Fall 4-12-2016

The value of CO2-geothermal bulk energy storage to CO2

Jonathan Ogland-Hand
The Ohio State University, ogland-hand.1@osu.edu

Jeffrey Bielicki
The Ohio State University

Thomas Buscheck
LLNL

The Value of CO_2-Geothermal Bulk Energy Storage for Reducing CO_2 Emissions

Jonathan D. Ogland-Hand

CO_2 Summit II: Technologies and Opportunities

April 10-14, 2016

The Ohio State University

Energy Sustainability Research Laboratory

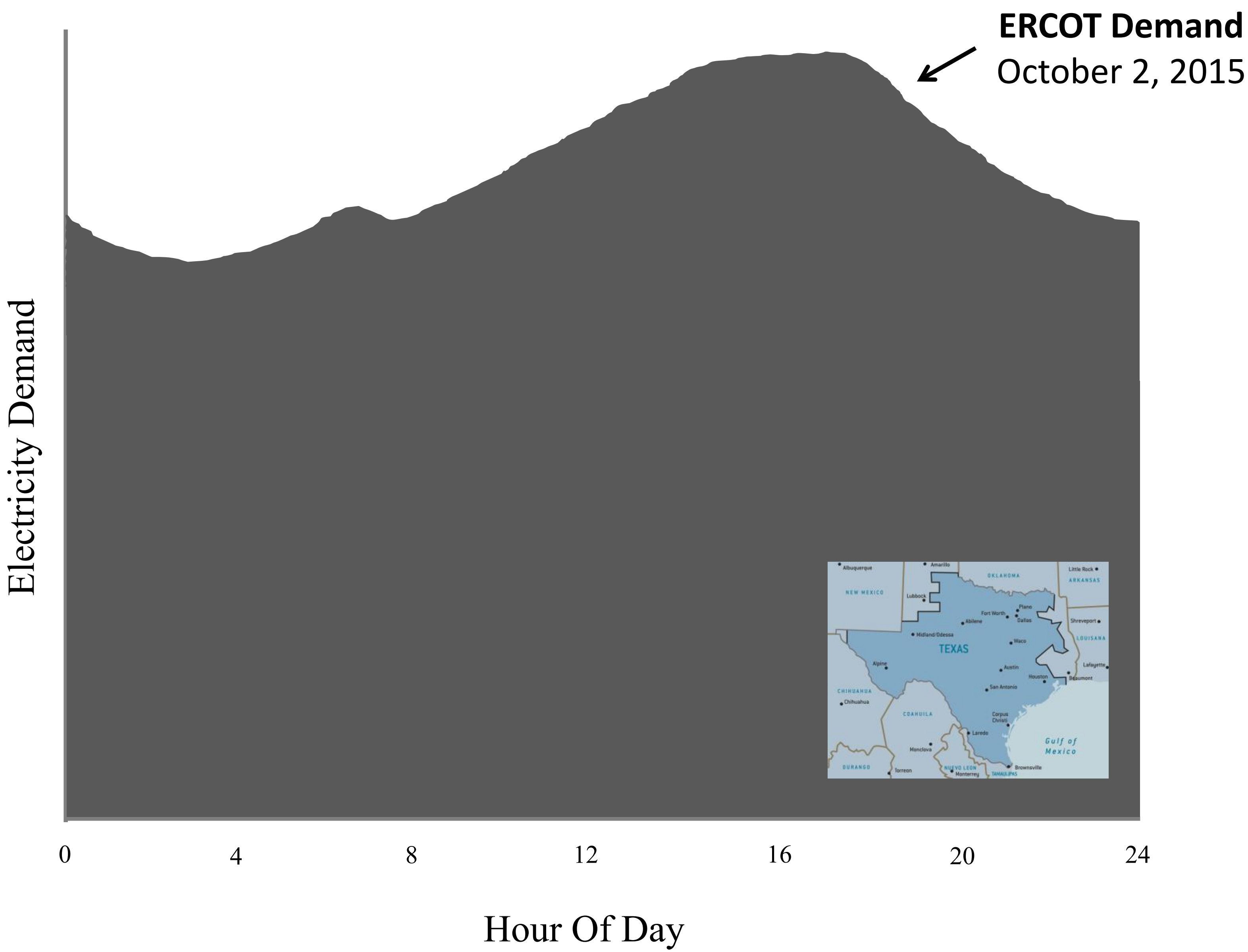
Mentors

Jeffrey M. Bielicki, Ph.D.
Civil, Environmental, and Geodetic Engineering and The John Glenn College of Public Affairs
The Ohio State University
bielicki.2@osu.edu

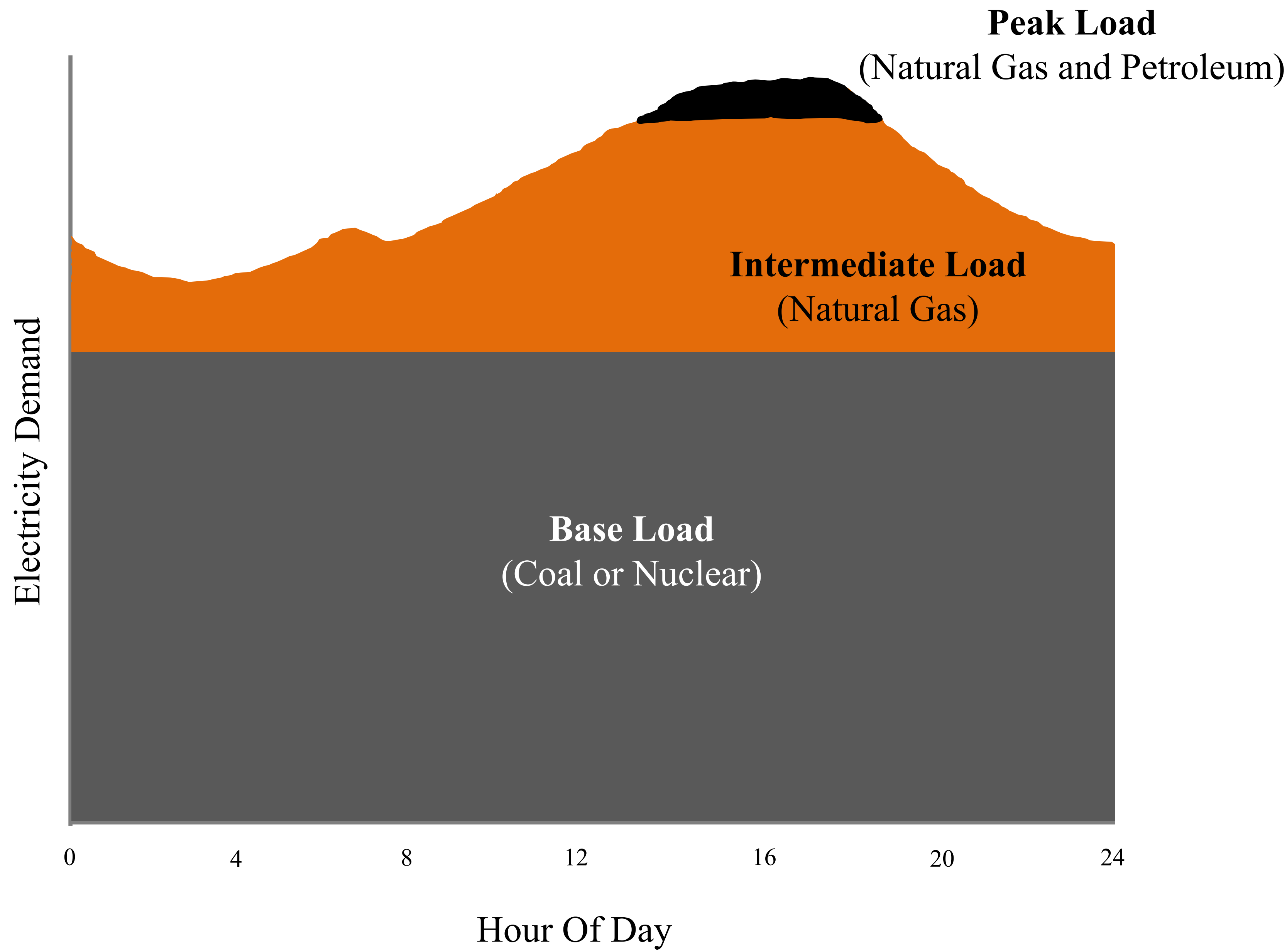
Thomas A. Buscheck, Ph.D.
Atmospheric, Earth, and Energy Division
Lawrence Livermore National Laboratory
buscheck1@llnl.gov

