NARUC Winter Policy Summit

Staff Electricity Subcommittee

Fossil Energy R&D Analysis

Benefits Analysis of Fossil Energy R&D

NARUC Clean Coal & Carbon Management Subcommittee – February 2018

Chris Nichols
Analyst, Systems Engineering and Analysis

Outline

- **Introduction to the Systems Engineering and Analysis Directorate at NETL**
- **Overview of energy market modeling**
  - Promod Economic Dispatch
  - NEMS/CTUS results with EOR, tax credits, and R&D
  - MARKAL Energy Modeling Forum Results
- **Conclusions**

NETL Enduring Core Competencies

Computational Engineering

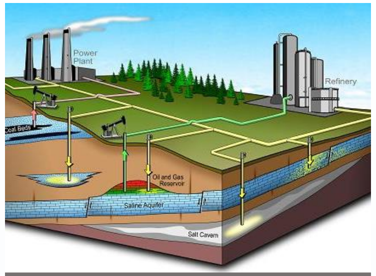
High Performance Computing

Data Analytics

Materials Engineering & Manufacturing

Structural & Functional

Design, Synthesis & Performance



Geological & Environmental Systems

Air, Water & Geology

Understanding & Mitigation

Energy Conversion Engineering

Component & Device

Design & Validation

Systems Engineering & Analysis

Process & System

Optimization, Validation & Economics

Effective Resource Development
~
Efficient Energy Conversion
~
Environmental Sustainability

Systems Engineering & Analysis

Vision

The Systems Engineering & Analysis Directorate's vision is

- to become the world's premier resource for the development and analysis of innovative advanced energy systems and
- to provide unprecedented breadth of integrated modeling and optimization capability to support decision making and analysis across multiple scales.

This competency will support technology innovation and maturation at the process level as well as enable better identification, evaluation and prioritization of R&D concepts at earlier stages, including the consideration of broader energy system and market needs and impacts.

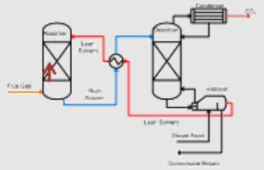
Systems Engineering & Analysis (SEA)

Teams and Scope

Energy Process Analysis

Energy Process Design, Analysis, and Cost Estimation

- Plant-level modeling, performance assessment
- Cost estimation for plant-level systems
- General plant-level technology evaluation and support



Advanced Technology Design & Cost Estimation

Energy Systems Analysis

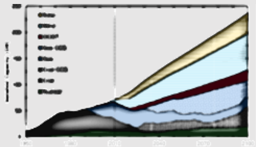
Resource Availability and Cost Modeling

- CO_2 storage (saline and EOR)
- Fossil fuel extraction
- Rare earth elements
- General subsurface technology evaluation and support

Grid modeling and analysis

Environmental Life Cycle Analysis

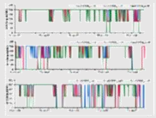
Energy Markets Analysis



Regional & National Energy-Economy Model

Energy Economy Modeling and Impact Assessment

- Enhanced fossil energy representation
- Multi-model scenario/policy analysis
- Infrastructure, energy-water



Grid, Infrastructure, & Energy Reliability

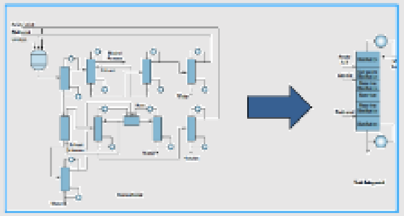
- Economic impact assessment
- General regulatory, market and financial expertise

Process Systems Engineering Research

- Process synthesis, design, optimization, intensification
- Steady state and dynamic process model development
- Uncertainty quantification
- Advanced process control

Design, optimization, and modeling framework to be expanded to all SEA "systems"

Advanced Energy Systems through Process Systems Engineering



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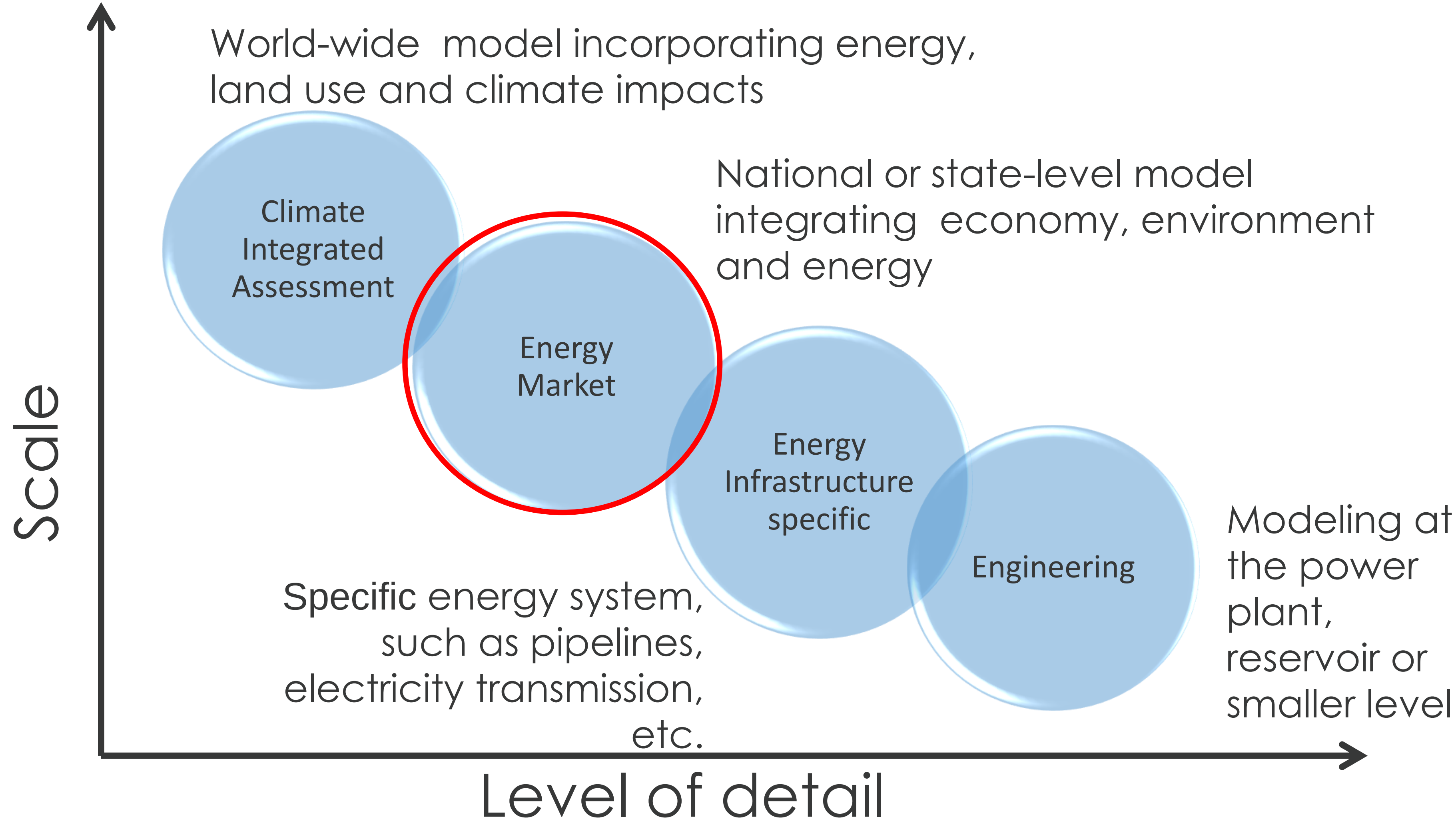
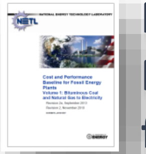
Models are representations of the physical world – energy models span a large scale



Assessing Program Portfolio Impacts:

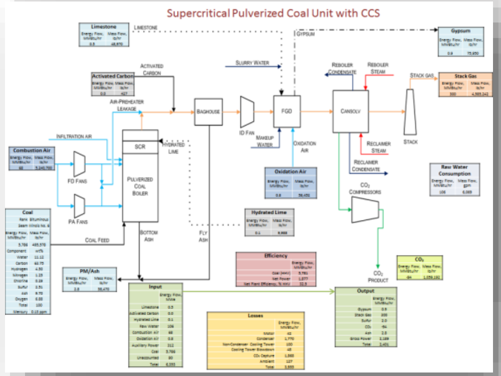
Coal Program Example

Baseline Data & Model Development → Set R&D Goals and Evaluate Progress → Project deployment of Technologies → Estimate Potential Benefits of RD&D

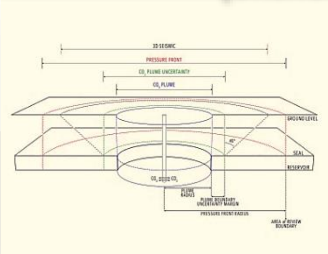


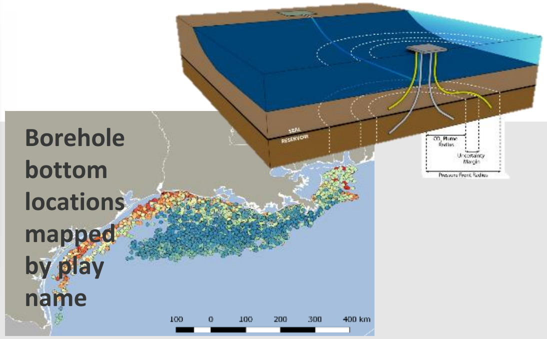
NETL Cost and Performance Baseline for Fossil Energy Plants

- *Detailed, transparent account of plant information*
- *Key resource for government, academia and industry*

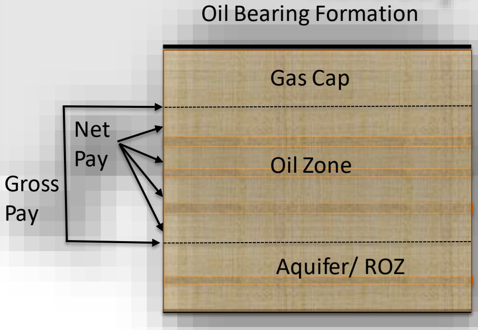


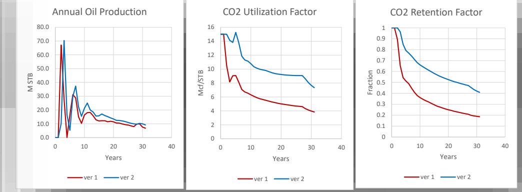
NETL CO_2 Saline Storage Cost Model (onshore and offshore)





