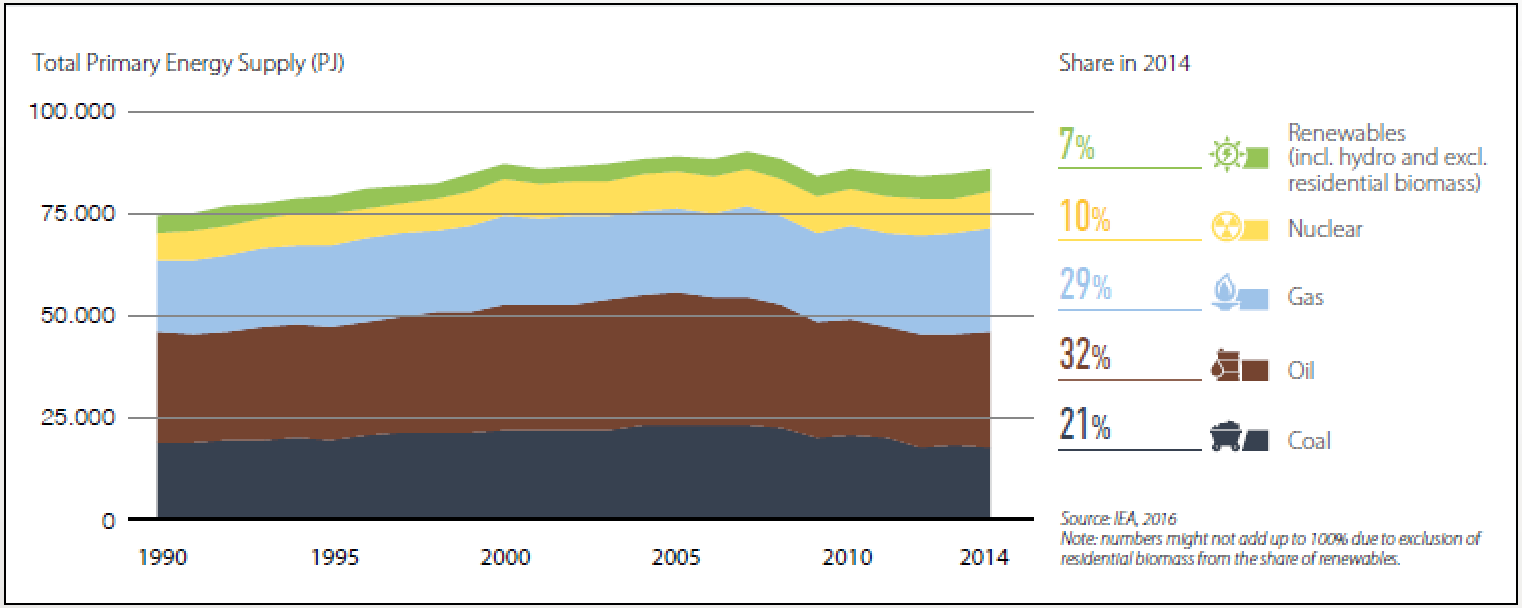

Cumulative Load Duration Curve
Percent of Peak Load
100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0
Peak Load Plants
Intermediate Load Plants
Baseload Plants
Capacity (MW) * MCF
0 500 1,000 1,500 2,000 2,500 3,000 3,500 4,000 4,500 5,000 5,500 6,000 6,500
Cumulative Hours

Strategic Power Plant Investment Planning under Fuel and Carbon Price Uncertainty by Ansgar Geiger 2010

