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NEMS-CCUS: A Model and Framework for Comprehensive Assessment of CCUS and Infrastructure

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Abstract

The National Energy Technology Laboratory (NETL) has funded development of a NEMS-CCUS (National Energy Modeling System - CO_2 Capture, Utilization, and Storage) Model that enables modeling of CO_2 pipelines and pipeline networks across the forty-eight contiguous states. An existing NEMS-based analysis used by NETL to assess carbon capture utilization and storage (CCUS) for existing coal-fired power plants was updated to include CO_2 capture from both existing coal-fired and new gas- and coal-fired plants, factor in plant specific variations in the costs of CO_2 capture and include regional variations in the costs of the transmission and storage of CO_2. Pipeline networks in the updated model are configured endogenously to be optimally consistent with the latest capacity and cost data for the U.S. storage resource base. The model enables analysis of various source, sink, and pipeline combinations under different economic and policy scenarios. This paper presents a recent application of the model to assess the role of CO_2 capture, utilization and storage in both carbon tax and clean energy standard Cases. Documentation is presented for key parts of the model, including: (1) capture costs – an update of the original generic model that includes corrections for other site specific details such as space constraints and location, based on the AEP Conesville Unit 5 CCUS retrofit study (Ciferno, 2007), which originally included corrections based on capacity, heat rate, and emission control configuration; (2) sequestration capacity and costs - NATCARB[1] and other databases are used for storage capacity and formation properties which are combined with drilling, monitoring, and other cost estimates in various cost models; (3) transmission costs - pipeline cost data and GIS data on siting constraints are combined in a General Algebraic Modeling System (GAMS) based optimizer that configures an evolving pipeline network ; (4) NEMS integration - the GAMS GDX utility is used to interface NEMS and the GAMS based optimizer (Capture Transportation Storage Module - CTS) such that the evolving pipeline network and its associated cost adders for transmission and sequestration are consistent with the penetration of CCUS in NEMS.

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[1] NATCARB refers to the National Carbon Sequestration Database and Geographical Information System started as a joint project among the State Geological Surveys of five Midwestern states (Illinois, Indiana, Kansas, Kentucky, and Ohio). The project was later expanded to include the seven Regional Carbon Sequestration Partnerships and a prototype to integrate databases for terrestrial carbon sequestration with databases on geologic sequestration. The purpose of NATCARB is to assess the carbon sequestration potential in the United States and to develop a national Carbon Sequestration Geographic Information System (GIS) and relational database covering the United States and parts of Canada.

Introduction

The National Energy Technology Laboratory (NETL) has funded development of a NEMS-CCUS (National Energy Modeling System - CO_2 Capture, Utilization, and Storage) model that enables the modeling of CO_2 source-to-sink pipelines and pipeline networks across the forty-eight contiguous states. NEMS is an energy system simulation model developed by the Energy Information Administration (EIA) for use in *Annual Energy Outlook* (AEO) projections, as well as requests for analysis from Congress and Federal agencies. The NEMS model performs annual simulations to forecast the composition of the U.S. energy economy through 2035.[2] NETL developed the Capture, Transport, and Storage (CTS) Network Model to estimate CO_2 transport and storage costs using site-specific data. When integrated with NEMS, the Network Model's CTS Module interacts with the NEMS Electricity Capacity Planning Module (ECP) by providing CO_2 capture, transport, and storage costs for capacity planning and tracking the CO_2 captured by power plants (both existing and new) equipped with capture-technology. In this study, NETL exercised the model in several case studies that analyzed the research, development, and demonstration (RD&D) goals of NETL's Existing Plants, Emissions, and Capture (EPEC) program under a carbon tax case and clean energy standard case.

Previously, representation of CCUS in the NEMS released by the EIA assumed plant retrofit costs that were based on capacity and heat rate, a generic value representing transport and storage costs independent of plant/sink location, and unlimited storage capacity. This modeling effort focused on improving representation of three primary areas: (1) capture costs – additional plant specific variations were introduced to the costs of retrofitting existing plants, including cost scaling, pollution controls, cooling requirements, economies of scale, and space constraints; (2) carbon storage capacity and costs – regionalization of storage costs to account for changes in geologic parameters between basins; and (3) transportation – the use of a pipeline network model to connect low-cost storage to sources and endogenously derive associated costs based on pipeline diameter and distance transported.

The CO_2 capture, transport, and storage network is modeled in the CTS Module of the Network Model and is constructed in the General Algebraic Modeling System (GAMS). The CTS Module relies on mixed-integer programming that represents the interaction of CO_2 capture, transport, and storage amongst the various types of capture sites, injection sites, and pipeline options. Physical and economic data characterize each functional category – capture, transport, storage, and monitoring. Scenarios can be designed and the module can be easily updated through changes in the data sets, thuslimiting the amount of data code manipulation necessary to keep the module current.

NETL modified the AEO-2010 version of NEMS in order to integrate the newly developed CTS Network Model to yield the NEMS-CCUS model, which enables in NEMS the option for a CO_2 capture, transport and storage network to develop over time. The Network Model's CTS Module interfaces with the NEMS Electricity Capacity Planning (ECP) Module to provide the ability for detailed representation of a CCUS market in the electricity generating sector. Future potential Module development includes the integration of the CTS Module with the NEMS Industrial Market Module (IDM) and Liquid Fuels Market Module (LFMM), to incorporate alternate CO_2 sources (high purity vents), and alternate CO_2 uses (including enhanced oil recovery (EOR)).

Methodology

The CTS Module relies upon mixed-integer programming (MIP) to advance an optimization approach to the network problem. The module is regional and maps all capture and storage sites to NEMS fuel regions. The module's time horizon corresponds to the forecast period for NEMS, which is through 2035 in the AEO-2010 version. The module's objective for optimization is to minimize total costs of transport, storage, and monitoring of CO_2 – offset by carbon prices. All costs are discounted over time to account for the value of money throughout the forecast period. General module assumptions are as follows:

<u>Assumptions</u>

- Source plants can physically support retrofits
- Retrofits can be done during regularly scheduled maintenance periods. Extended outages will not be necessary.
- Pipelines ideally will be operated at full or close to full capacity.