NETL CO_2 Prophet Model



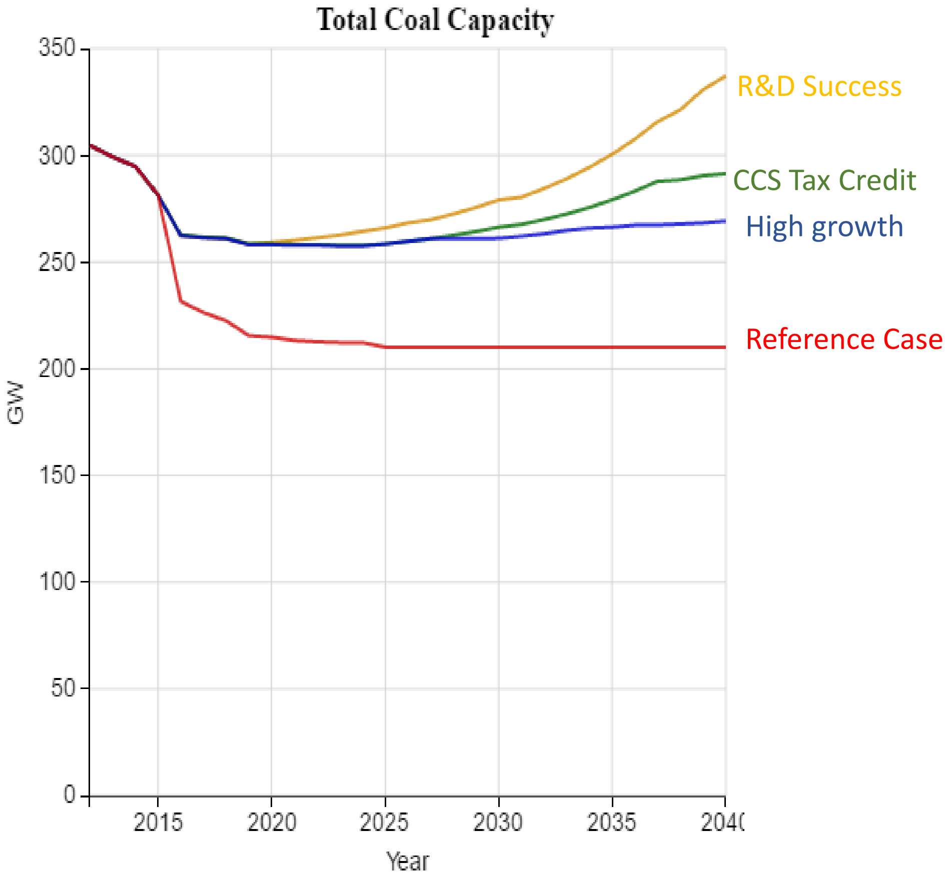


NETL CO_2 Capture, Transport, Storage and Utilization - National Energy Modeling System (CTUS-NEMS)

- *Adopted by EIA; used in AEO's 2014/15/16*
- *Facilitates and encourages EPSA interactions*

Assessing Program Portfolio Impacts:

Baseline Data & Model Development → Set and Evaluate Progress to R&D Goals → **Project Deployment of Technologies** → **Estimate Potential Benefits of RD&D**



U.S. Benefits of the Program, Cumulative through 2040	
Benefit Area	**Metric**
Economic Growth	Total Electricity Expenditure Savings
	Employment
	Income
	Gross Domestic Product (GDP)
Environmental Sustainability	CO_2 Captured at Coal and Gas CCS Facilities
Energy Security	Additional Domestic Oil Production via EOR

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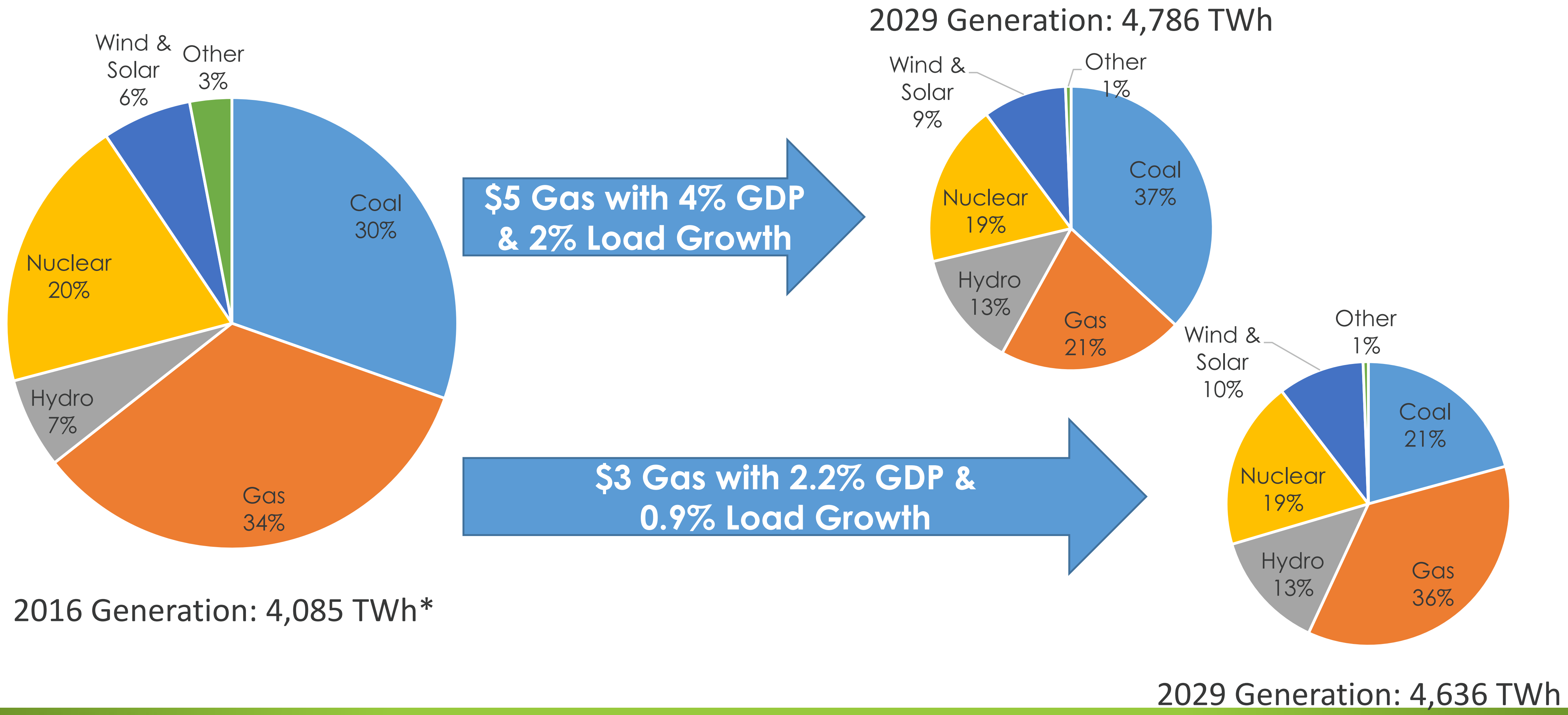
Electric Sector Dispatch Analysis - PROMOD

- **PROMOD 11.1 is a commercial, widely-used off the shelf security-constrained, economic dispatch modeling program that utilizes known power system information to identify the most economic utilization of the power system**
  - Inputs include hourly power plant characteristics for each grid-connected unit, including heat rates, operation and maintenance (O&M) and fuel costs, interconnection location, and load profiles for each power system balancing area
- **Current types of system sensitivities evaluated:**
  - Fuel prices
  - Demand
  - Generation retirements/service entry
- **Potential types of sensitivities:**
  - Monthly emissions prices
  - Monthly forced outage rates
  - Monthly O&M cost variation
  - Hourly ramping
  - Maintenance rates/duration/deration
- **Vendor currently developing sub-hourly modeling capabilities**

Fossil Market Shares depend on relative price and load growth



*2016 Generation from EIA Short Term Energy Outlook, January 2017; NETL calculations using PROMOD

Higher Gas Prices and Improved Heat Rates

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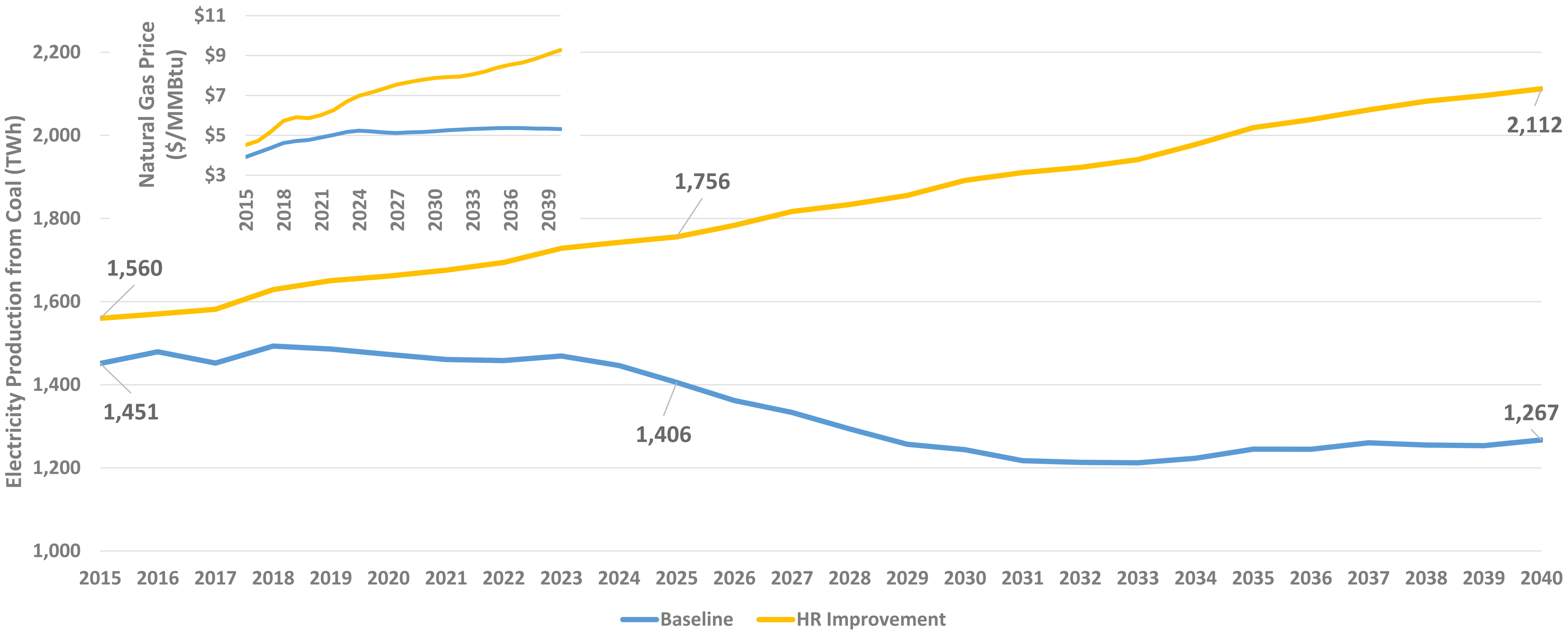