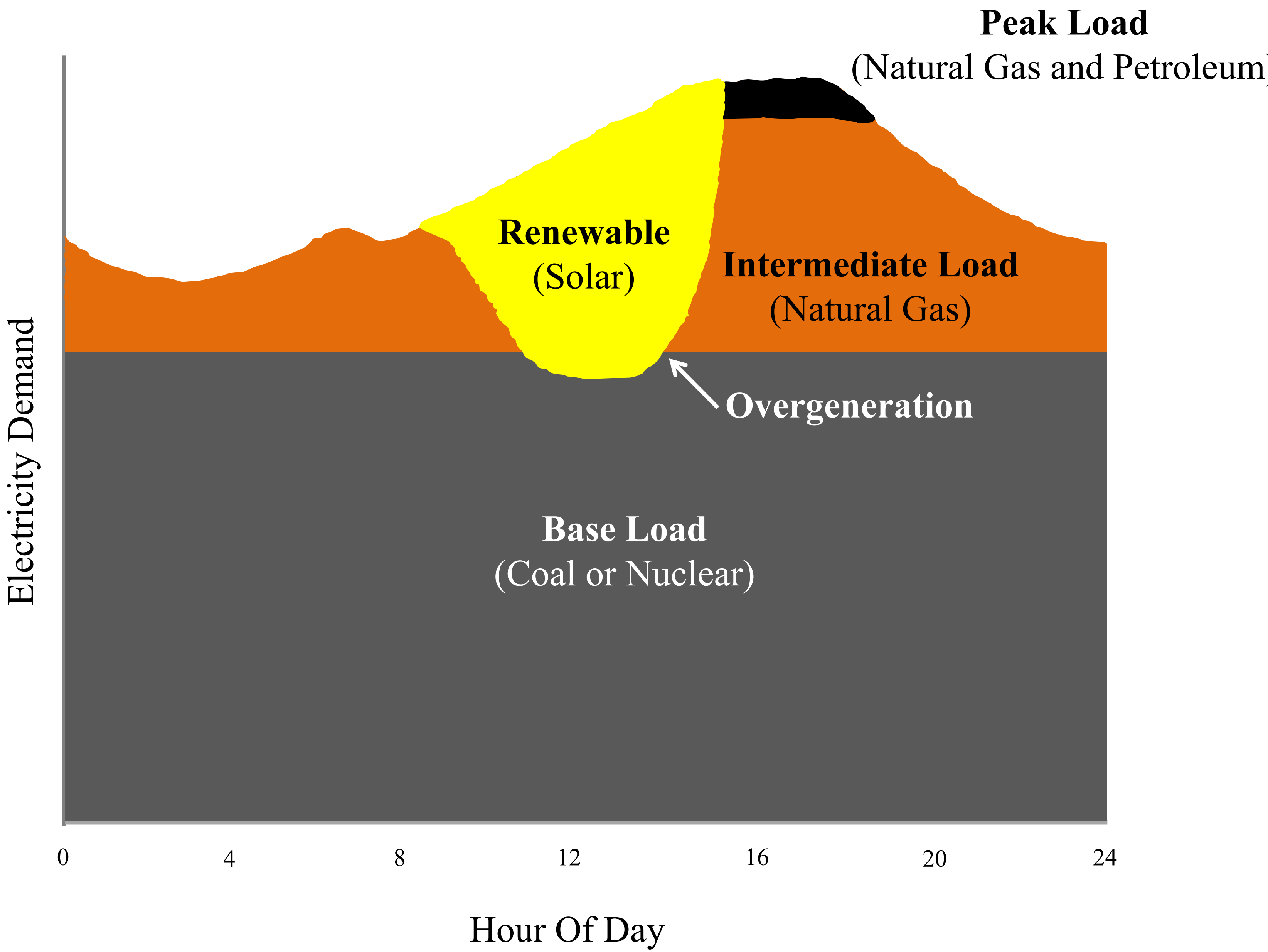
Sustainable Energy Pathways program (grant 1230691)