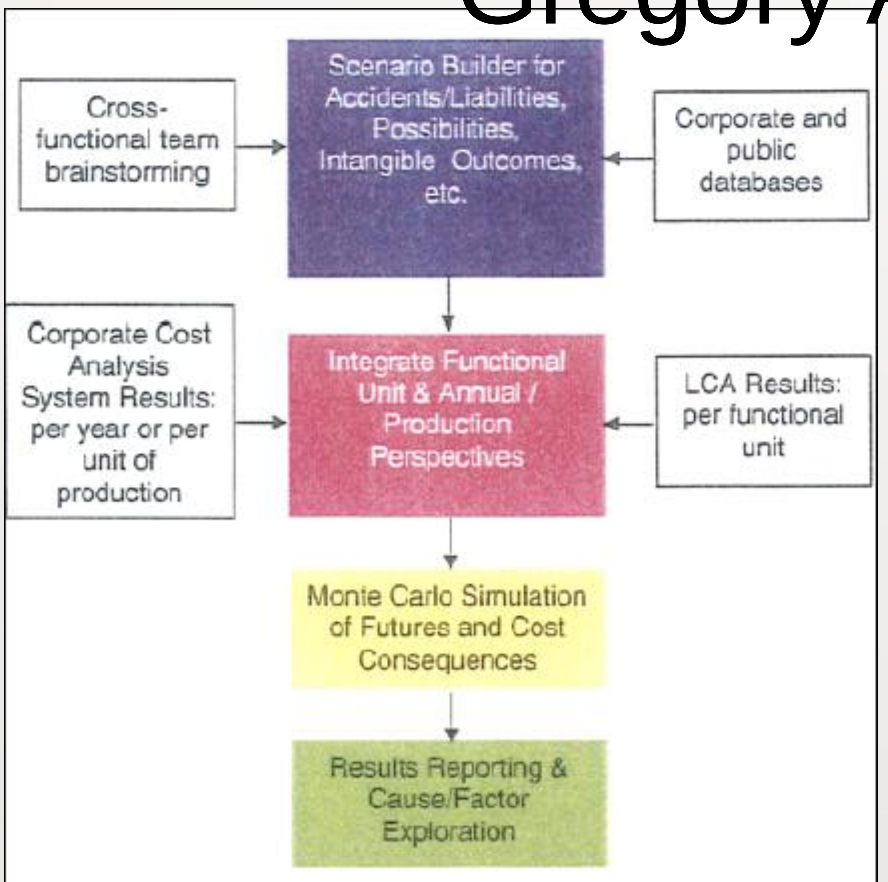



Original Oil in Place: 596 Billion Barrels*
"Stranded" Oil in Place: 400 Billion Barrels*
Future Challenge
400 Billion Barrels
Cumulative Production
175 Billion Barrels
Proved Reserves
21 Billion Barrels
*Excludes deepwater Gulf of Mexico
Source: Advanced Resources Int'l. (2008)

Idem befor (31)



Integrating Life Cycle Cost Analysis and LCA, InLCA: Selected Papers Gregory A. Norris



Cost Type	Description
Type 1: Direct	Direct costs of capital investment, labor, raw mater costs. Includes both capital and O&M costs
Type 2: Indirect	Indirect costs not allocated to the product or proce Includes both capital and O&M costs
Type 3: Contingent	Contingent costs such as fines and penalties, costs liabilities
Type 4: Intangible	Difficult to measure costs, including consumer acc wellness, corporate image, community relations
Type 5: External	Costs borne by parties other than the company (e.

Integrating Life Cycle Cost Analysis and LCA, InLCA: Selected Papers Gregory A. Norris

Tool/Method	LCA	LCC
Purpose	Compare relative environmental performance of alternative product systems for meeting the same end-use function, from a broad, societal perspective	Determine cost-effectiveness of alternative investments and business decisions, from the perspective of an economic decision maker such as a manufacturing firm or a consumer
Activities which are considered part of the 'Life Cycle'	All processes causally connected to the physical life cycle of the product; including the entire pre-usage supply chain; use and the processes supplying use; end-of-life and the processes supplying end-of-life steps	Activities causing direct costs or benefits to the decision maker during the economic life of the investment, as a result of the investment
Flows considered	Pollutants, resources, and inter-process flows of materials and energy	Cost and benefit monetary flows directly impacting decision maker
Units for tracking flows	Primarily mass and energy; occasionally volume, other physical units	Monetary units (e.g., dollars, euro, etc.)
Time treatment and scope	The timing of processes and their release or consumption flows is traditionally ignored; impact assessment may address a fixed time window of impacts (e.g., 100-year time horizon for assessing global warming potentials) but future impacts are generally not discounted	Timing is critical. Present valuing (discounting) of costs and benefits. Specific time horizon scope is adopted, and any costs or benefits occurring outside that scope are ignored