Results of simulations using ABB PROMOD IV

Need for Improved Availability

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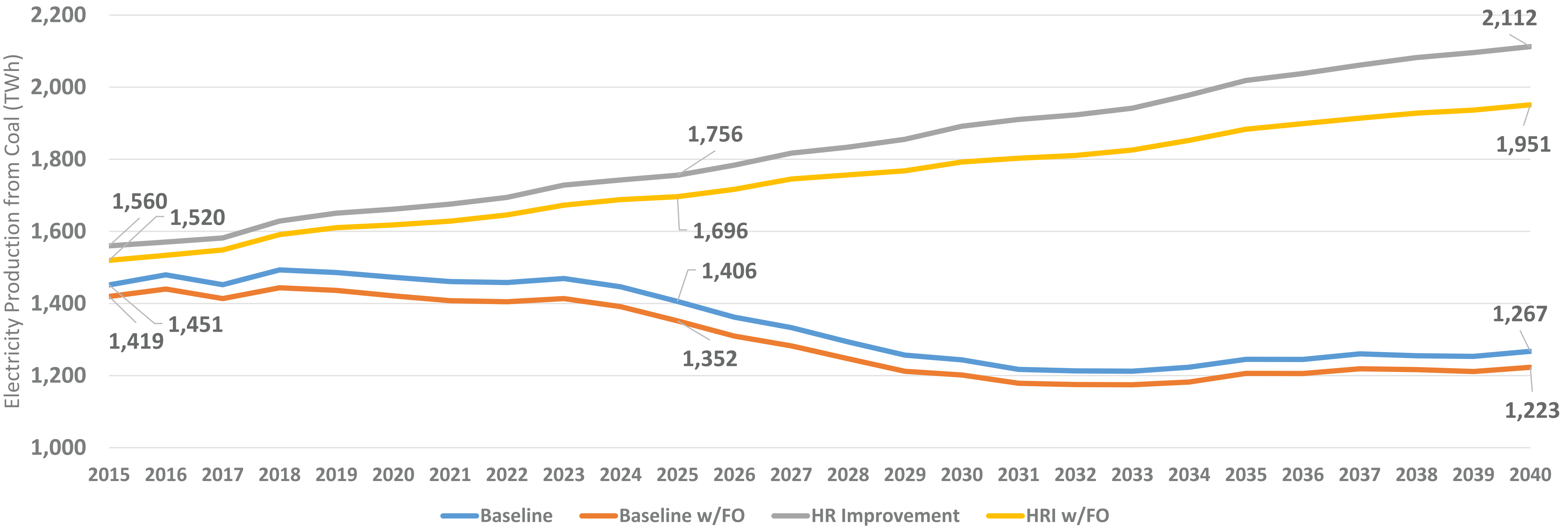
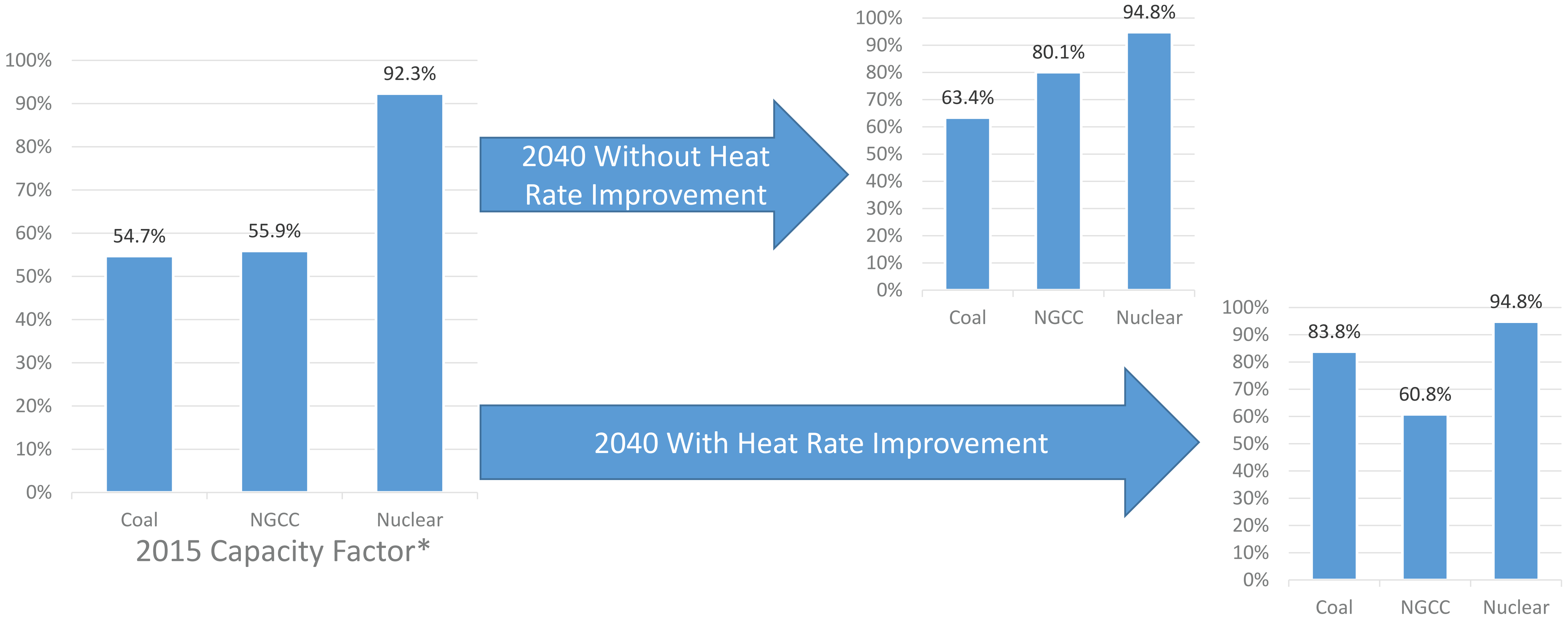


Inclusion of forced outages reduces generation by 2-3% annually in the baseline scenario, and up to 8% with assumed heat rate improvement.

U.S. DEPARTMENT OF ENERGY

Results of simulations using ABB PROMOD IV

Existing Plant PROMOD Analysis: Coal's Increasing Role in Dispatch



*2015 Capacity Factor from EIA Electric Power Monthly, January 2017

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NEMS – typical inputs and outputs

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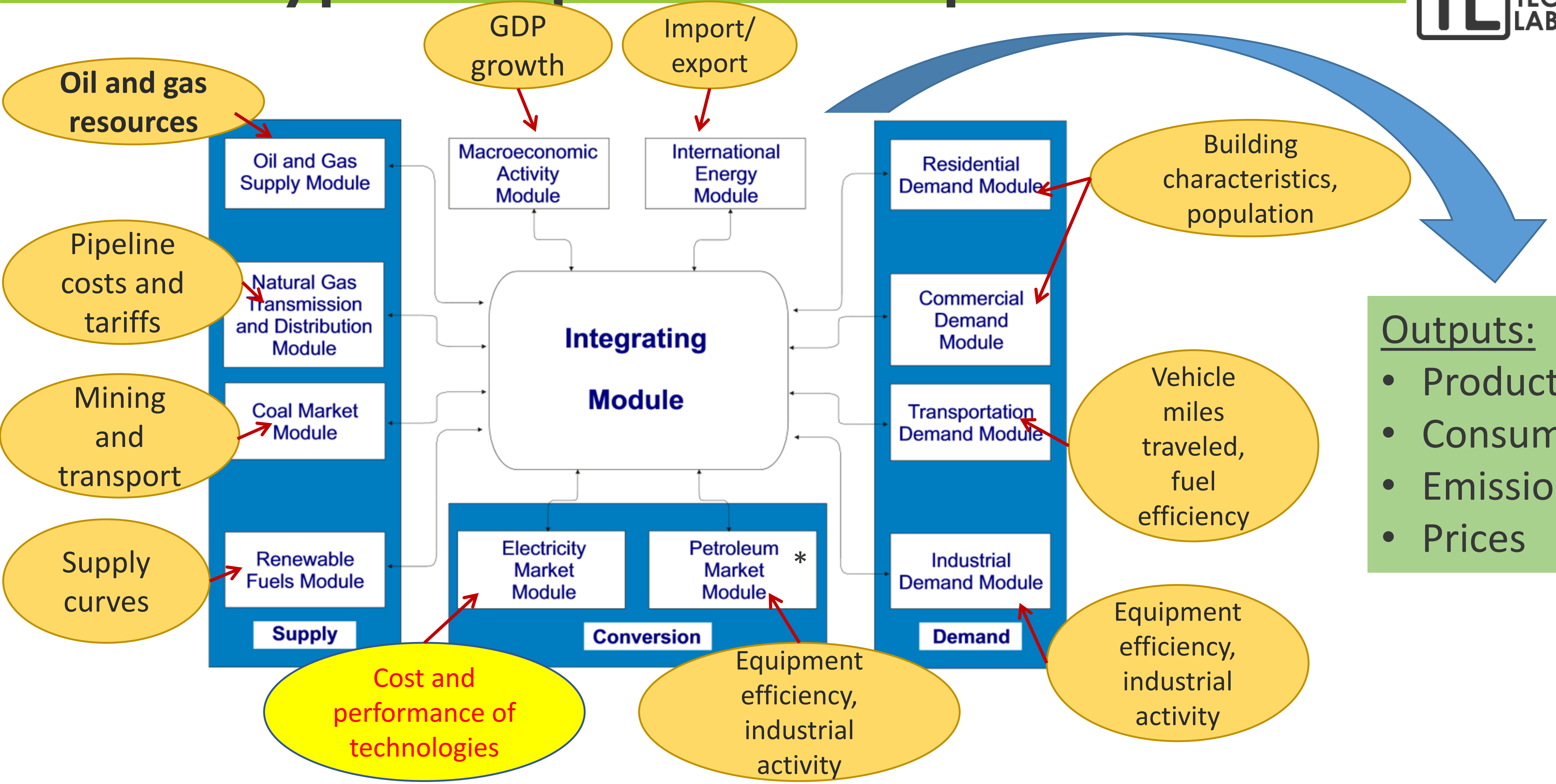