Two Primary Challenges



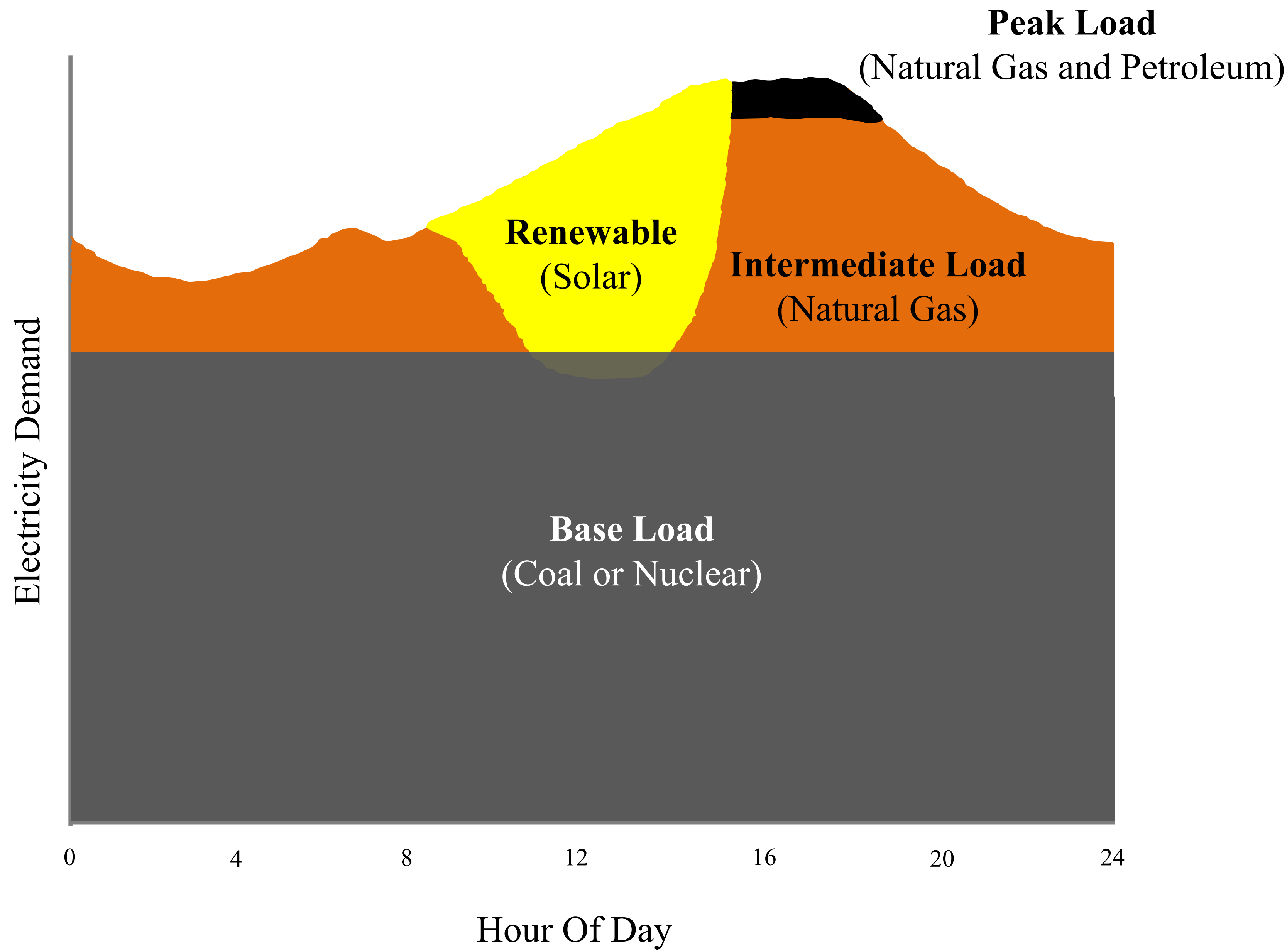
ERCOT Demand
October 2, 2015
Electricity Demand
0
4
8
12
16
20
24
Hour Of Day
TEXAS


Peak Load
(Natural Gas and Petroleum)
Intermediate Load
(Natural Gas)
Base Load
(Coal or Nuclear)
Electricity Demand
0
4
8
12
16
20
24
Hour Of Day