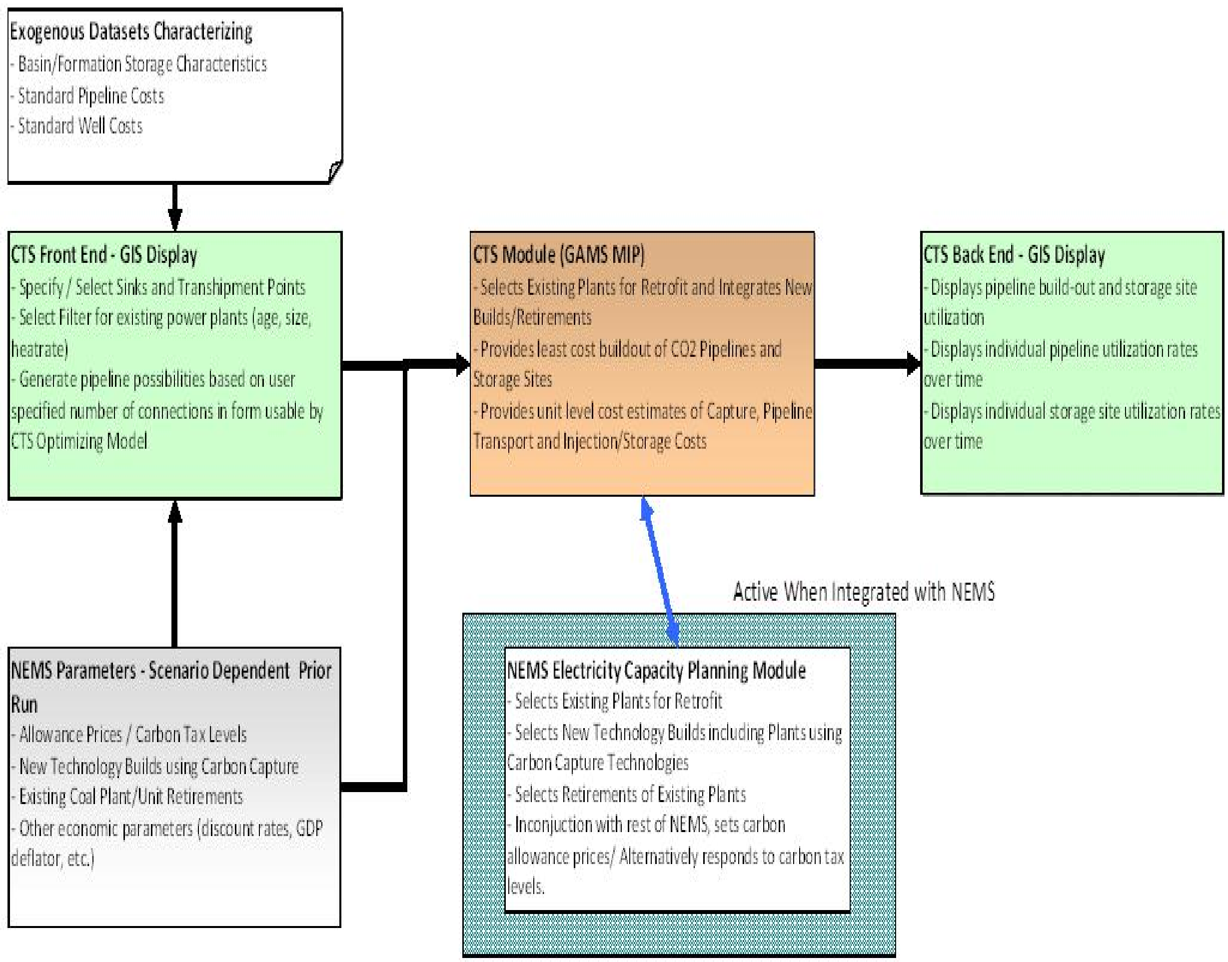
[2] NETL integrated a modified version of EIA's NEMS AEO-2010 with the CTS Network Model it developed.

- If planned properly, a pipeline can be built while several plants feeding it are retrofitted on a staggered schedule, such that all plants are ready to supply the pipeline when it is completed.

This module does not address the scheduling aspect of implementing retrofits. [In NEMS the schedule of retrofits is established in the Capacity Planning module.]

The CTS Module is linked to the ECP Module in NEMS, and the ECP Module passes a list of carbon capture sites to the CTS Module. The CTS Module uses these data to determine the best network of pipelines, and the timing of these activities, weighing the total cost of capture, transport, and storage over time against the CO2 offset price. Figure 1, below, illustrates the data flow between the ECP and CTS modules.

Figure 1. CTS Modeling Framework



The CTS Module is data driven. The module builds costs from first principles using published engineering cost equations. This lends transparency to the module and allows it to be easily updated as new data become available. Data are categorized along functional roots (capture, transport, storage and monitoring). Below is a brief discussion of each category:

<u>Capture</u>

The capture input data are primarily used to associate retrofit costs with each unit, associate CO_2 output amounts (calculated based on unit characteristics) with each unit, and locate each unit geographically. Existing carbon sources are limited to coal-fired power generation units in the CTS Module. New carbon sources include both gas and coal-fired units.

Transport

The transportation input data are used to determine appropriate pipe diameters for given CO_2 volumes and flow rates and calculate fixed and variable costs associated with pipeline network build-out.

Storage

The storage input data are used to associate storage capacity with each site, calculate injectivity rates for each storage site, determine number of wells required for storage, and calculate costs associated with developing a storage site, and installing and operating wells.

Monitoring

The monitoring input data are used to calculate the cost of building and operating monitoring wells for the storage sites.
In order to characterize these four aspects of CCUS, various data sources and methodologies were evaluated. The final data used in the CTS Network Model are summarized below, with associated sources, in Table 1 below.

These data sources feed the input files for the CTS Module. A data source may be used alone or in combination with other data sources to create an input file.

Case Studies

Case studies included the AEO-2010 reference case (in which no CO_2 policy was present), a carbon tax case (based on the published Kerry-Graham-Lieberman EIA analysis), and a clean electricity standard case, each of these policy cases were ran with, and without the cost and performance goal associated with the NETL's Existing Plants Emissions and Capture Program (EPEC) incorporated.