Outputs:
- Production
- Consumption
- Emissions
- Prices

* Now known as Liquid Fuel Market Module

Improving EOR representation in NEMS with CTUS

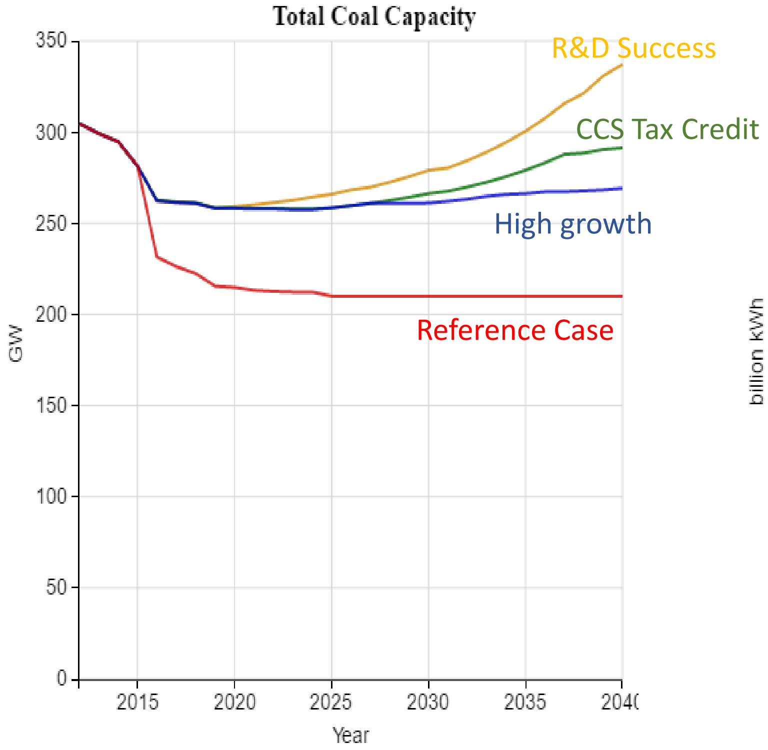
- NEMS did not include strong ties between captured CO_2, EOR and pipelines
- NETL developed the Capture Transport Utilization and Storage (CTUS) plug-in sub-module
- Multiple sources, sinks, and EOR sites spatially represented
- Estimates an optimal CCUS pipeline network
- Passes transport and storage cost back to potential CCUS technology options in the main CTUS-NEMS model

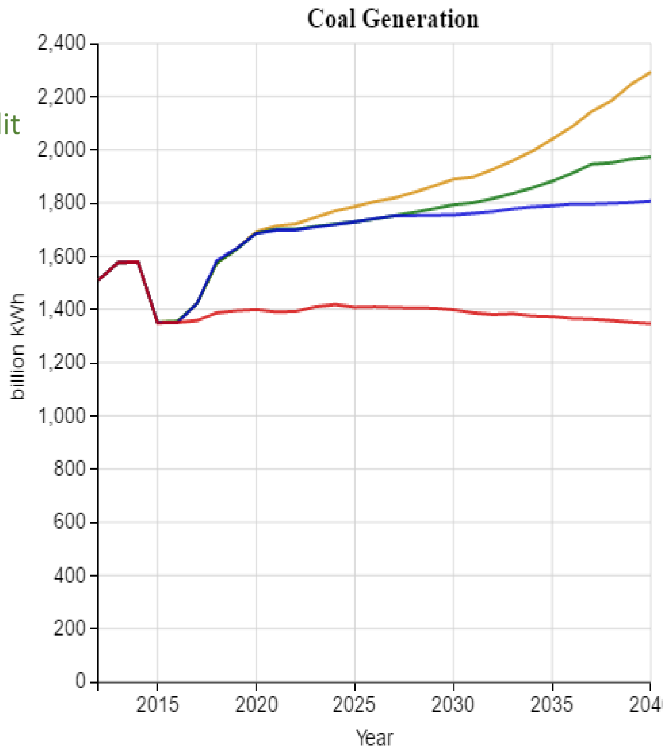
Tax Credit and R&D Impact Cases

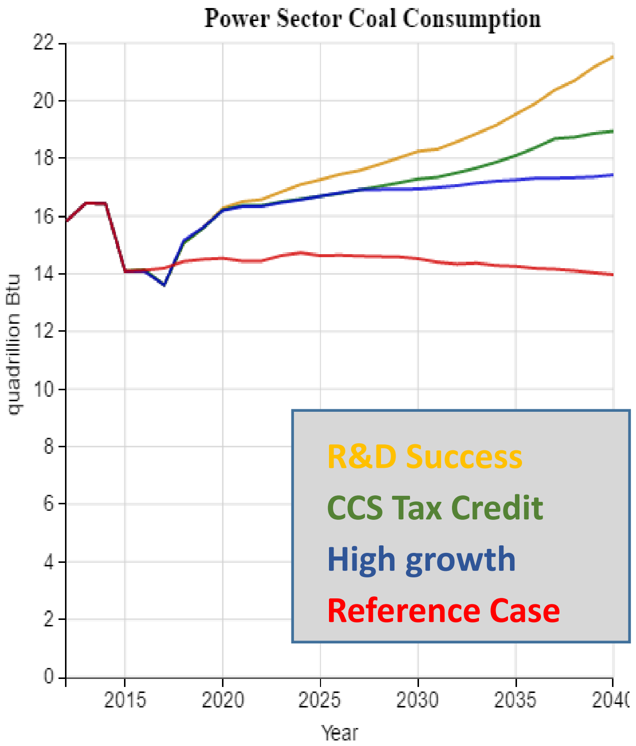
- Sensitivities using the NETL CTUS-NEMS model to analyze the impact of sequestration tax credits and R&D
  - AEO2016 No CPP case (**Reference**)
  - High Growth case: AEO2016 No CPP case with
    - higher gas prices, higher GDP growth, higher load growth (~ 2 percent per year);
    - lower EOR O&M costs; low cost heat rate improvements
    - planned coal retirements (14 GW) from 2017 onward removed (**High Growth**)
  - High Growth Case plus
    - 12-year sequestration tax credits 12 years providing \$35/ton CO_2 for EOR and \$50/ton CO_2 sent to geologic storage
    - new coal CCS capacity with 90% capture, state of the art technology (**Tax Credit**)
  - Tax Credit Case with CCS power plant program goals included (**R&D Success**)

Coal Capacity, Generation, and Consumption

- **Reference**: No new coal; **High Growth**: 13 GW
- **Tax Credit**: 35 GW; **R&D Success**: 80 GW



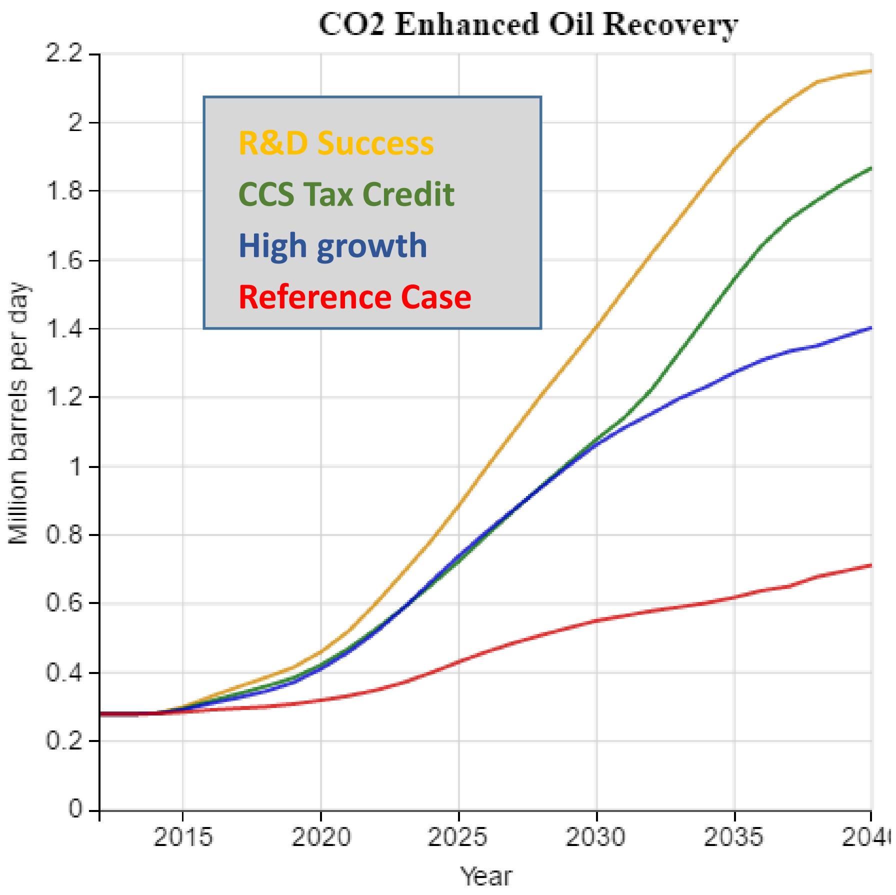




Growth of EOR Production, 2015-2040

- Reference: + 400k b/d
- High Growth: +1.1mb/d
- Tax Credit: +1.6 mmb/d
- R&D Success: + 1.8 mmb/d

CCUS improves energy security



Economic Impacts

- Economic Impacts of NETL RD&D in the sequestration tax credit cases were evaluated using the corresponding NEMS outputs with and without R&D
- The NETL-WVU Econometric Input-Output (ECIO) model was utilized to assess the economic impacts