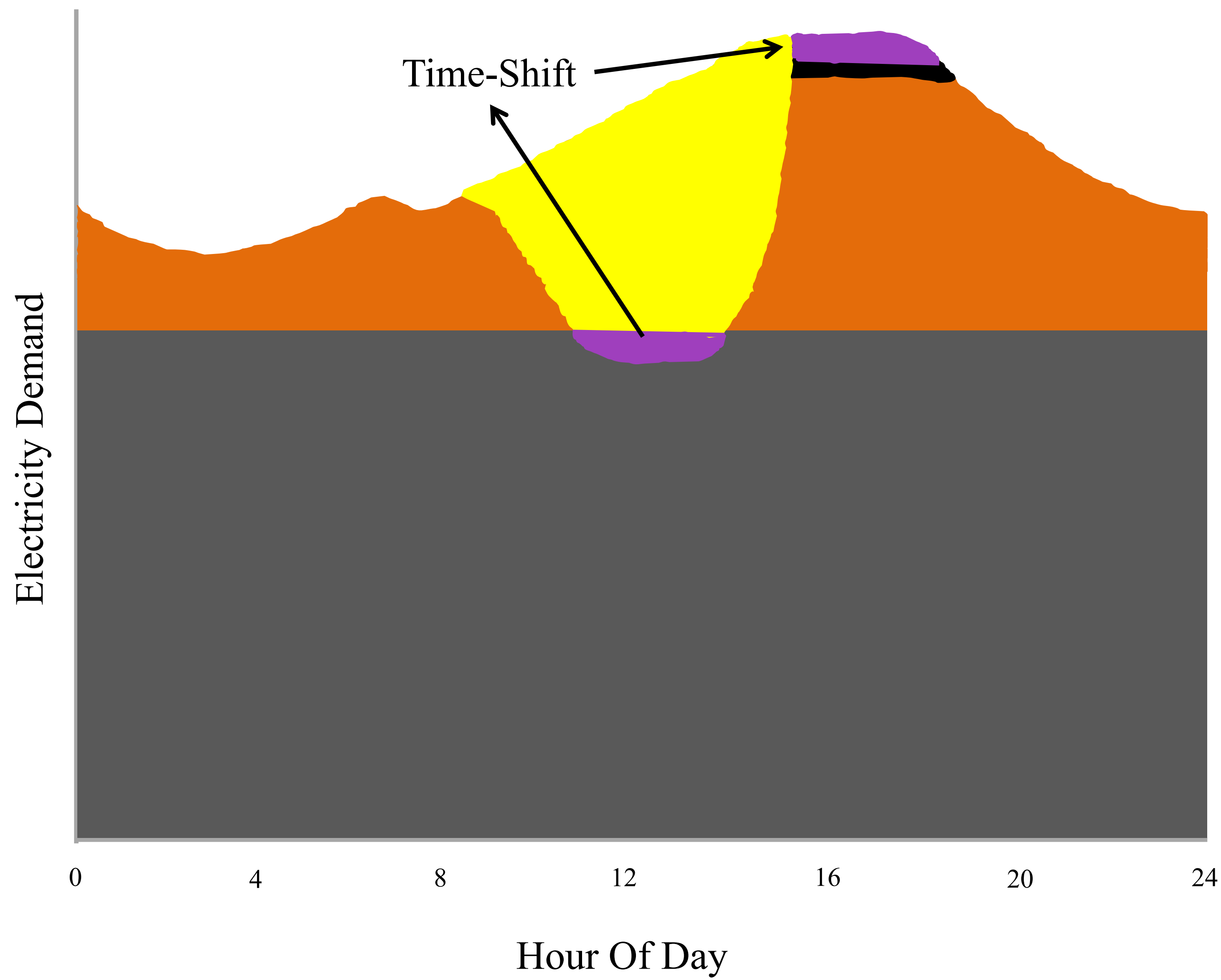
THE OHIO STATE UNIVERSITY

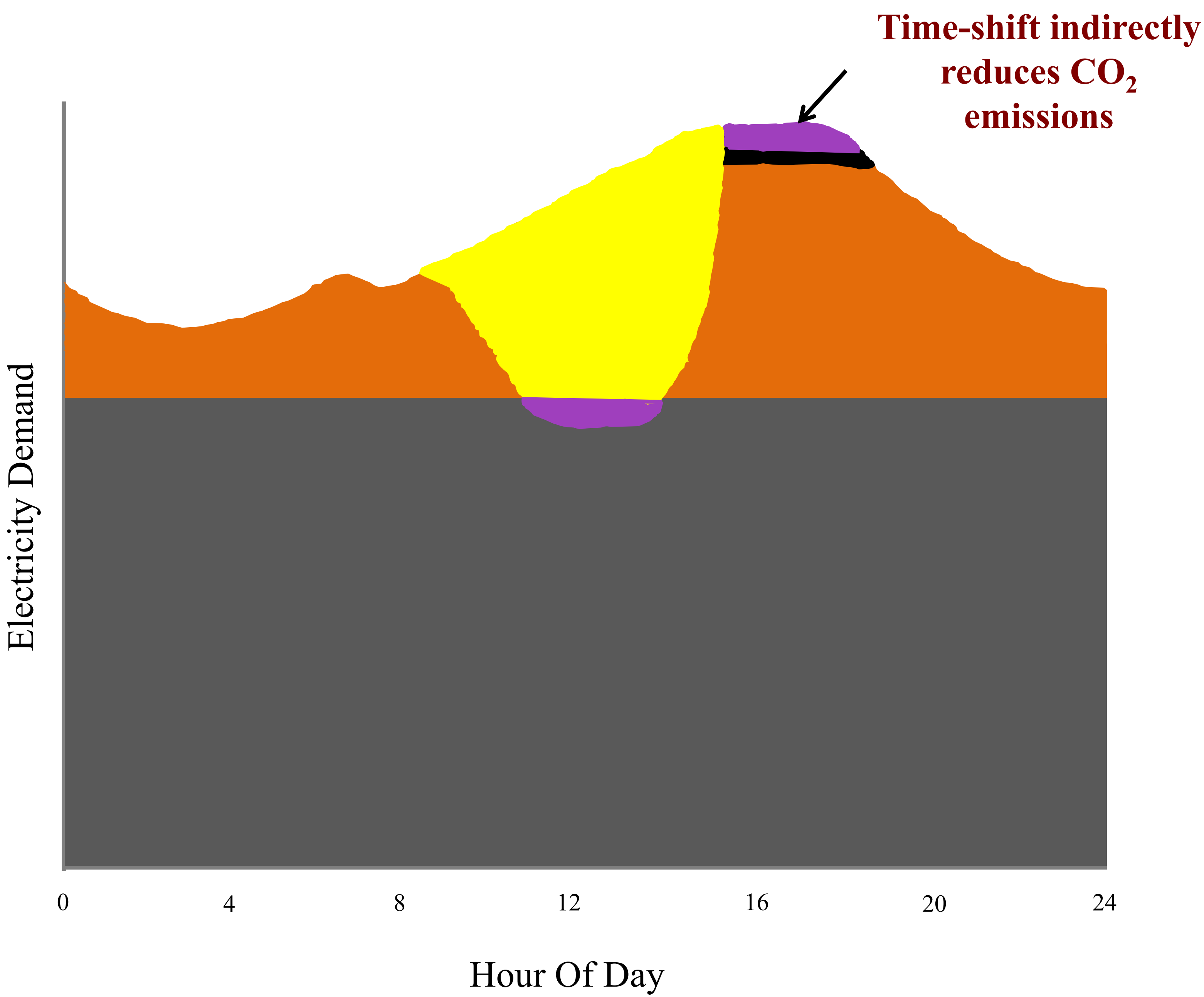
Energy Sustainability Research Laboratory



THE OHIO STATE UNIVERSITY

Energy Sustainability Research Laboratory

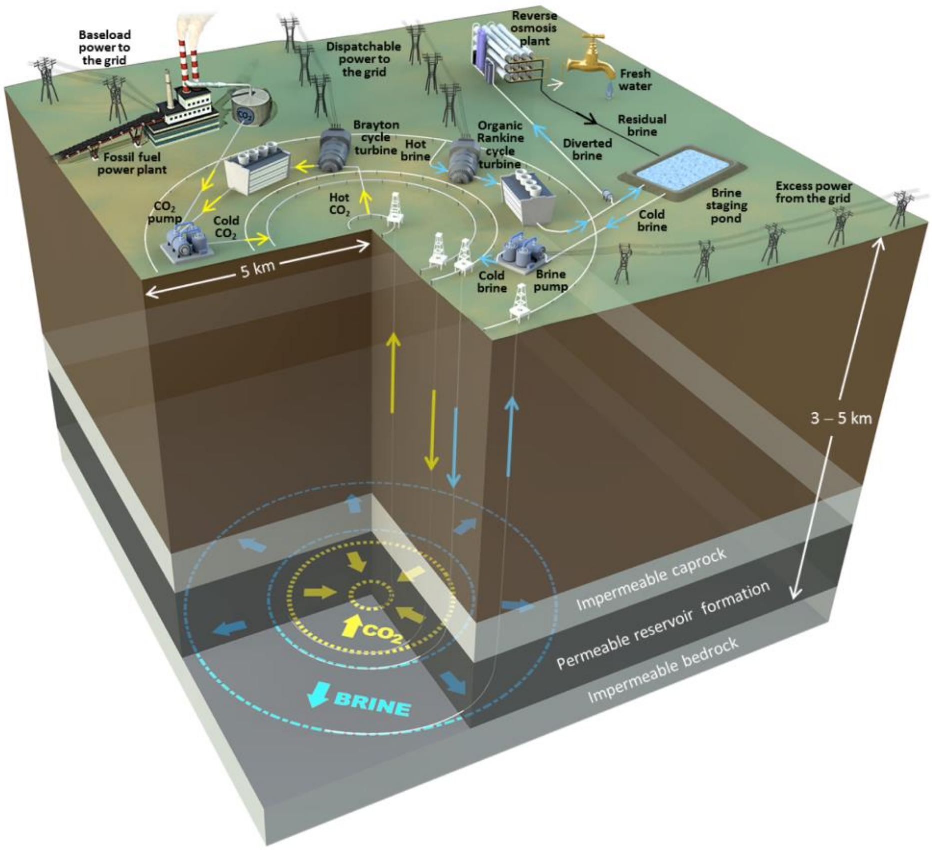

Time-Shift
Electricity Demand
0
4
8
12
16
20
24
Hour Of Day


Time-shift indirectly reduces CO_2 emissions
Electricity Demand
0
4
8
12
16
20
24
Hour Of Day