The NETL EPEC Program

NETL's EPEC program invests in a research, development, and demonstration (RD&D) portfolio to develop technologies that will enable power plant owners to affordably and efficiently capture CO_2. NETL estimates that using today's commercially available CCUS technologies would add approximately 80 percent to the cost of electricity for a new pulverized coal (PC) plant, and around 35 percent to the cost of electricity for a new advanced gasification-based plant. NETL's RD&D efforts are supporting activities to reduce these costs to a less than 35 percent increase in the cost of electricity for new PC power plants and a less than 10 percent increase in the cost of electricity for new gasification-based power plants.

The EPEC RD&D Goal of developing CCUS technologies that limit the increase in the cost of electricity generation (COE) to 35 percent of that generated by a plant without CCUS technology was incorporated into the NEMS-CCUS Model as **percentage reductions** in the following components:

- Capture capital costs = 50 percent
- Fixed O&M costs = 20 percent
- Variable O&M costs = 80 percent
- Energy (heat rate) penalty = 50 percent
- Transport, storage and monitoring cost = 20 percent.

These cost reductions were assumed to be achieved over the period 2020-2030. Any cost reductions that occurred prior to, or after that period were due to learning realized through capacity deployments and implemented in NEMS via learning curves.

Reference Case

The Reference Case for this study is based on the AEO-2010 Reference Case and the model is run with and without the EPEC RD&D Goal to estimate the impact of the RD&D activities on the deployment of new, and retrofit of existing coal-fired power plants with CCUS technology in the electricity sector.

Table 1. Data Sources for the CTS Network Model

	Data Element	Data Source
Capture	o Name; o EIA Plant Code; o Generator ID; o Location (State, Region); o Source Type; o Vintage; o Summer Capacity; o Heat Rate;	EIA-860 (2010)
	o Longitude and Latitude of units;	eGRID – EPA (2009)
	o Retrofit Capital Costs (Existing Units); o Capture Variable Costs (Existing Units); o Capture Rate;	NETL report, "Coal-Fired Power Plants in the United States: Examination of the Costs of Retrofitting with CO2 Capture Technology, Revision 3", January 2011
	o New Build Capital Costs.	AEO-2011m
Transport	o Capital Costs Calculations; o Fixed O&M Cost Calculations;	NETL, "Estimating Carbon Dioxide Transport and Storage Costs," 2010
	o Pipeline Diameter; o Pipeline Capacity.	MIT, Carbon Sequestration Technologies Program, "Carbon Management GIS: CO2 Pipeline Transport Cost Estimation," updated June 2009, for NETL
Storage	o Location; o Capacity ;	NatCarb, "2008 Carbon Sequestration Atlas II of the United States and Canada," and NatCarb online data files; www.natcarb.org
	o Porosity; o Permeability; o Thickness; o Depth;	NETL, Porosity-Permeability Values_National_090110.xlsx, derived from a study performed by ARI for NETL, 2010
	o Well Capital Costs; o Well Operating Costs;	NETL, "Estimating Carbon Dioxide Transport and Storage Costs," 2010
	o Well Injection Rate Calculations; o Well Number Calculations.	McCollum & Ogden, "Techno-Economic Models for Carbon Dioxide Compression, Transport and Storage and Correlations for Estimating Carbon Dioxide Density and Viscosity", UC Davis, October 2006
Monitoring	o Monitoring Cost Calculations.	Economic Impact Analysis for the Mandatory Reporting of Greenhouse Gas Emissions Subpart RR: Propose Carbon Dioxide Injection and Geologic Sequestration Reporting Rule, Draft Report, March 2010

Carbon Tax Case

The CO_2 Tax Case is based on the CO_2 price used in the EIA Kerry-Graham-Lieberman (KGL) basic cap-and-trade case published by EIA in July 2010, and the model is run with and without the EPEC RD&D Goal. The tax starts at $23 per tonne of CO_2 in 2013 and reaches $66 per tonne by 2035, growing at five percent annually to reflect the assumed discount rate for banking in the KGL case published by EIA. The NEMS-CCUS model factors the CO_2 tax into the delivered price of each fossil fuel based on its carbon content. The price of coal is impacted more than natural gas because it has higher carbon content; i.e., coal-fired electricity generation averages 2.095 pounds of CO_2 per kilowatthour (kWh) compared to natural gas-fired electricity generation which averages 1.321 pounds of CO_2 per kWh (EIA, 2000). As a result, coal prices increase about

300 percent by 2035 compared to the Reference Case and natural gas prices increase by 32 percent. This study assumes that power plants equipped with CCUS technology pay only 10 percent of the CO_2 tax imposed on the fuel price because the EPEC RD&D Goal is to capture 90 percent of the CO_2 that would otherwise be emitted into the atmosphere by the power plant.

Clean Energy Standard Case

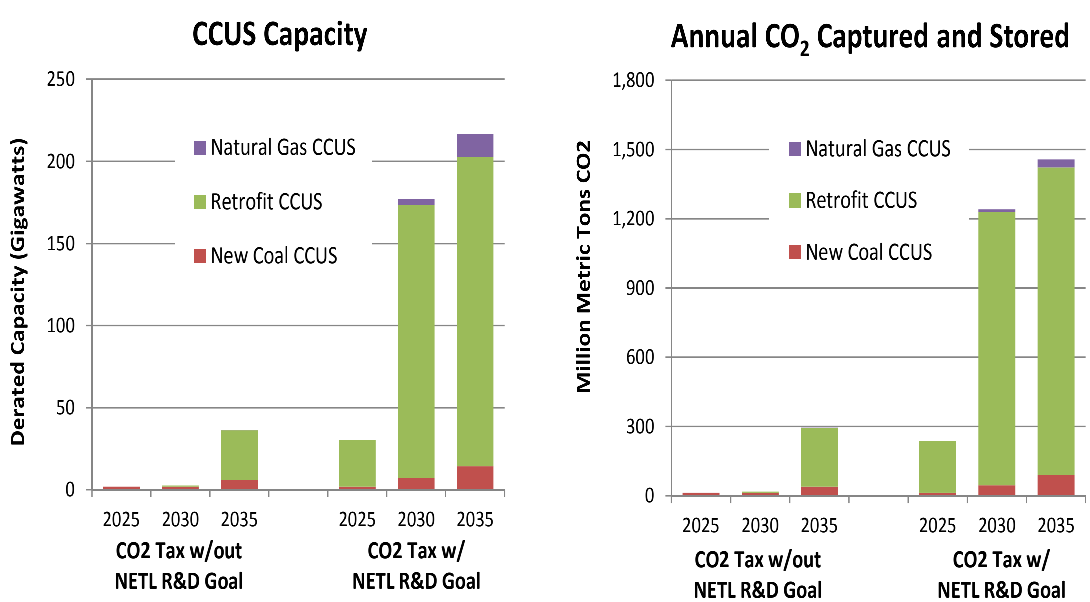
The CES case for this study was based on a target of 80 percent "clean" generation by the year 2035 (White House, 2011). The standard is defined as credits issued (expressed in kWh) as a percent of electricity sales and reaches 80 percent by 2035. In this respect it is similar to placing a cap on emissions. Clean sources are defined as coal or natural gas plants with CCUS technology, nuclear, renewables, and natural gas combined cycle plants (NGCC). CES credits are issued to each generator based on the technology's average CO_2 emissions reduction relative to a conventional coal plant. Thus coal and natural gas CCUS plants get 0.9 credits per kWh generated due to the technology capture rate of 90%, nuclear and renewables get 1.0 credits, and NGCC plants receive 0.5 credits per kWh. Credits are traded between generators and a marginal clearing price (credit price) is determined within the NEMS-CCUS Model. In the end, credit purchases and sales are reflected in electricity prices.