Models and Methods

The NETL/WVU ECIO Model

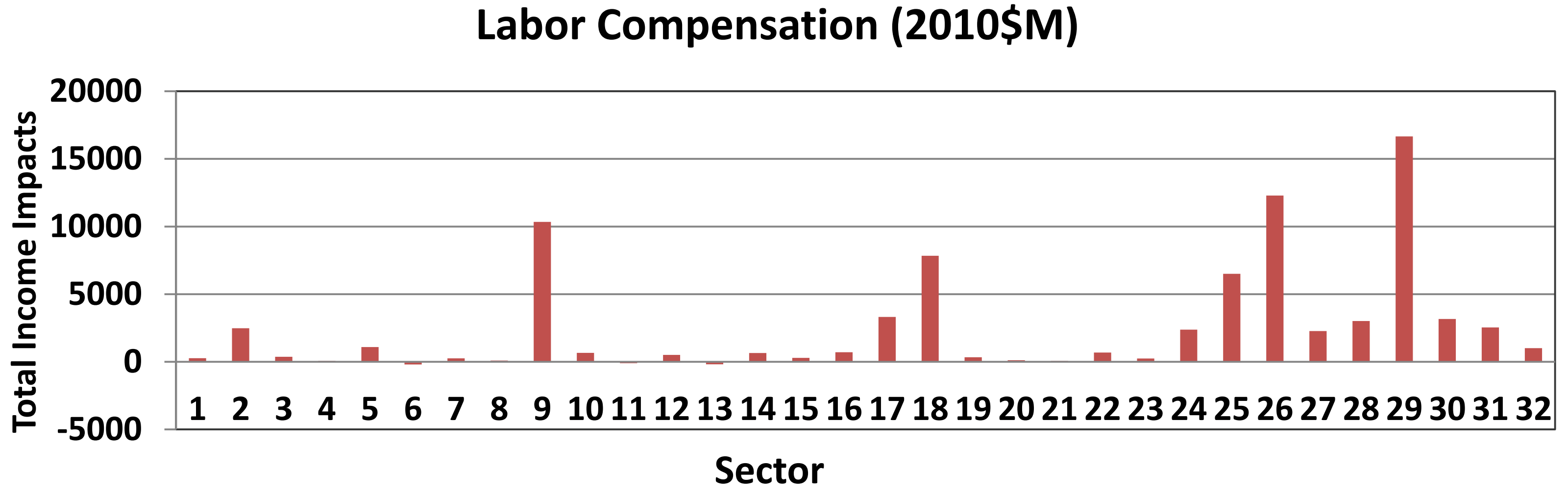
- The ECIO model is a time-series enabled hybrid econometric input-output (IO) framework that combines the time series capabilities of econometric models with the interindustry modeling strengths of IO models
- Designed to estimate the national economic and employment impacts of NETL's technology development, deployment, and operation over a corresponding NEMS forecast period
- Over the last six years, the NETL/WVU ECIO model has been developed and extended to serve the impacts forecasting needs of NETL

Summary Results, All Years

Category	Impact of NETL RD&D
Cumulative employment	4.1 million job years
Cumulative total income	$202 billion
Cumulative GDP	$304 billion
Total electricity expenditure savings	$49 billion (undiscounted)
Additional domestic oil production via EOR (billion barrels)	2.0

- **Both the largest employment and income impacts are in the Construction Sector (Sector 9)**

National Sector Results – All Years Total



Sector	Sector Description
1	Agriculture, forestry, fishing, and hunting
2	Oil and gas extraction
3	Coal mining
4	Mining, except oil and gas and coal
5	Support activities for mining
6	Electric power generation, transmission and distribution
7	Natural gas distribution
8	Water, sewage, and other systems
9	Construction
10	Primary and Fabricated metal products
11	Machinery
12	Motor vehicles and other transportation equipment
13	Other durable manufacturing
14	Other nondurable manufacturing
15	Petroleum and coal products
16	Chemical, plastics, and rubber products
17	Wholesale trade
18	Retail trade
19	Air, rail, and water transportation
20	Truck transportation
21	Pipeline transportation
22	Transit, sightseeing transportation, and transportation support services
23	Warehousing and storage
24	Information
25	Finance, insurance, real estate, rental, and leasing
26	Professional, scientific, and technical services
27	Management of companies and enterprises
28	Administrative, support, waste management, and remediation services
29	Educational services, healthcare, and social assistance
30	Arts, entertainment, recreation, accommodation, and food services
31	Other services (except public administration)
32	Government

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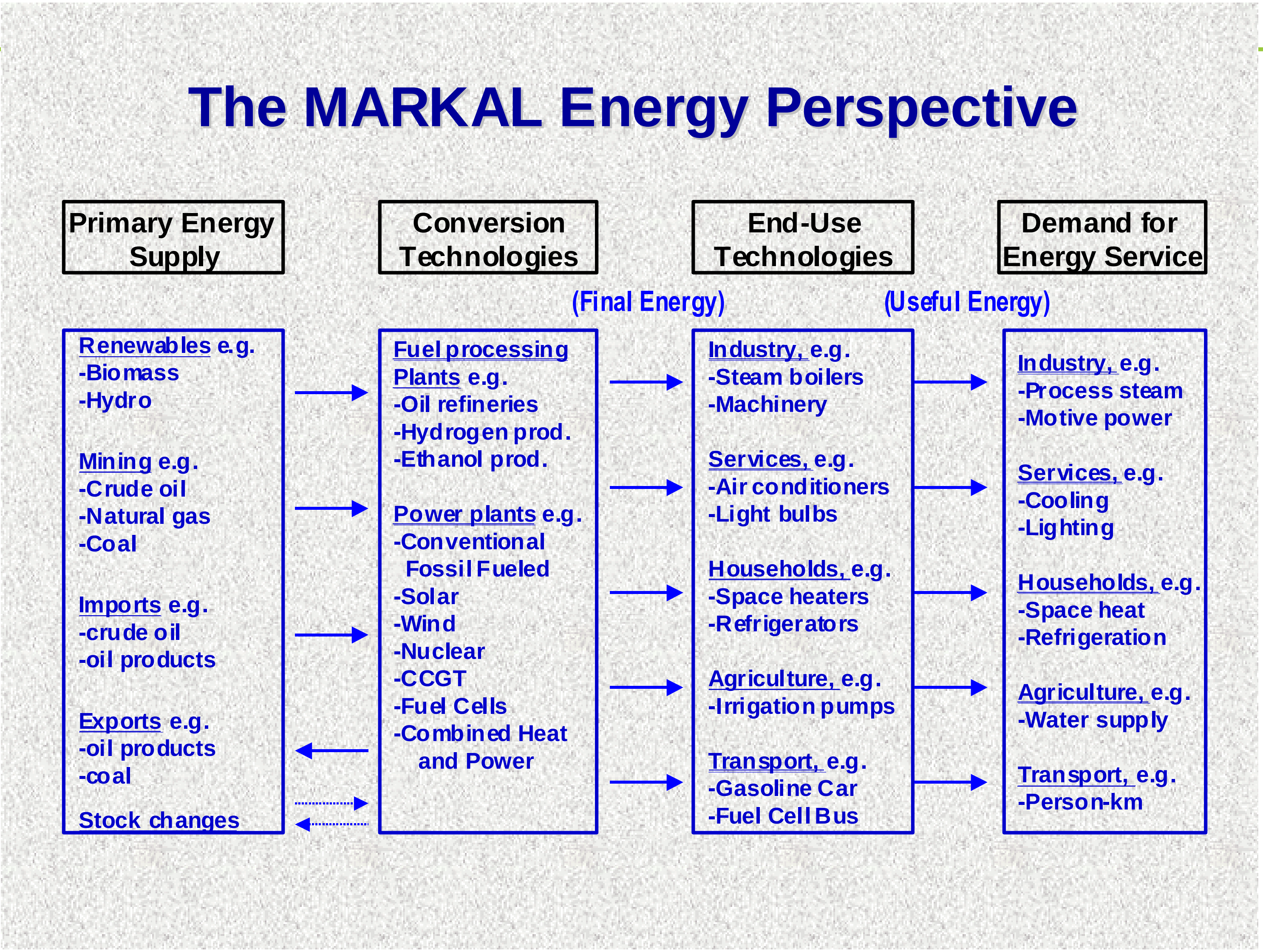
What is MARKAL?

- An energy-technology-environment model
- Uses a bottom-up representation of energy-producing, -transforming, and –consuming technologies
- Finds a least cost set of technologies to satisfy end-use energy service demands AND policies specified by the user
- Calculates resulting environmental emissions and water consumption/withdrawals

How MARKAL Does It



Developed under the Energy Technology Systems Analysis Program of IEA

Linear programming type optimization ; based on Reference Energy System

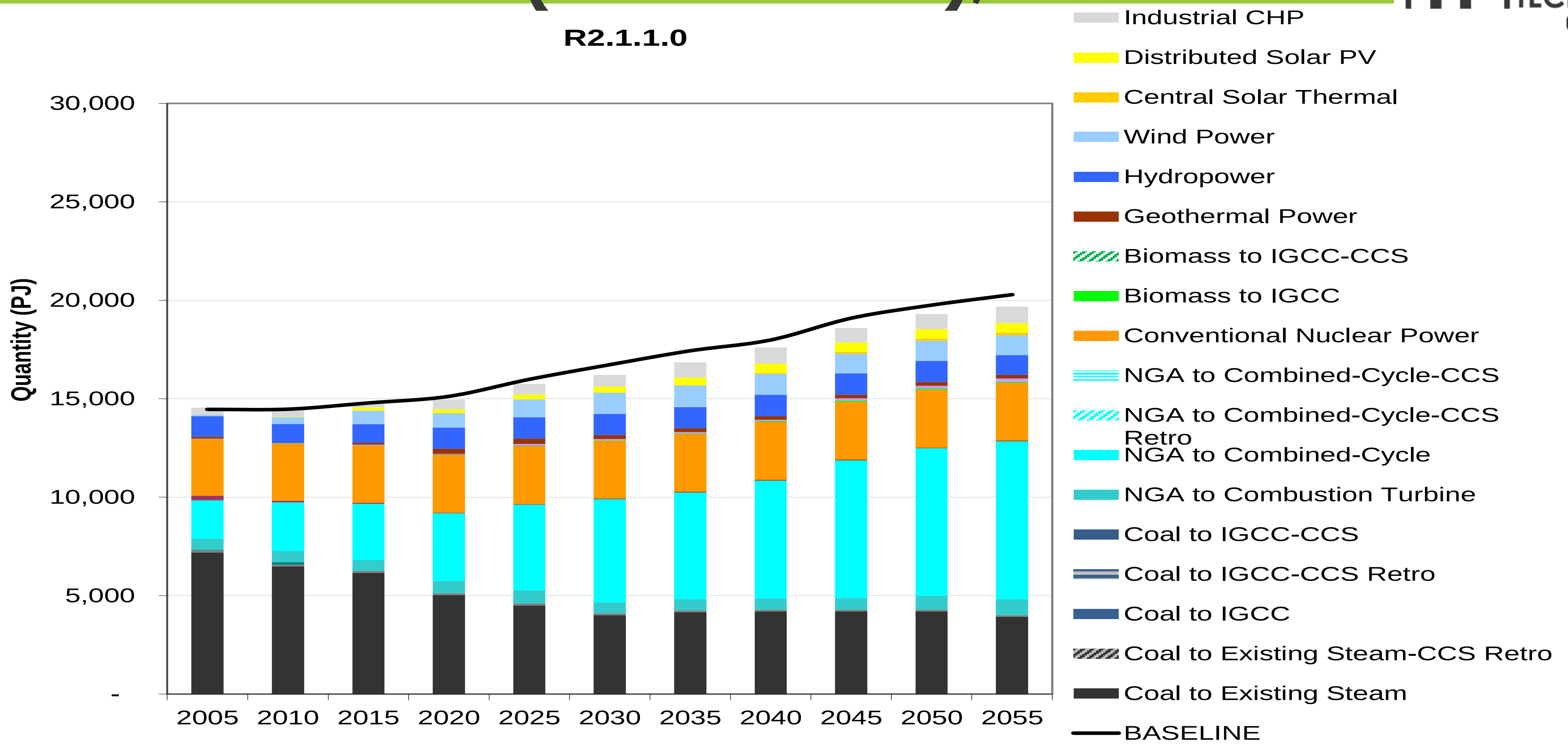
Detailed modeling of energy resources and supply chains