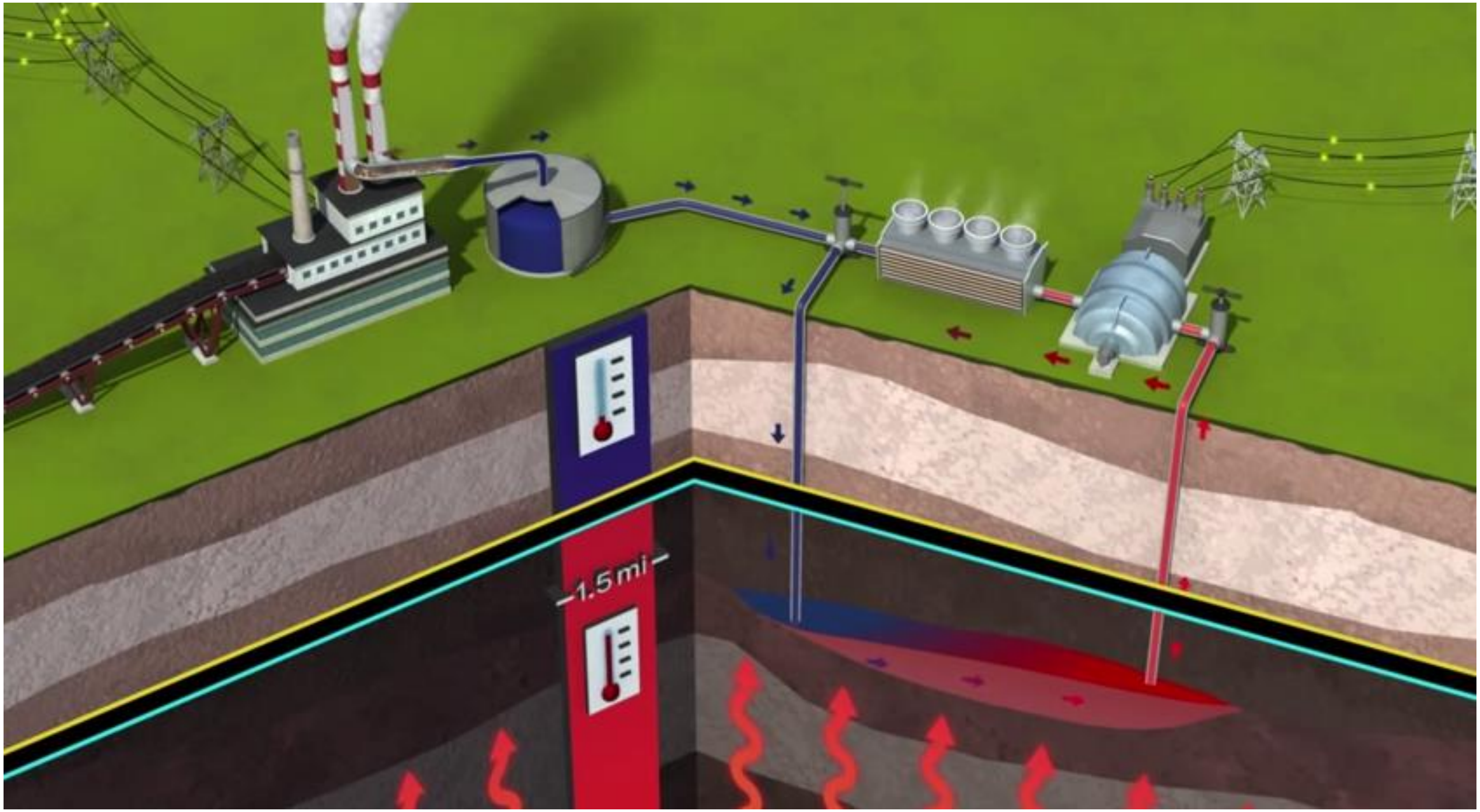
Earth Battery

CO_2-Geothermal Bulk Energy Storage

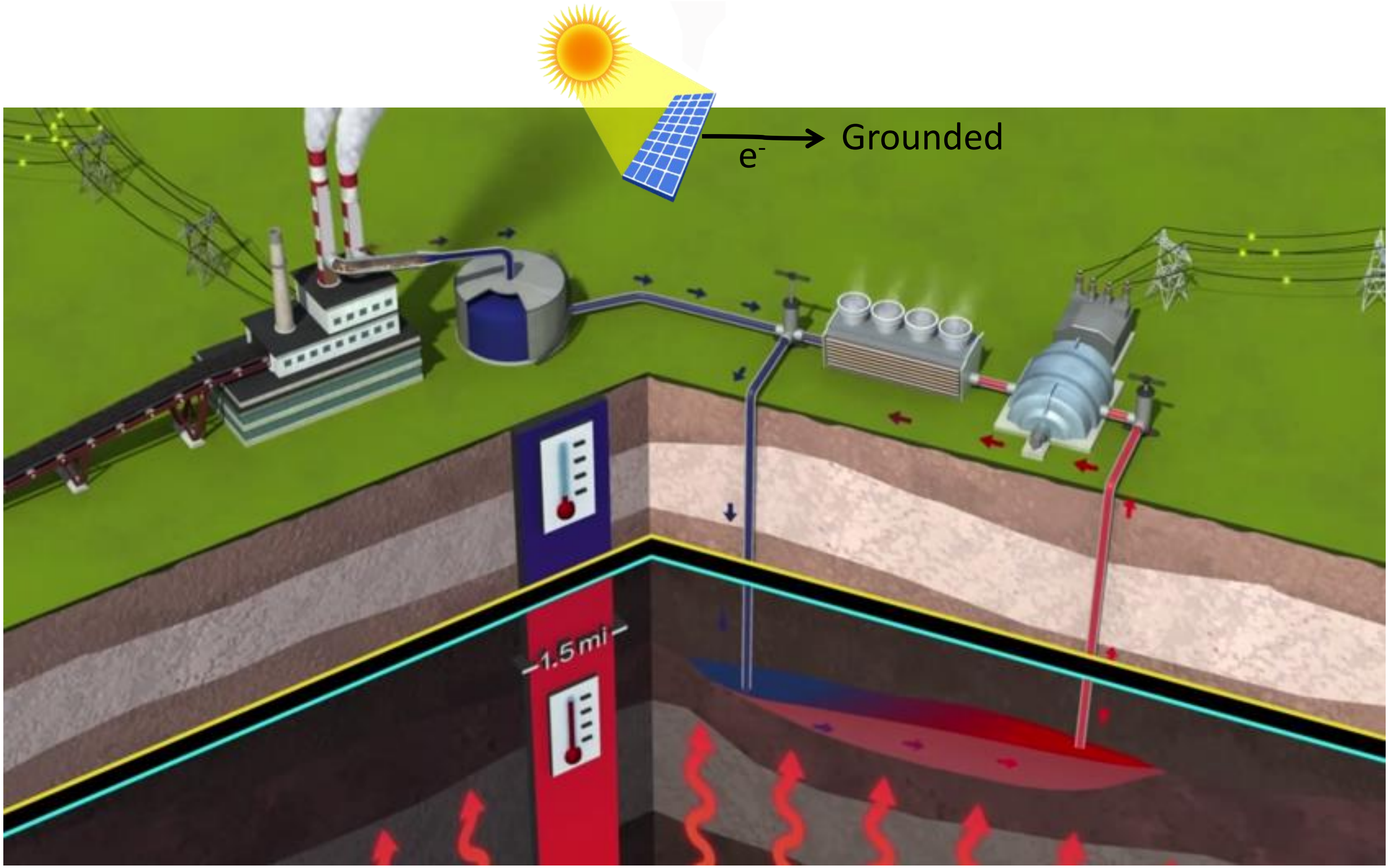
(CO_2-BES)