CO2 Enhanced Oil Recovery
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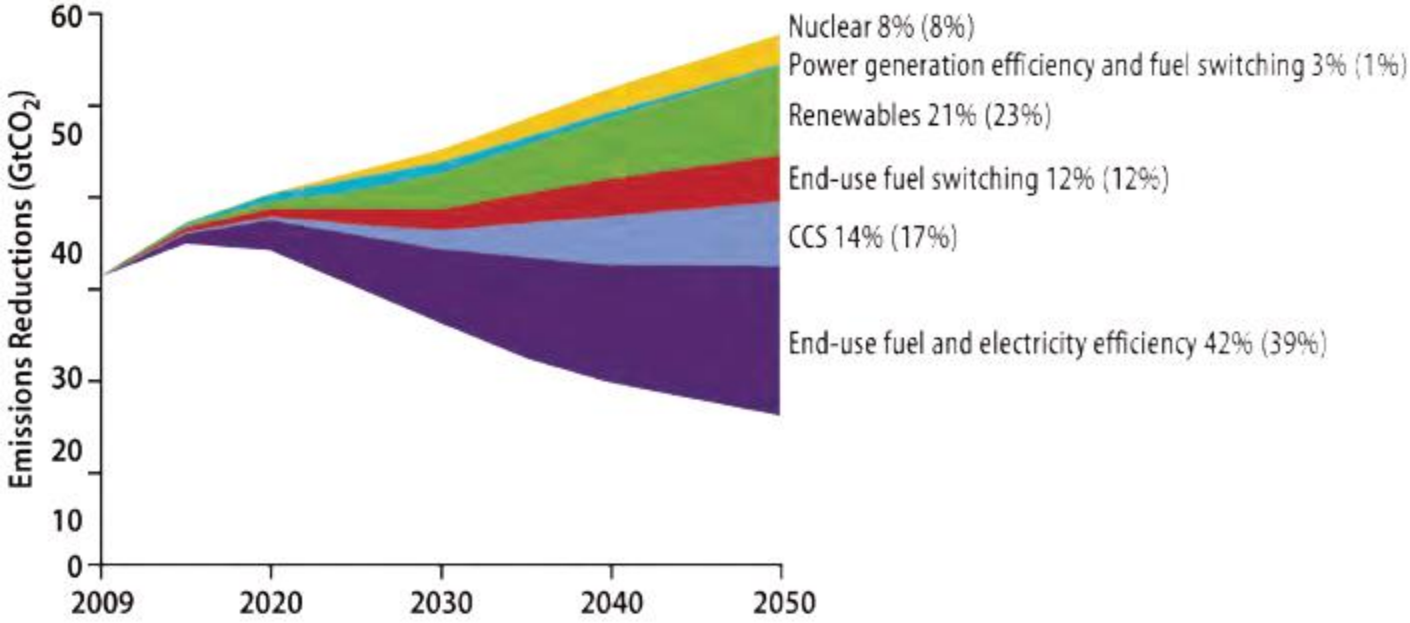


Note: Per IEA, the numbers in parentheses are shares in 2050. For example, 14% is the share of CCS in cumulative emission reductions through 2050, and 17% is the share of CCS in emission reductions in 2050, compared with the 6 °C Scenario.

(Source: 2013 IEA Global CCS Roadmap).