Includes electricity generation and transmission planning

EMF cases

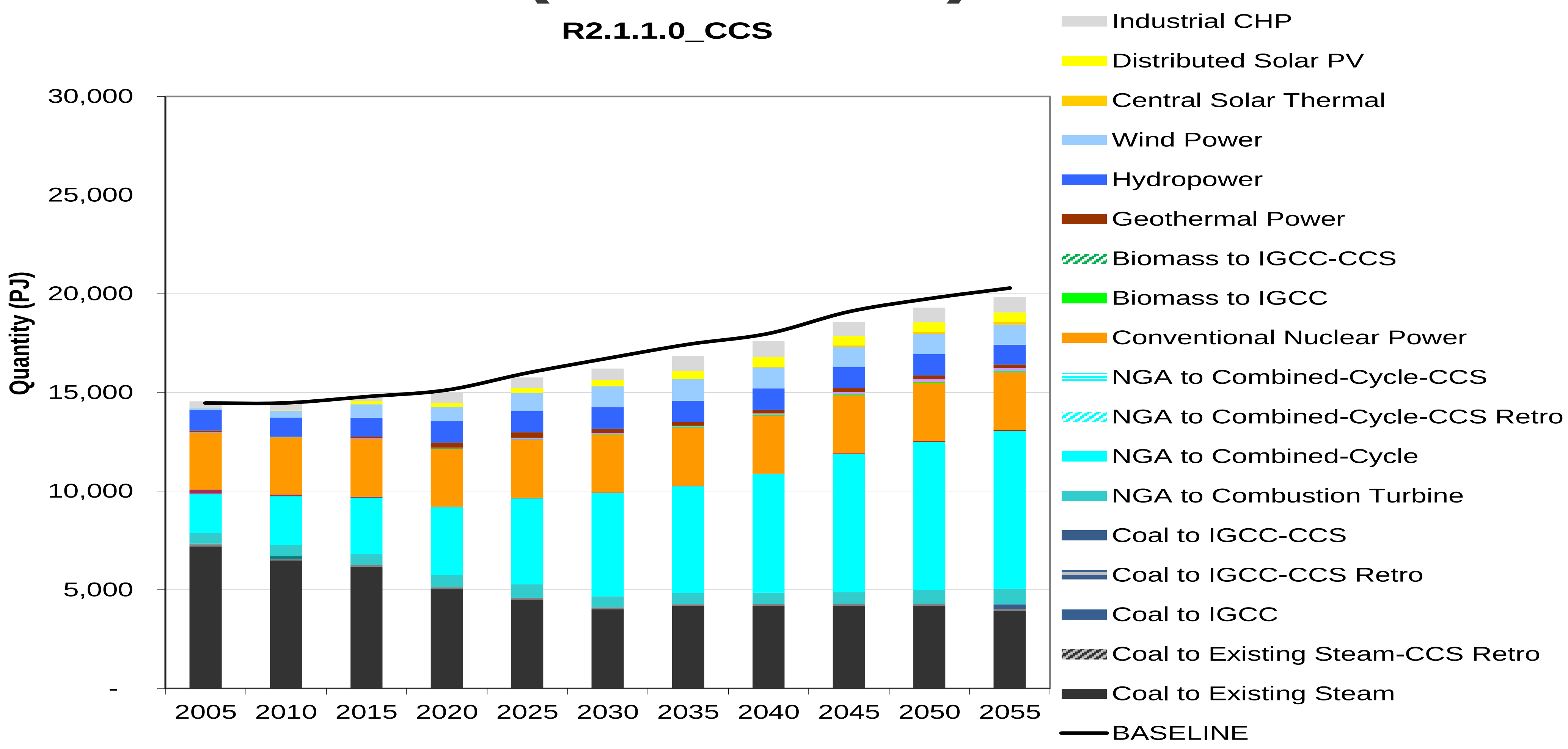
- **NETL-SEA participates in the Energy Modeling Forum, a cross-organization, multi-model effort which examines an energy sector of interest to all participants**
  - All participants agree on base scenarios to run, then compare results across scenarios and models
- **We used MARKAL to model the EMF scenarios and examined side issues of interest to NETL:**
  - Reference, Clean Power Plan, CO2 Tax, 80% reduction cases
  - With and Without R&D, Vary Natural Gas Prices
- **We found that in the reference and CPP cases, no CCS deploys, higher CO2 incentives and R&D are required to spur deployment**