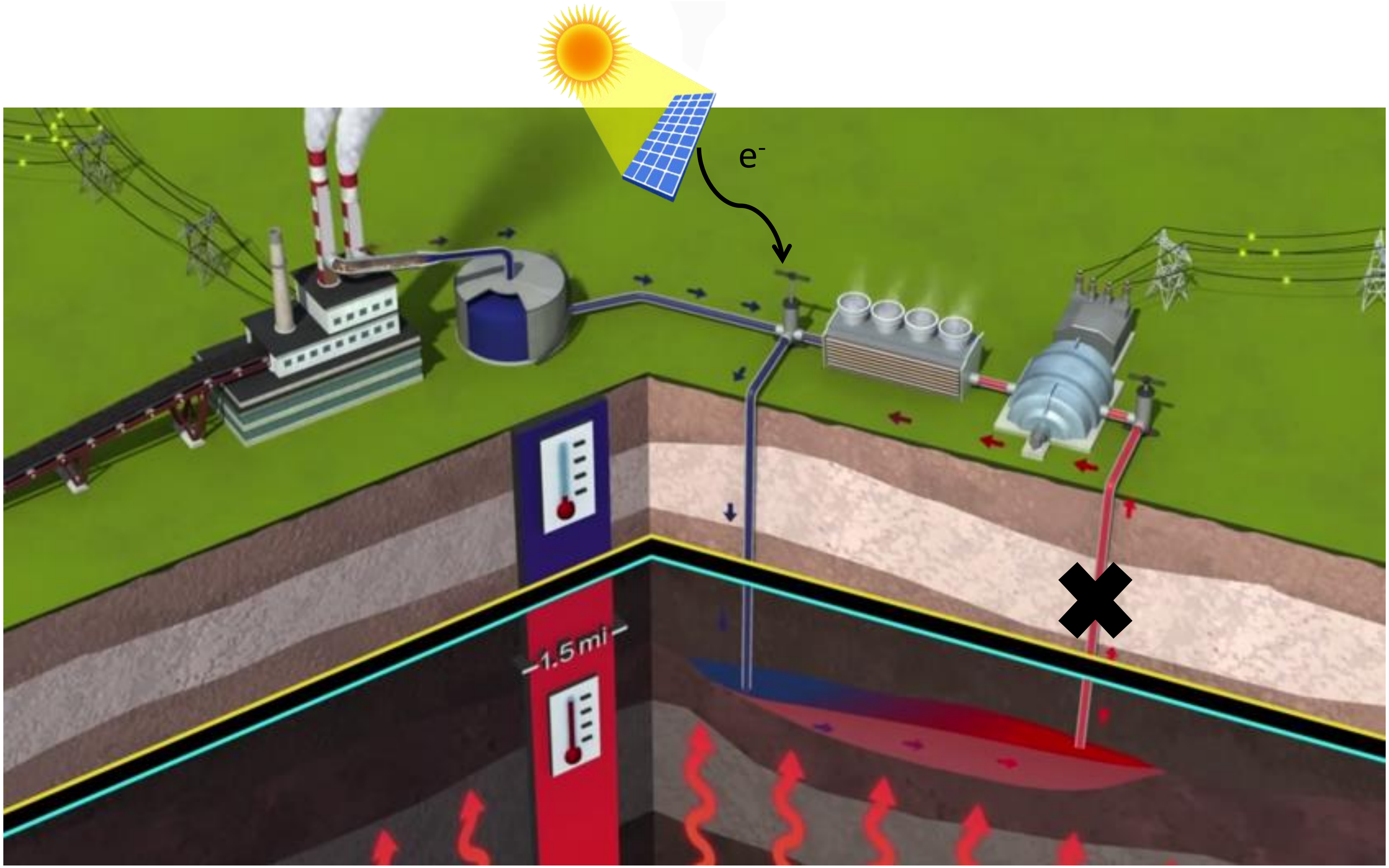
Buscheck, T.A. et al., 2016. Multi-Fluid Geo-Energy Systems: Using Geologic CO_2 Storage for Geothermal Energy Production and Grid-Scale Energy Storage in Sedimentary Basins. *Geospheres*