New unabated1 coal is not compatible with keeping global warming below 2°C

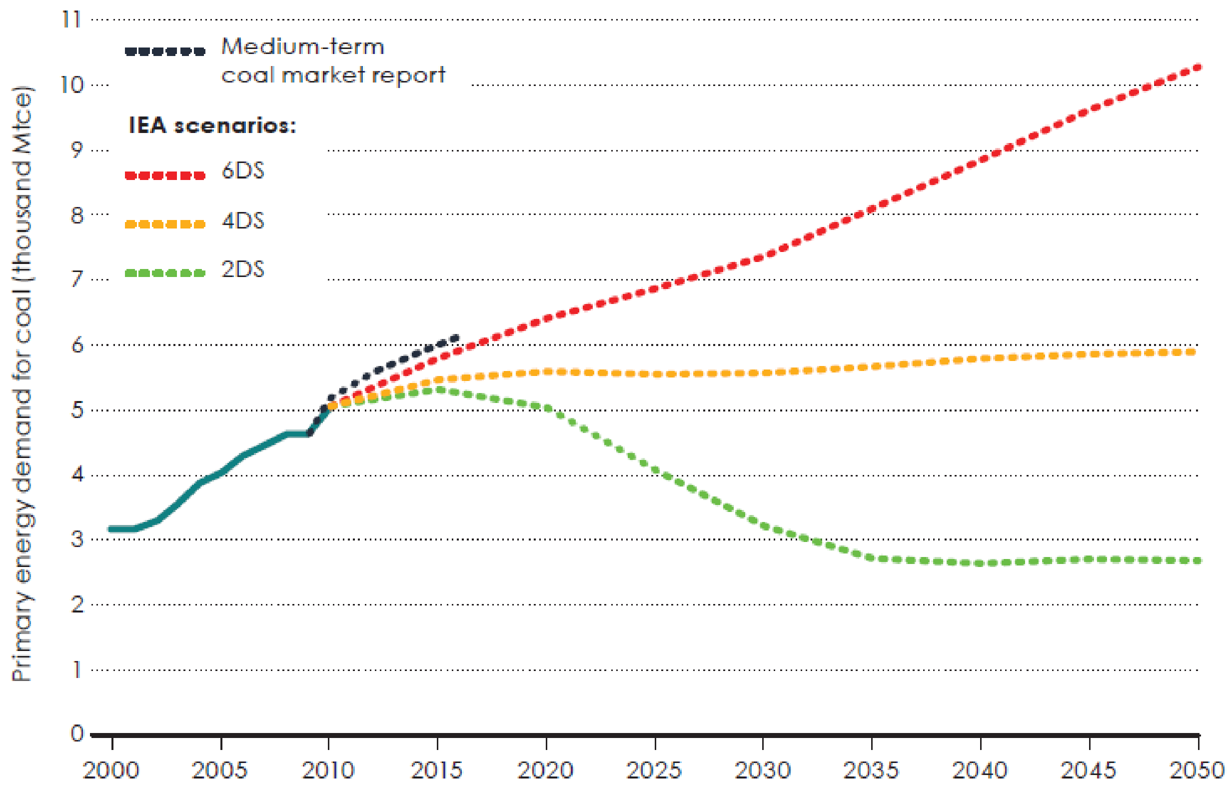
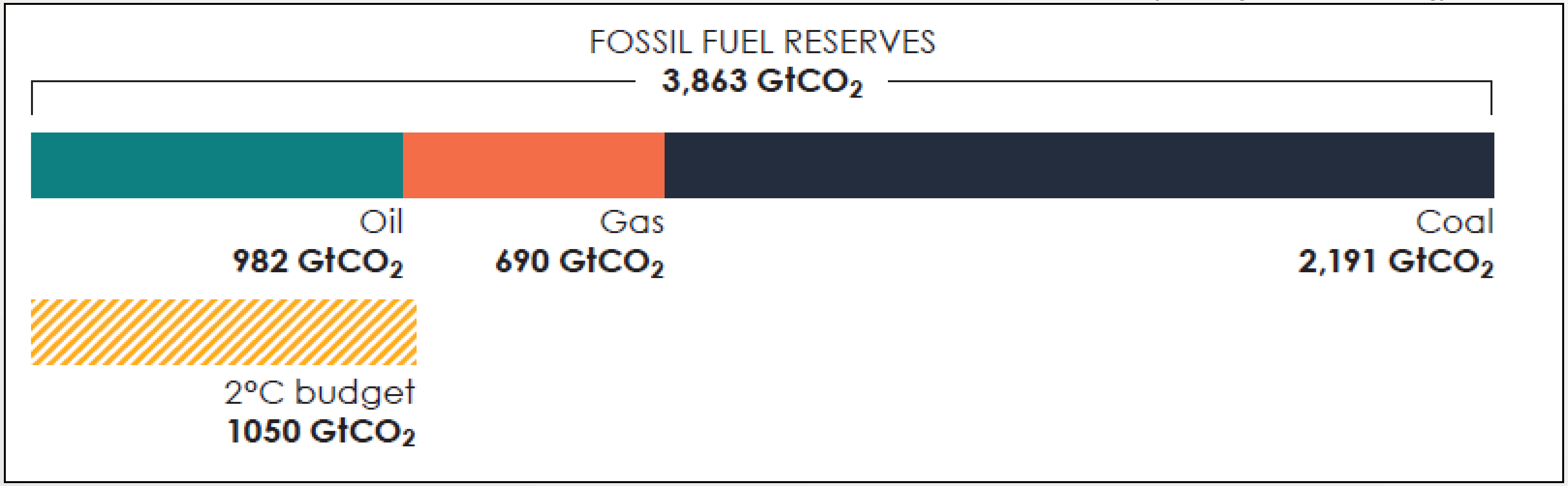


Figure 3: Primary energy demand for coal under IEA's medium-term coal market report and IEA Scenarios 2DS, 4DS and 6DS consistent with 2, 4 and 6 degrees warming above pre-industrial levels in the long term. Source: IEA/Gagné, 2012, adapted.

New unabated1 coal is not compatible with keeping global warming below 2°C

Statement by leading climate and energy scientists



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