Clean Power Plan (rate-based), no R&D



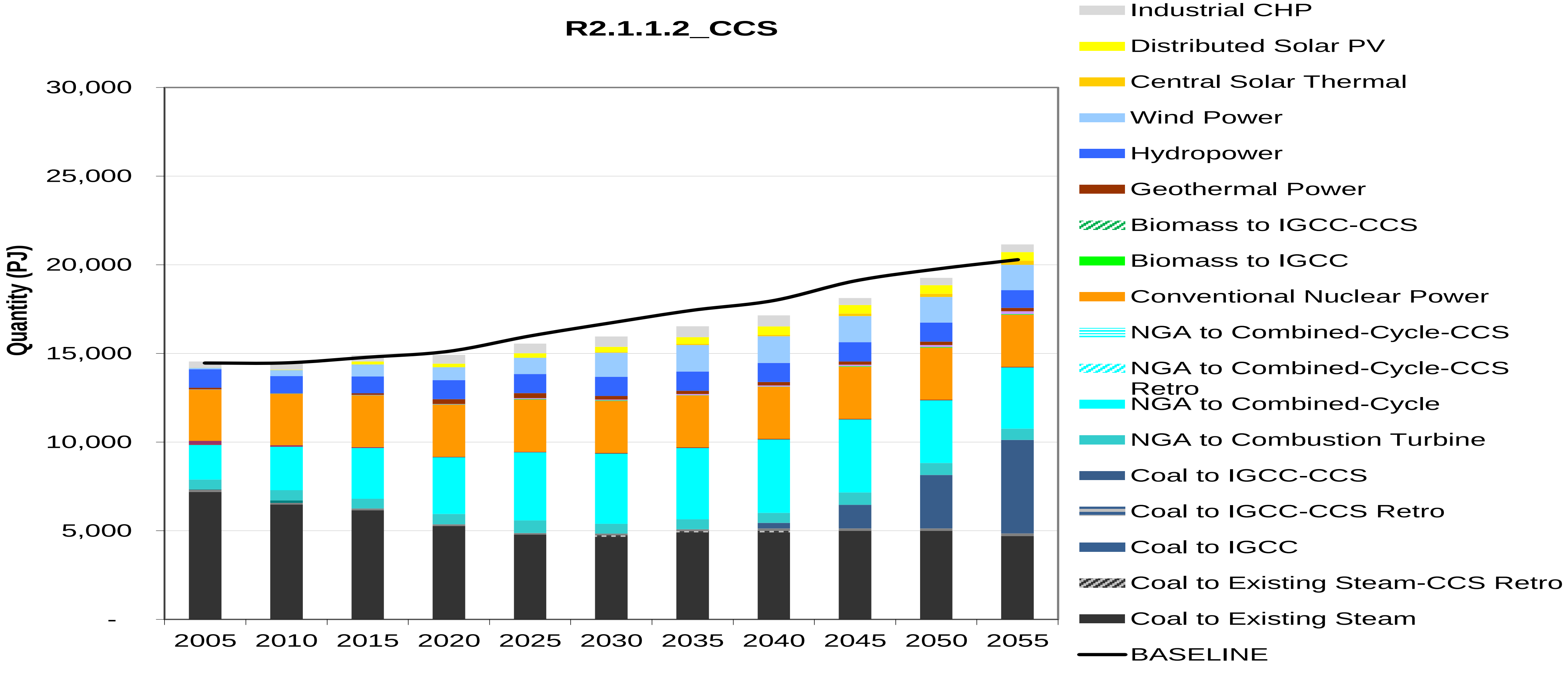
No CCS Deploys

Clean Power Plan (rate-based) with R&D



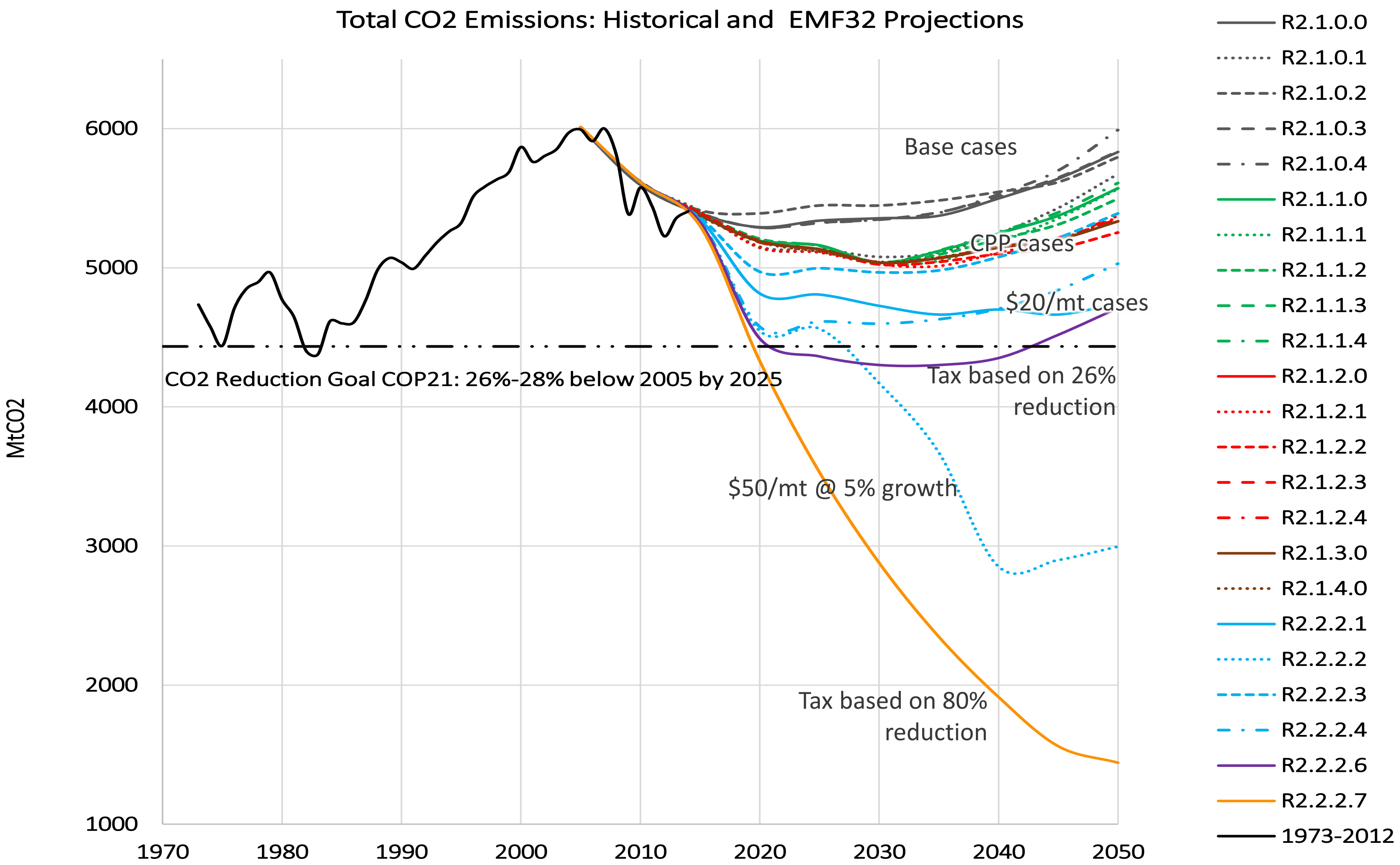
No CCS Deploys

Clean Power Plan (RB), High Gas Prices, with R&D

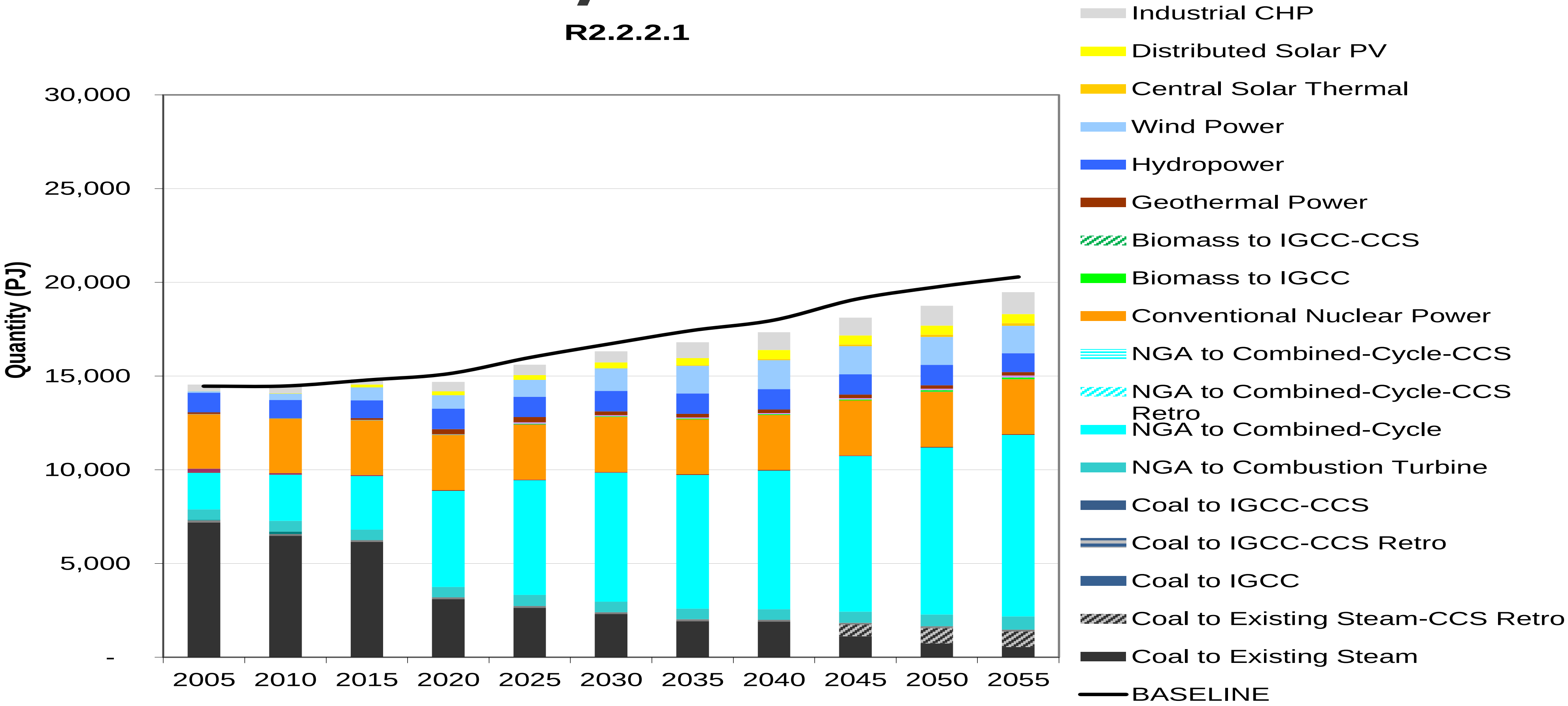


Limited CCS retrofits

CO2 Emissions-Economy wide, CPP and tax scenarios

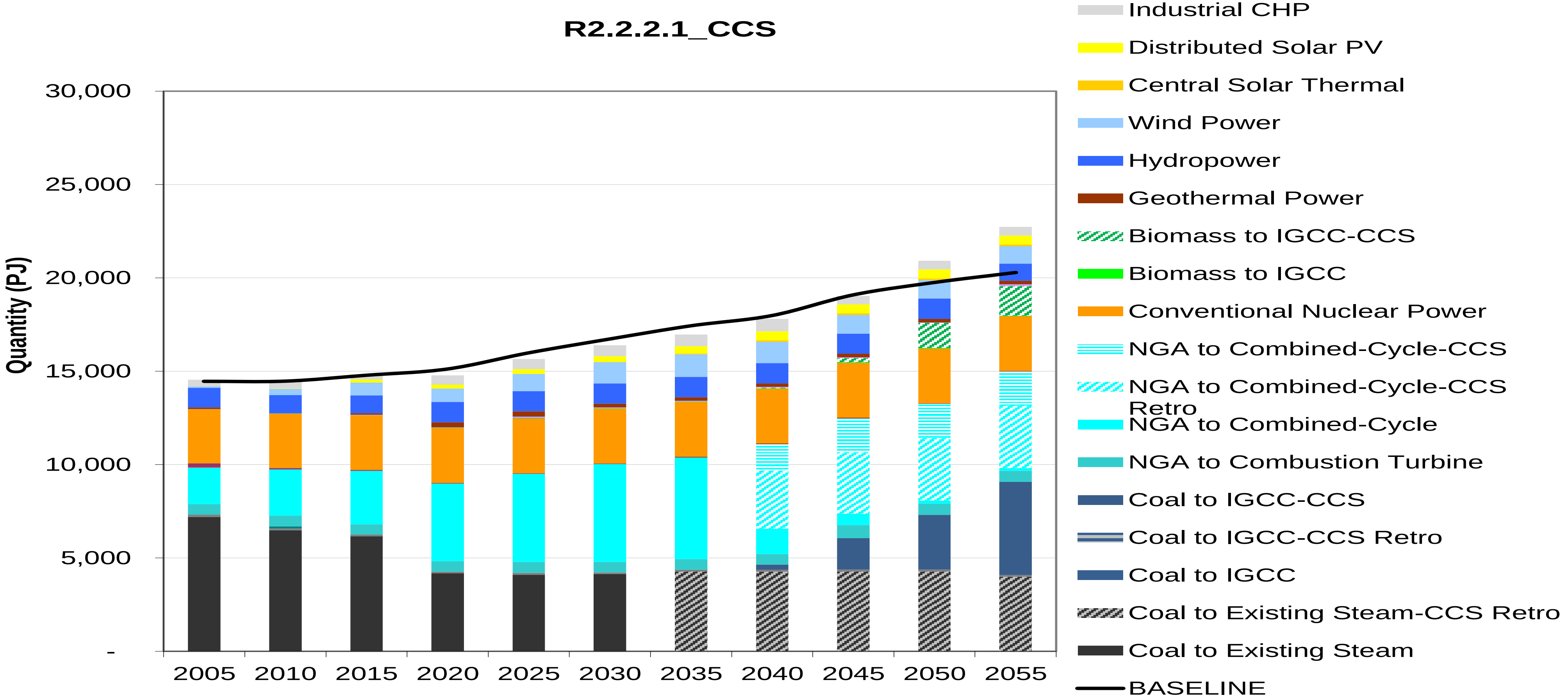


CO2 tax beginning in 2020 at $25 and increase 5% annually until 2050



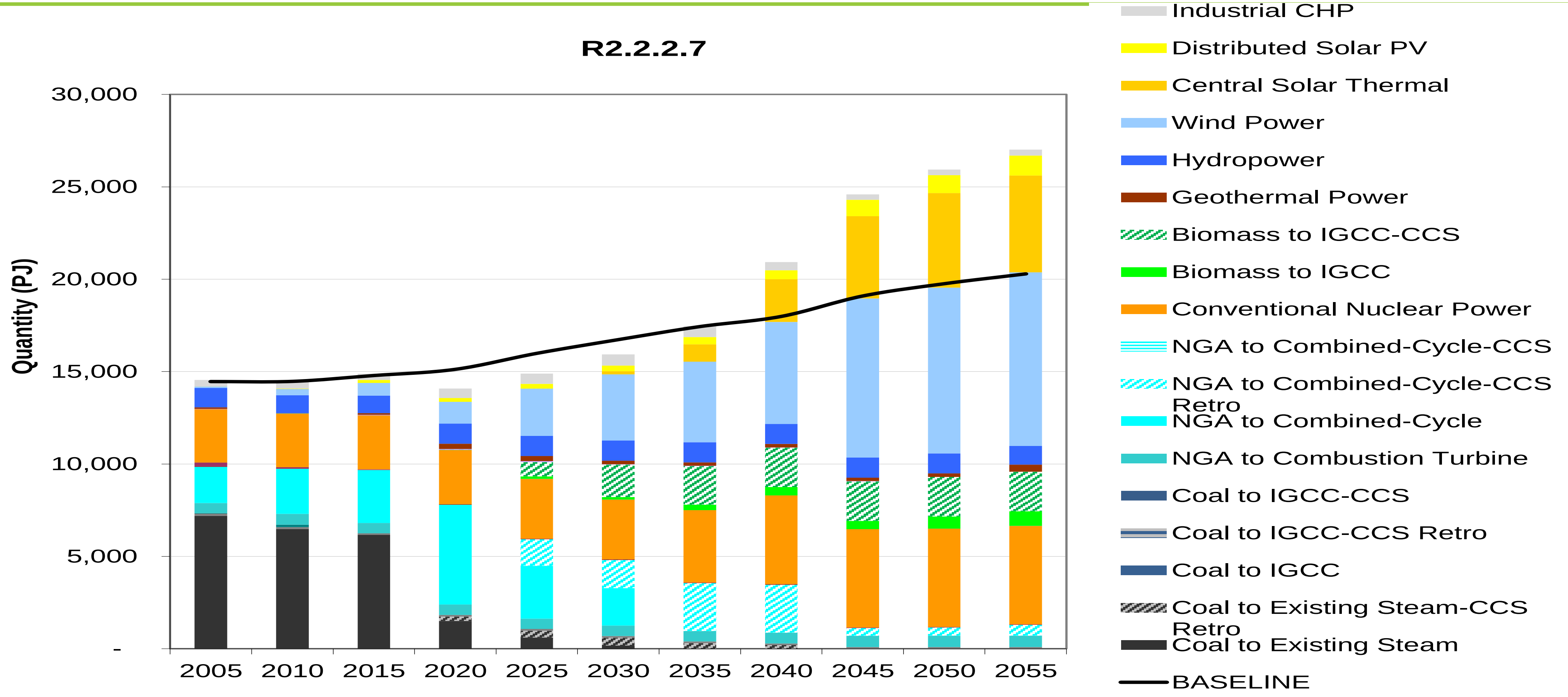
Limited CCS retrofits, mostly uncontrolled NGCC

CO2 tax ($25, 5% growth) with R&D



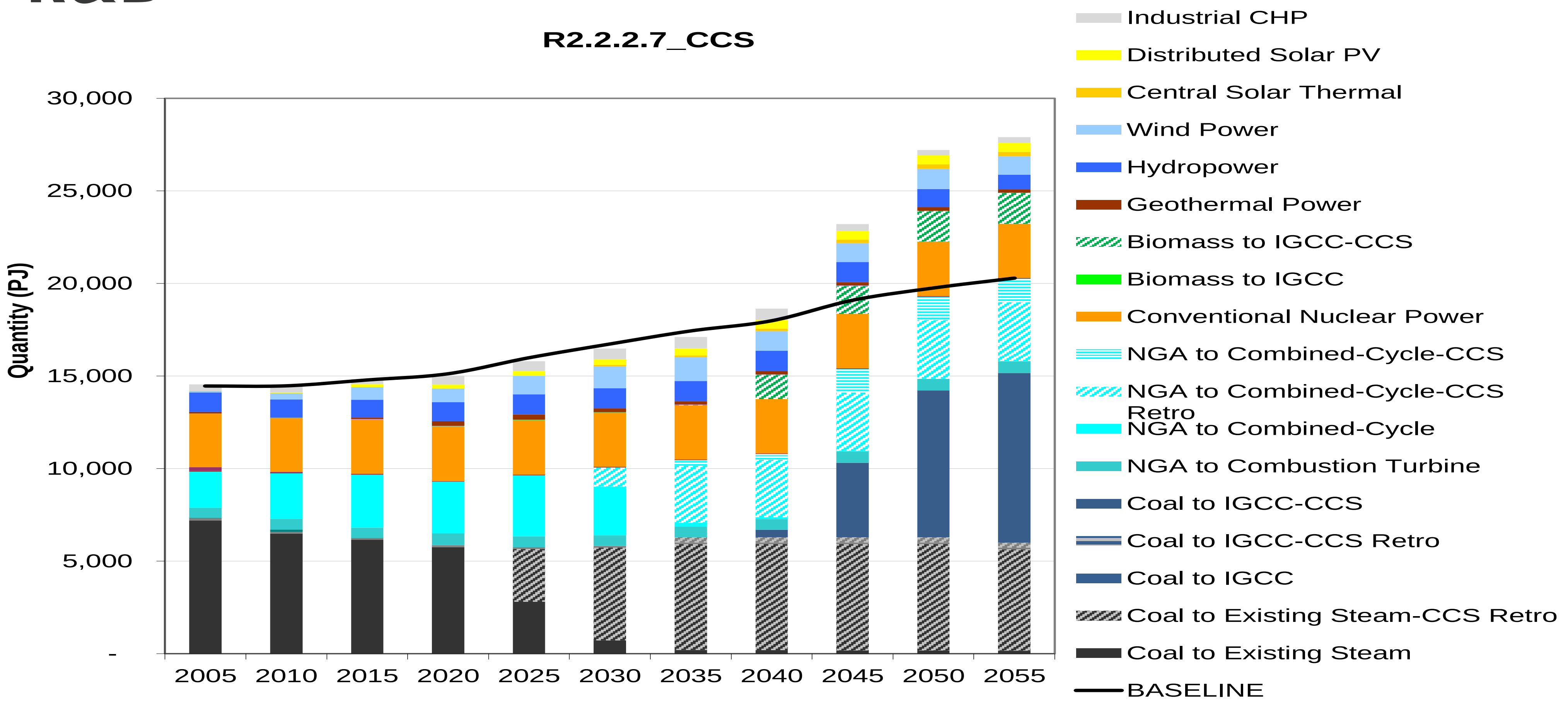
Substantial CCS Deployments on both Coal and Gas

80% CO2 emissions reduction by 2050, no R&D



System Swings to Renewables and Biomass CCS

80% CO2 emissions reduction by 2050, with R&D



With R&D, Fossil CCS Dominates in Deep Decarb Scenario

MARKAL takeaways

- **CCS technologies do not significantly deploy in most Clean Power Plan scenarios without R&D**
  - Even with R&D, some additional stress to the system is required
  - Large fleet of NGCCs usually built with post-2030 CO2 implications