Findings

The results of the NEMS-CCUS runs with and without the EPEC RD&D Goal for the AEO-2010 Reference Case are identical because this scenario lacks an economic driver to add CCUS technology to a power plant given there is no climate change policy in effect in this case. However, two gigawatts (GW) of new coal with carbon capture are stimulated due to investment tax credits for CO_2 sequestration granted under the Energy Improvement and Extension Act of 2008 and funding through the Clean Coal Power Initiative (CCPI). A total of four 500 megawatt (MW) plants are assumed to be built, two plants in 2016 and two in 2017, in the southeast (SERC) region. No plants are retrofitted for carbon capture and no additional new carbon capture capacity is built.

The results of the NEMS-CCUS runs in the climate change policy cases indicate that between 45 and 60 percent of existing coal capacity would be potential candidates for CCUS retrofit if the EPEC RD&D Goal is met. In the CO_2 Tax Case, the EPEC RD&D Goal results in 217 GW of net (derated, accounting for parasitic load) CCUS capacity by 2035; these plants are able to capture almost 1,500 million metric tons (MMT) CO_2 annually. As illustrated in the graphs below, most of these plants are retrofitted after 2025.

Figure 2. Carbon Dioxide Tax Case



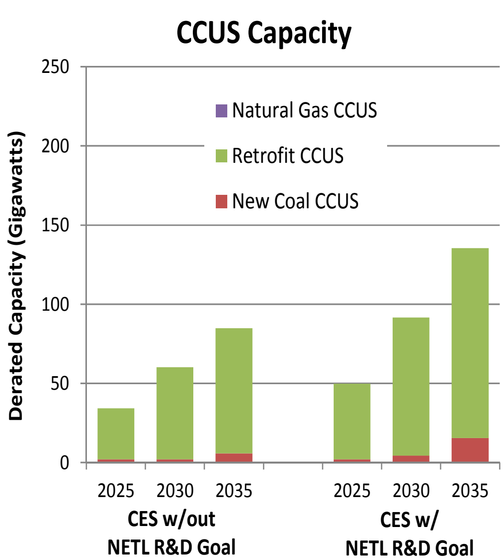
In the 2025-2035 period of the EPEC RD&D Goal run, the majority of new low-carbon generation capacity is existing coal-fired power plants that are retrofitted with CCUS technology (Table 2). However, in the No-Goal run renewable energy options (Biomass IGCC and Other Renewables[3]) dominate the new low-carbon generation mix and few existing coal-fired power plants are retrofitted with CCUS technology until 2035.

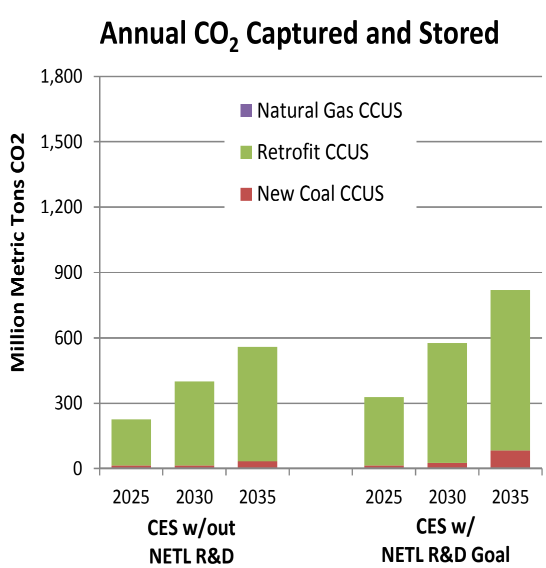
Table 2. New Low-Carbon Generation Capacity in CO_2 Tax Case (Change from Reference Case)

	CO2 Tax w/out R&D Goal				CO2 Tax w/ R&D Goal		
	2025	2030	2035		2025	2030	2035
New Coal CCUS	0%	0%	3%		0%	2%	4%
Retrofit CCUS	0%	1%	21%		61%	72%	63%
Natural Gas CCUS	0%	0%	0%		0%	2%	5%
Nuclear	18%	29%	24%		11%	9%	13%
Biomass IGCC	29%	21%	13%		11%	6%	5%
Other Renew	53%	50%	38%		17%	9%	10%

In the CES Case, power plants are retrofitted with CCUS technology in both the EPEC RD&D Goal and No Goal runs. Total CCUS capacity built in the Goal run is 135 GW by 2035, or about 60 percent more capacity than in the No Goal run (Table 3). No natural gas plants with CCUS were built in the CES case, although a small amount was added in the later years in the Goal CO_2 Tax run.

Figure 3. Clean Energy Standard Case





[3] Other Renewables include solar, wind, and geothermal electricity generation capacity.