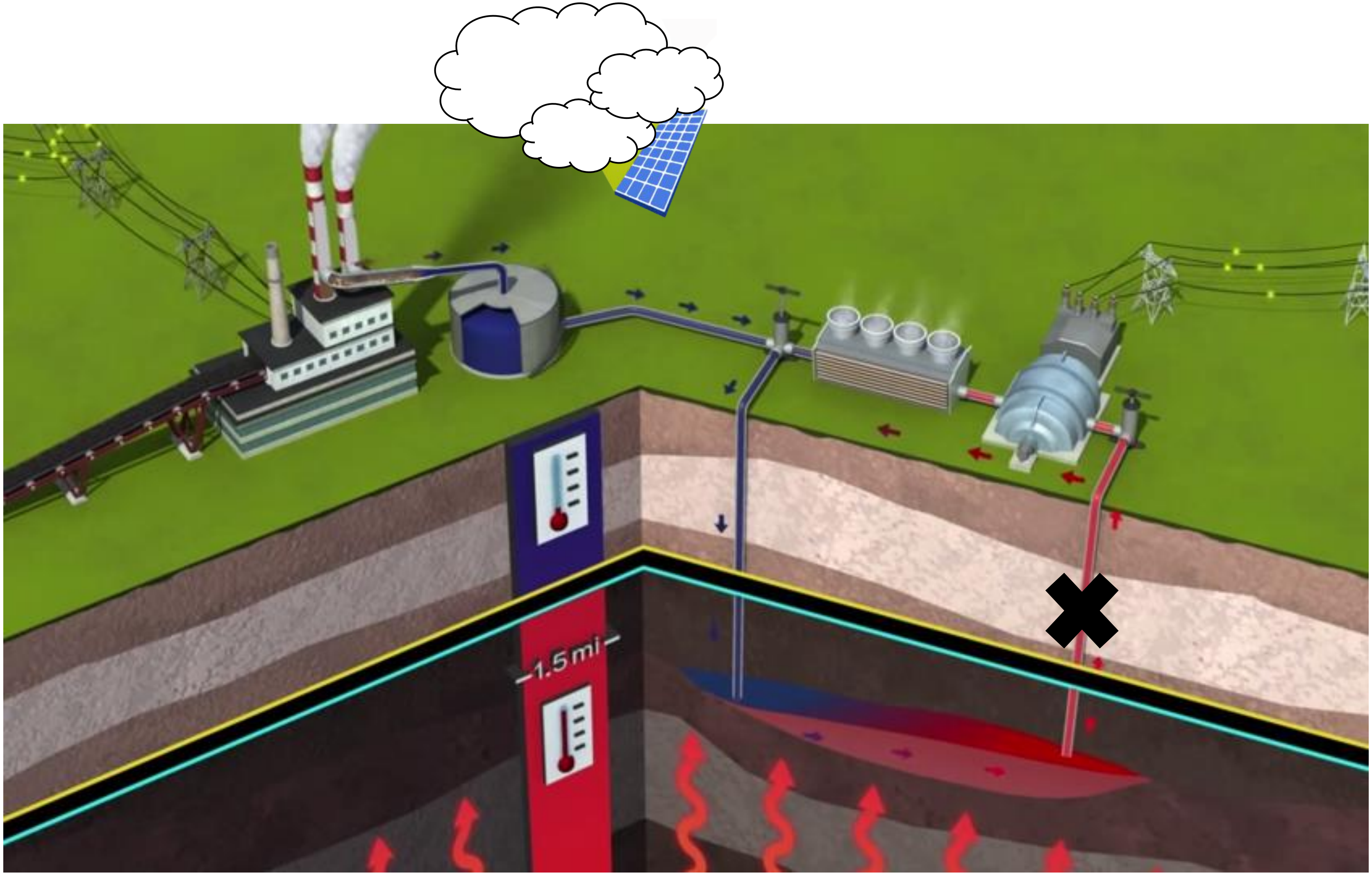
www.energypathways.org



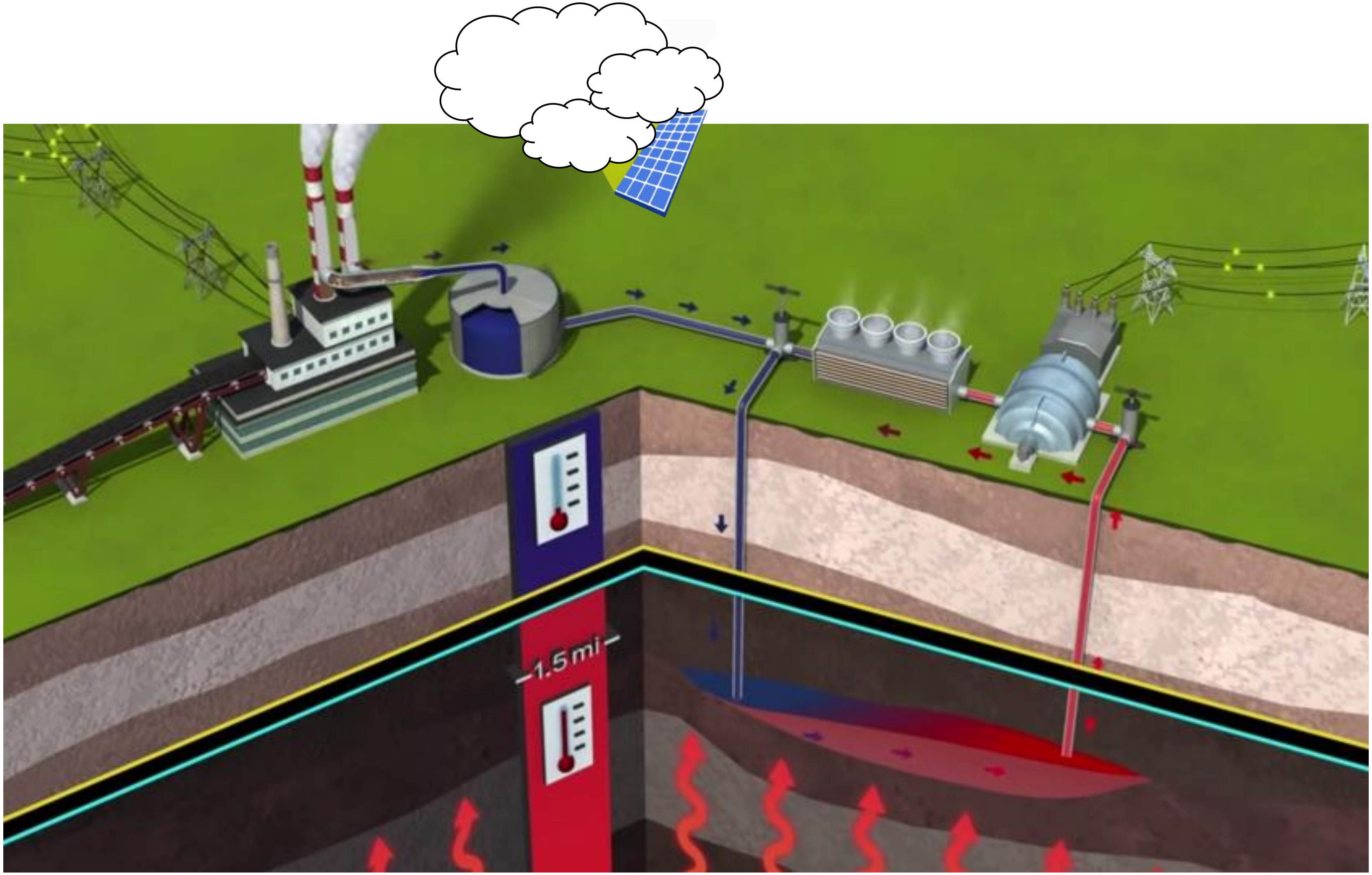
www.energypathways.org



www.energypathways.org



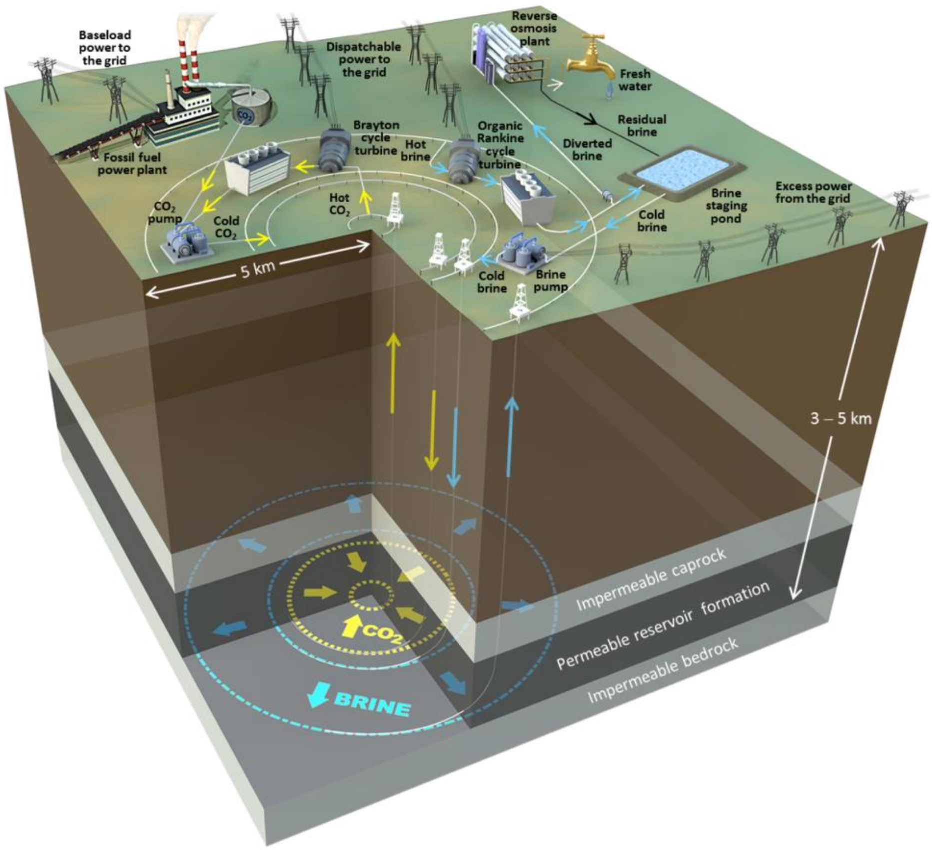
www.energypathways.org



www.energypathways.org

Earth Battery

CO_2-BES