- **CO2 taxes at $25 or $50 per tonne provide impetus to the system to radically reduce emissions**
  - R&D prompts major shift to CCS technologies to meet these targets

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Conclusions

- With regulatory relief, higher economic growth, higher load growth, and increased use of competing fuels, coal-fired power plants can compete
- New capacity can be built and existing coal units remain operational
- Efficiency gains are meaningful
- CCS may deploy as oil prices rises, with tax incentives and EOR.
- CO2 from power plants and industrial sources can contribute to energy security
- Under deep CO2 reduction scenarios, with R&D, Fossil CCS dominates.

Acknowledgements

- Material created by Chuck Zelek, John Brewer and Nadejda Victor (NETL), Frances Wood (On Location, Inc), and Randall Jackson (WVU).

For more information…

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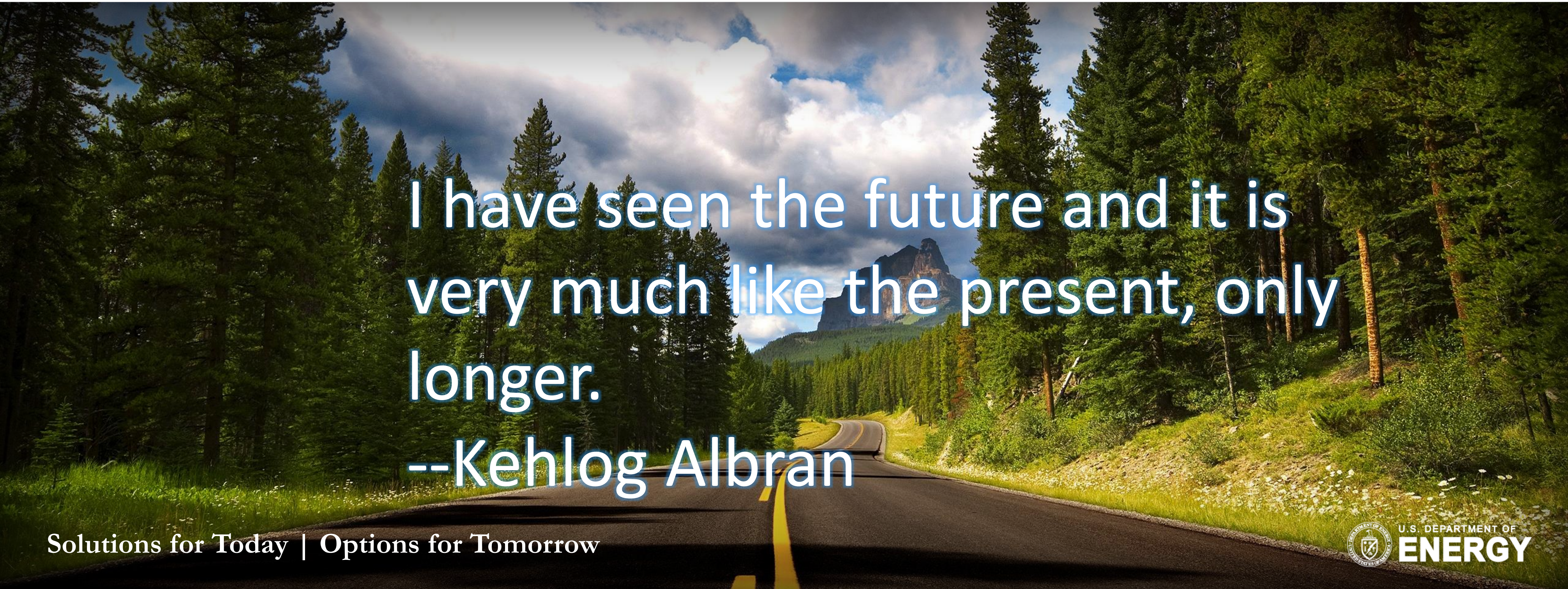

I have seen the future and it is very much like the present, only longer.

--Kehlog Albran

Additional Material

Staff Electricity Subcommittee