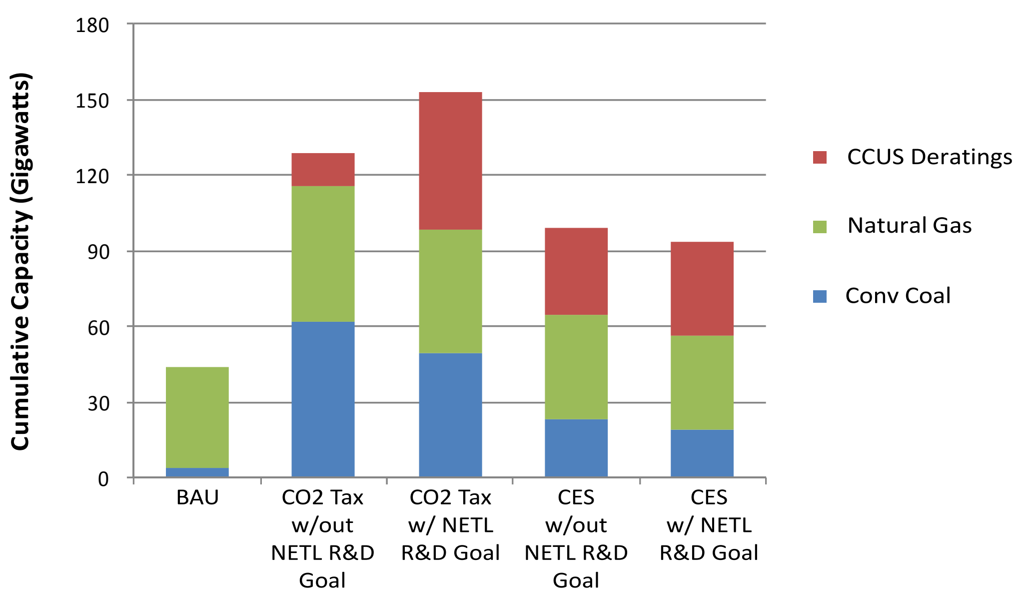
The Goal and No Goal runs in the CES Case reflect differences in the mix of least-cost generation chosen to meet the standard. In the case of new low-carbon electricity generation capacity, about a third of the capacity in the No Goal run is existing power plants retrofitted with CCUS technology, rising to slightly more than 50 percent in the EPEC RD&D Goal run. This is a significant contrast from the CO_2 Tax Case in which very little retrofit CCUS capacity was added in the No Goal run. This is because the CES sets an annual low-carbon generation target that must be met regardless of the cost of the low-carbon options, thus some CCUS plants are retrofitted in the No Goal run even though the technology is more costly than when the EPEC goal is realized. When the cost of CCUS technology is reduced due to RD&D advances, additional plants are retrofitted with CCUS technology, when compared to the No Goal run, as noted in Table 3.

Table 3. New Low-Carbon Generation Capacity in CES Case (Change from Reference Case)

	CES w/out R&D Goal				CES w/ R&D Goal		
	2025	2030	2035		2025	2030	2035
New Coal CCUS	0%	0%	2%		0%	2%	6%
Retrofit CCUS	37%	38%	34%		56%	58%	55%
Natural Gas CCUS	0%	0%	0%		0%	0%	0%
Nuclear	14%	14%	14%		10%	13%	15%
Biomass IGCC	9%	14%	16%		0%	3%	5%
Other Renew	40%	34%	34%		34%	24%	19%

Under both policy cases, electricity generation capacity is lost due to a combination of retirements of conventional coal and natural gas (mostly steam plants, as well as coal capacity lost in the CCUS retrofit process (i.e., CCUS deratings)). There are fewer retirements of conventional coal and natural gas plants in the Goal runs than the No Goal runs (Figure 4). Further, the large number of existing coal-fired power plants retrofitted with CCUS technology in the CO2 Tax Goal run results in an increase loss of capacity due to deratings (Exhibit 3-3), but results in more CO2 captured and stored (Exhibit 3-2) and less energy expenditures (See Section 3.3 Energy Expenditures later in this report). It should also be noted that the derating per plant will be less for the plants in the Goal run compared to the run without the RD&D goal, because the Goal run plants are more efficient.

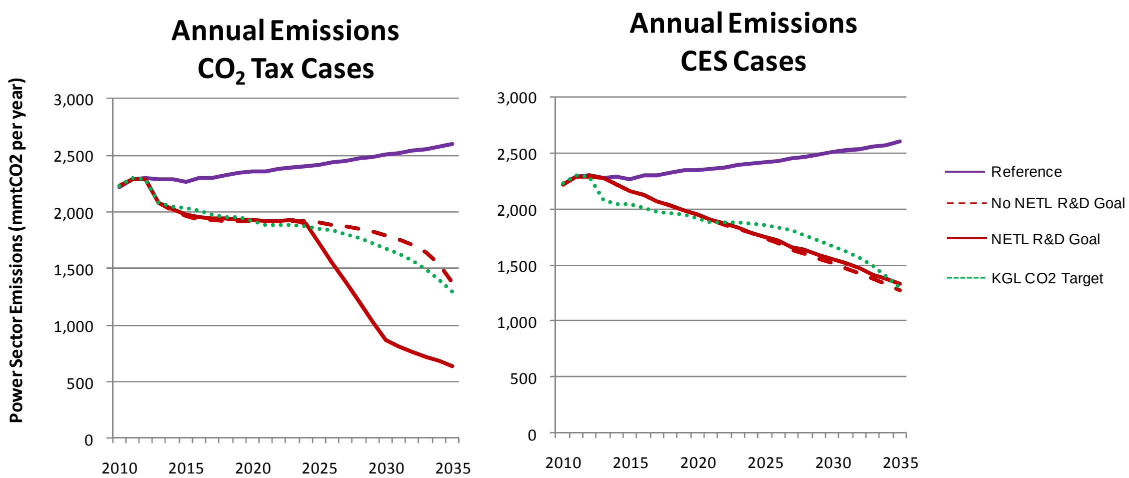
Figure 4. Capacity Lost Due to Retirements and CCUS-Deratings by 2035



Annual CO_2 emissions from the power sector were similar in all runs except the CO_2 Tax Case with the EPEC RD&D Goal, which further reduces emissions about 50 percent due to the large number of CCUS technology retrofits after 2025 (Figure 5).

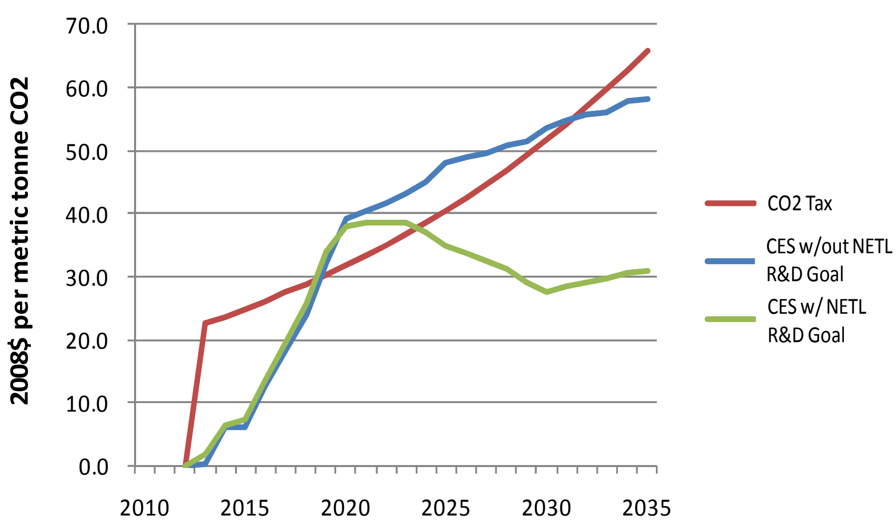
In fact, CO_2 emissions in the power sector fall well below the KGL target after 2025 in the EPEC RD&D Goal CO_2 Tax run due to the large-scale retrofitting of existing coal-fired power plants with CCUS technology. In contrast, CO_2 emissions in the CES runs are essentially "capped" so retrofits replace other low-carbon electricity generation options instead of further reducing emissions.

Figure 5. Power Sector Annual Carbon Dioxide Emissions



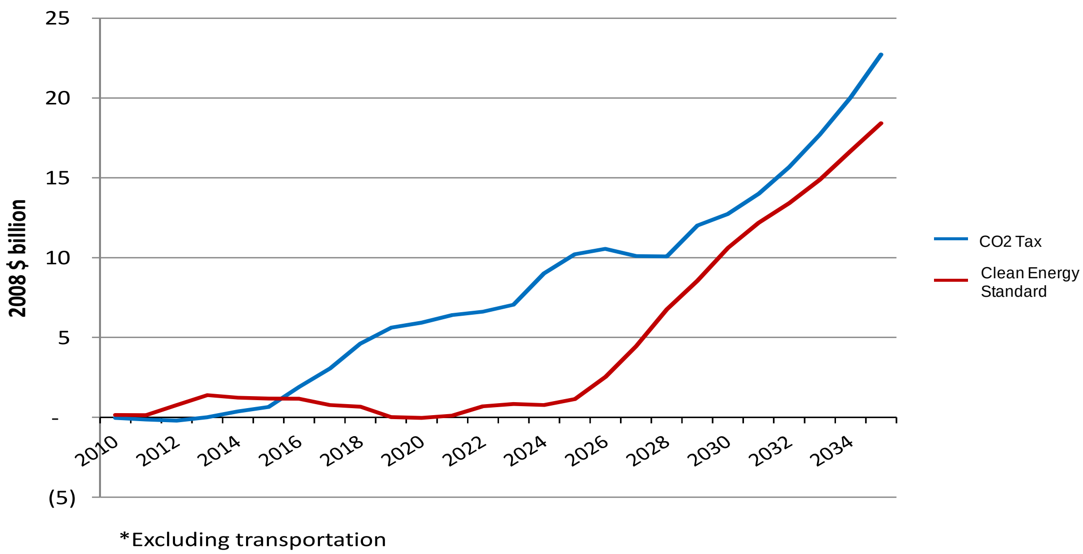
The graph below converted the CES credit price to an equivalent dollars per tonne of CO_2 to compare them directly with the tax schedule used in the CO_2 Tax Case to better understand the economic impacts of the two policies. The CO_2 tax starts out higher than the implicit price in both CES Goal and No-Goal runs, but then dips below it in 2019 (Figure 6). It rises above the CES Goal run around 2025 and surpasses the CES No Goal run after 2031. By 2035, the CO_2 tax is about 13 percent higher than the CES price for the No-Goal run and more than double the price from the EPEC RD&D Goal run. In other words, while a CO_2 tax policy results in a larger amount of CO_2 emissions being reduced in the electric power sector than a CES policy, the cost to reduce each metric tonne of CO_2 is higher – increasing from about \$40 per tonne in 2025 to \$65 per tonne in 2035 in the CO_2 Tax Case, while staying at about \$30 per tonne in the CES Goal run in that period. This result is due primarily to the acheivment of the EPEC RD&D goals which supports the deployment of CCUS technology allowing natural gas and coal-fired power plants/units to meet the clean energy standard after 2020.

Figure 6. CO_2 Tax vs. CES Credit Price



Under any carbon policy, energy prices are likely to be higher than a business-as-usual case that treats emissions as an externality because there is an added cost in keeping the CO_2 from being emitted into the atmosphere. In this study, energy expenditures[4] for the No-Goal runs are compared to those in the Goal runs. The total energy savings over the 2010 – 2035 period are larger under the Carbon Tax scenario than the CES scenario. In the Carbon Tax Case, the cumulative difference between the energy expenditures of the No Goal and EPEC RD&D Goal runs is $84 billion over the 25 year period, compared to $77 billion in the CES Case. When estimated in terms of annual net present value at a 7 percent discount rate over the period 2010 - 2035, the energy expenditures savings in the Carbon Tax Case is $23 billion, compared to $18 billion in the CES Case (Figure 7). The larger net present value savings in the Carbon Tax Case is driven by the higher cost per tonne of carbon in many years (and in particular the early years) that increases the economic advantage of carbon capture, which is then accelerated by the assumed achievement of the EPEC goal. While the EPEC RD&D goal is the same in the two policy cases, the relatively lower equivalent cost per tonne of carbon in the CES Case reduces the economic pressure, and therefore yields lower savings when comparing the scenarios with and without the achievement of the RD&D Goal.

Figure 7. Savings in Energy Expenditures (Goals vs. No Goals)*
(Net Present Value at 7% Discount Rate)



Two key elements of CCUS are the transport and storage of CO_2 from the power plant to a geological storage site where it will be monitored to verify that it does not leak back into the atmosphere. In this study, the CO_2 that is captured at the coal-fired power plants tends to be stored locally – within 100 miles of the power plant, on average – thus significantly more intraregional pipelines are built than interregional (Table 4).

[4] Energy expenditures include expenditures for oil, gas, coal and electricity across all sectors other than transportation.

Table 4. Capture – Transport – Storage Data

	CES No Goals	CES Goals	CTX No Goals	CTX Goals	Total Possibility Set
Plant Retrofits (Gross GW)	113	157	43	243	322
New Builds (Gross GW)	6	16	6	14	
Year of Initial Retrofit/Build	2020	2020	2030	2024	
Storage Sinks	20	26	17	28	30
Pipelines					
Intraregional	71	122	35	181	
Interregional	22	35	8	62	

The CTS Network Model used in this study has the capability to either build a dedicated pipeline to transport the CO_2 from the power plant to the storage site, or utilize a trunk line that enables multiple power plants to connect to this pipeline, which then transports the CO_2 to a storage sink. This study found that the economics of a nearby sink outweigh the economies of scale achieved by accessing a trunk line. In general, a dedicated pipeline is 3 times more likely to be used over a trunk line to transport the CO_2 (Table 5). The average pipeline distances are 95 miles for dedicated lines and roughly twice that for trunk lines (188 miles).

Table 5. Carbon Dioxide Transport Pipeline Data

	CES No Goals	CES Goals	CTX No Goals	CTX Goals	Total
Pipelines	**93**	**157**	**43**	**243**	
Intraregional	71	122	35	181	
Interregional	22	35	8	62	
Dedicated Pipelines	**67**	**114**	**36**	**148**	
Intraregional	52	89	28	113	
Interregional	15	25	8	38	
Plants using trunklines	**26**	**43**	**7**	**95**	
Intraregional	19	33	7	68	
Interregional	7	10	0	27	
Nodes Accessed	**8**	**12**	**3**	**17**	**19**

Despite the desirable geological characteristics of the Gulf Coast sinks, sinks in the Ohio River Valley receive the most CO_2 in the NEMS-CCUS runs, due to the high concentration of coal-fired power plants in that region of the country that are retrofitted with CCUS technology in this study. The three graphs of the United States which follow (Figures 8-10) illustrate how the capture-transport-storage network develops over time in CO_2 Tax Goal run. In 2025, the first movers to CCUS technology are primarily in the ECAR, SERC and ERCOT regions (Figure 8). In 2030, there is five times the amount of CO_2 transported and stored annually compared to 2025 and the development of pipelines is expanded in most regions of the nation (Figure 9). In the 2035 time horizon most of the additional CO_2 volume comes from new CCUS power plants and the bulk of the transshipment points and sinks are utilized in the network (Figure 10).

Figure 8. 2025 Carbon Transportation and Storage GIS

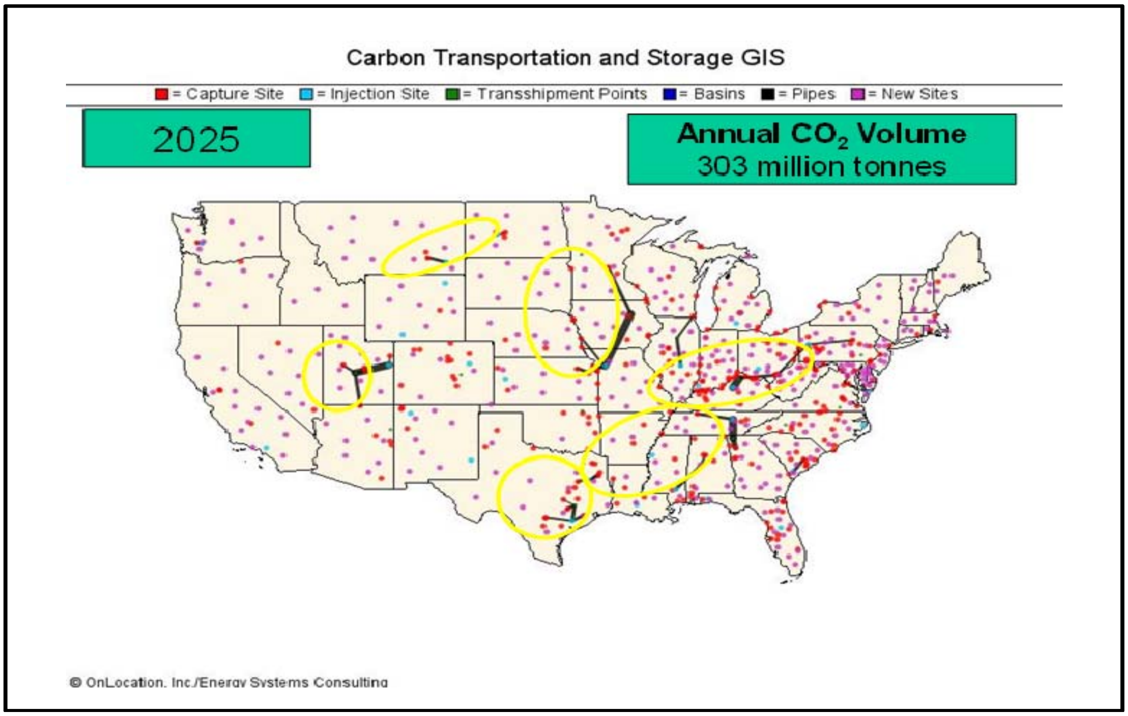


Figure 9. 2030 Carbon Transportation and Storage GIS

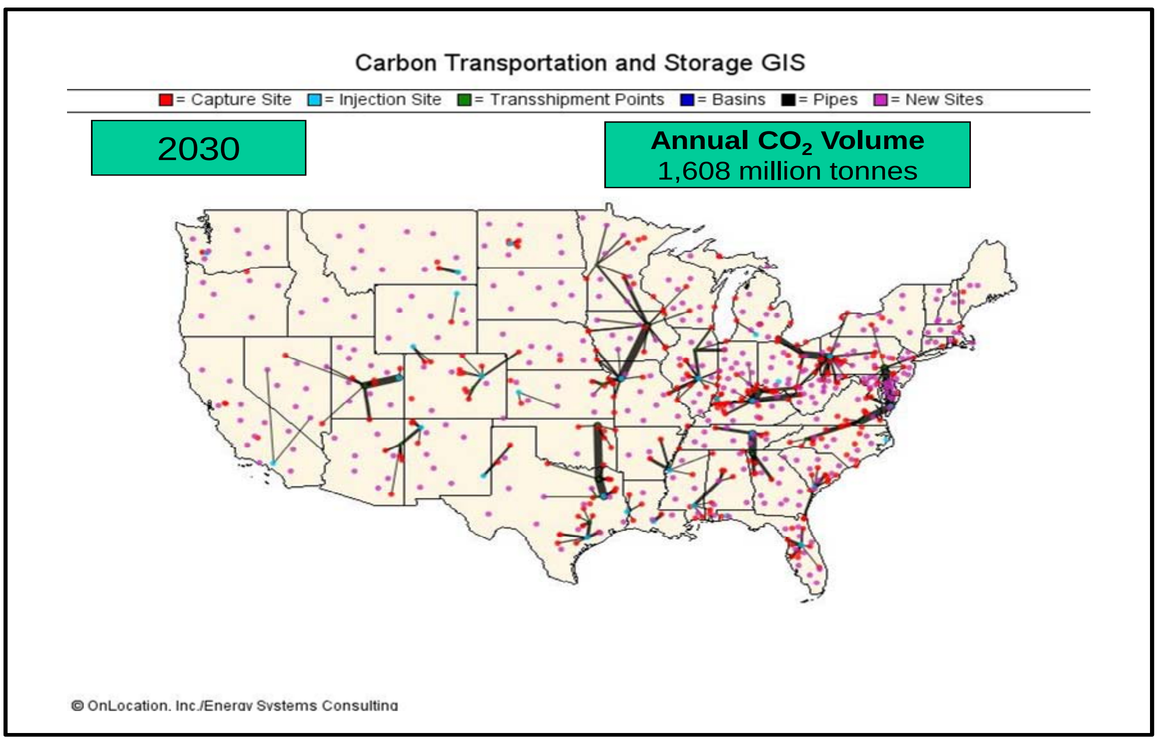
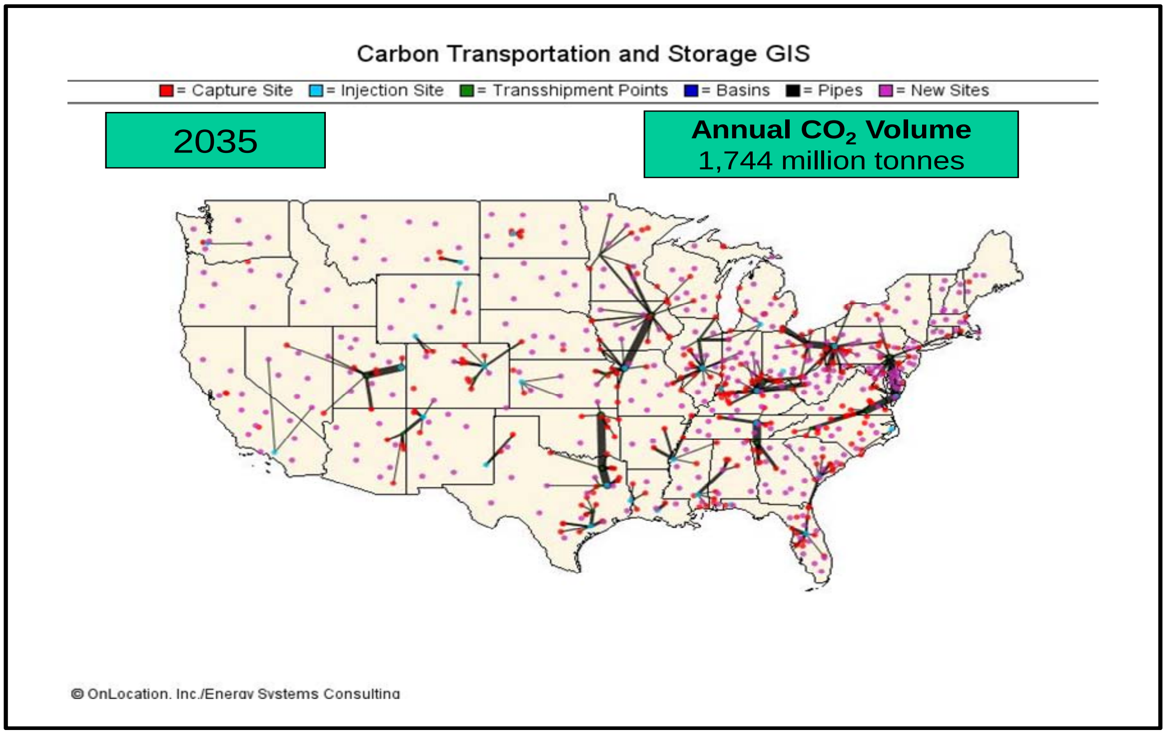


Figure 10. 2035 Carbon Transportation and Storage GIS



Conclusions

The NEMS-CCUS Model provides a robust framework to assess the viability of a CO_2 capture, transport, utilization and storage market under various scenarios. This extended capability in NEMS provides the analyst the information needed to assess:

- development of a pipeline network that links sources and sinks;
- evaluation of trunk lines as a part of the pipeline network;
- evaluation of the geographical distribution of sinks; and
- determination of the most appropriate time horizon.

Application of this new modeling framework to various CO_2 policies indicate that both new power plants equipped with CCUS technology, as well as existing plants retrofitted with CCUS technology , can significantly contribute to attaining targets set in CO_2 reduction regimes. In fact, through case studies examined in this paper, from 45 and 70 percent of the coal-fired power plants generating electricity in the United States today are good candidates for retrofit with CCUS technology when the EPEC Program's RD&D goal is met. Under the Carbon Tax Case, CCUS technology can play a key role in significantly reducing CO_2 emissions from coal-fired power plants. Under the CES Case, CCUS technology can play a key role in reducing the cost of meeting the clean energy requirement.

Currently, the NEMS-CCUS model only considers on-shore saline formations for CO_2 storage. Further development is planned for the model, including the introduction of coal bed methane and offshore CO_2 storage opportunities, representation of industrial sources, and the introduction of CO_2 utilization in the form of enhanced oil recovery (EOR). These improvements are scheduled to be completed in FY 2012.

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