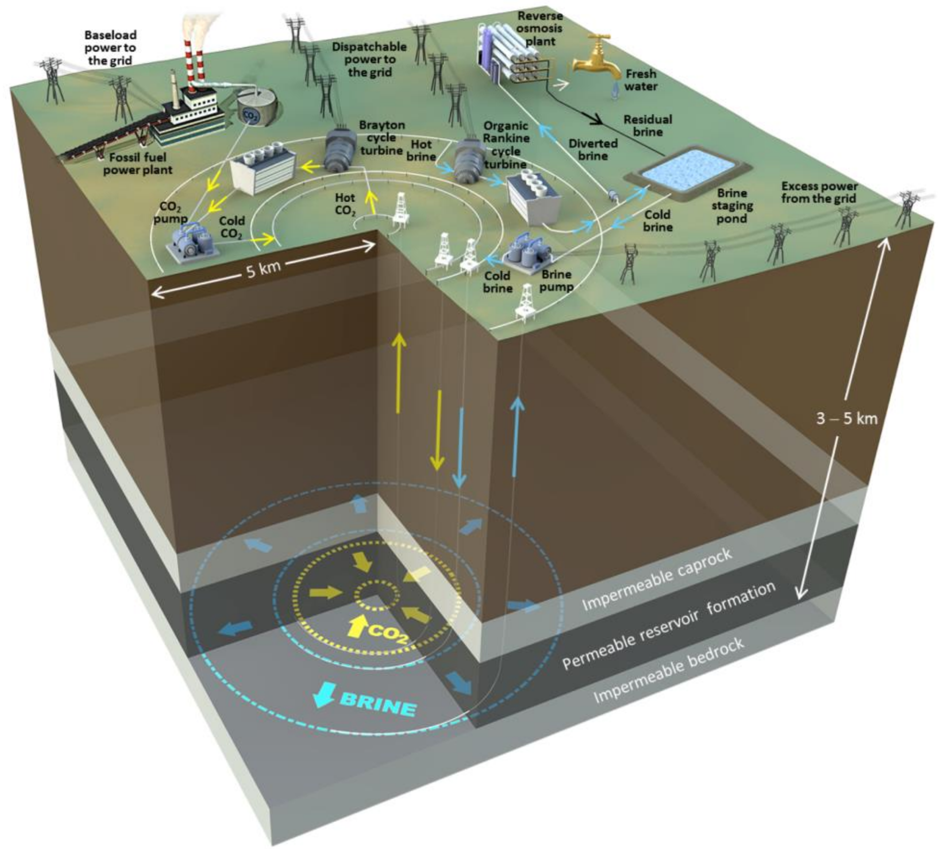
Earth Battery

CO_2-BES

<u>This Evening</u>

Using geologic CO_2 storage for enhanced geothermal energy and water recovery and energy storage

Time: 17:25-17:50



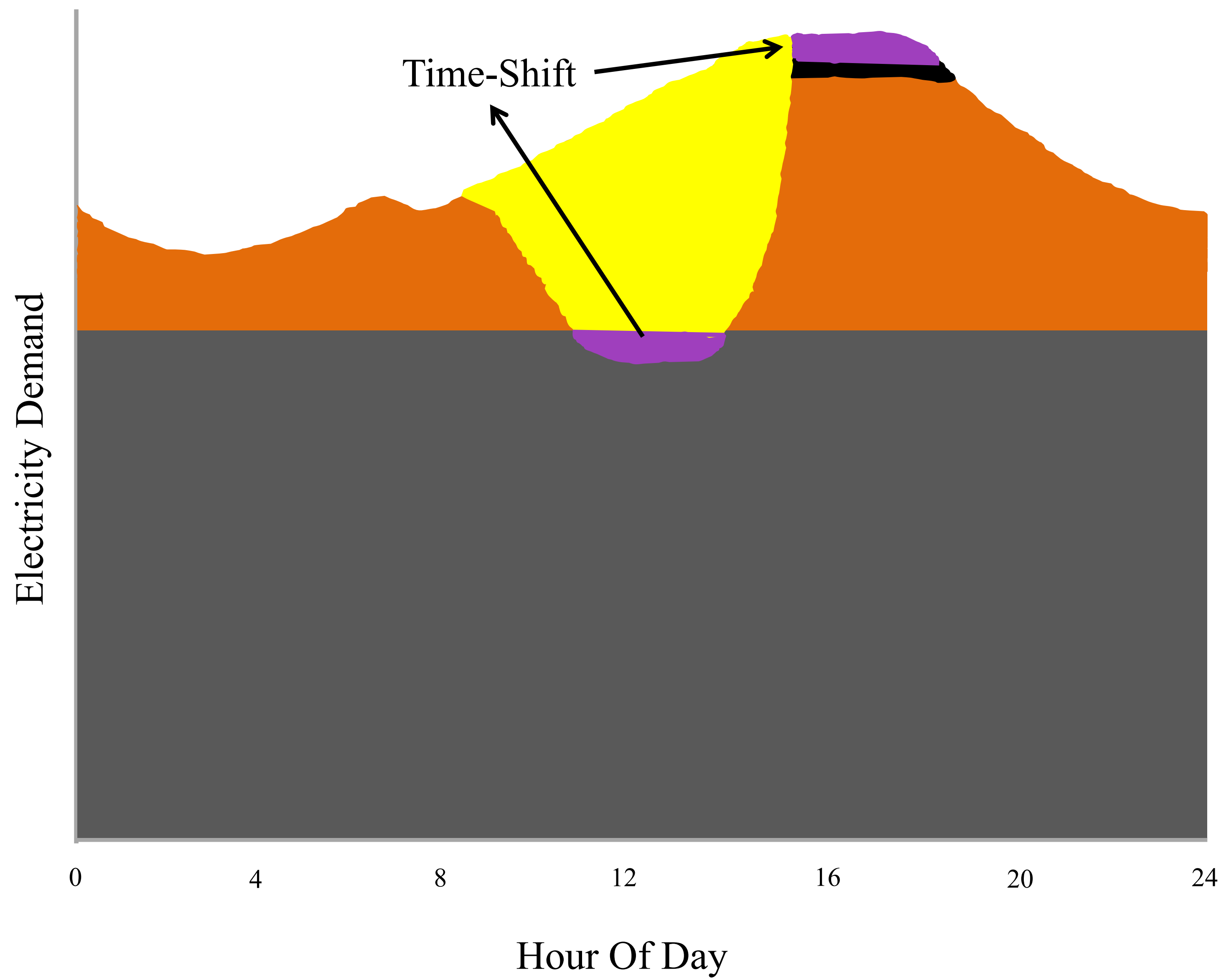
What is the Value?

Indirect CO_2 Emissions Reductions
(time-shift)

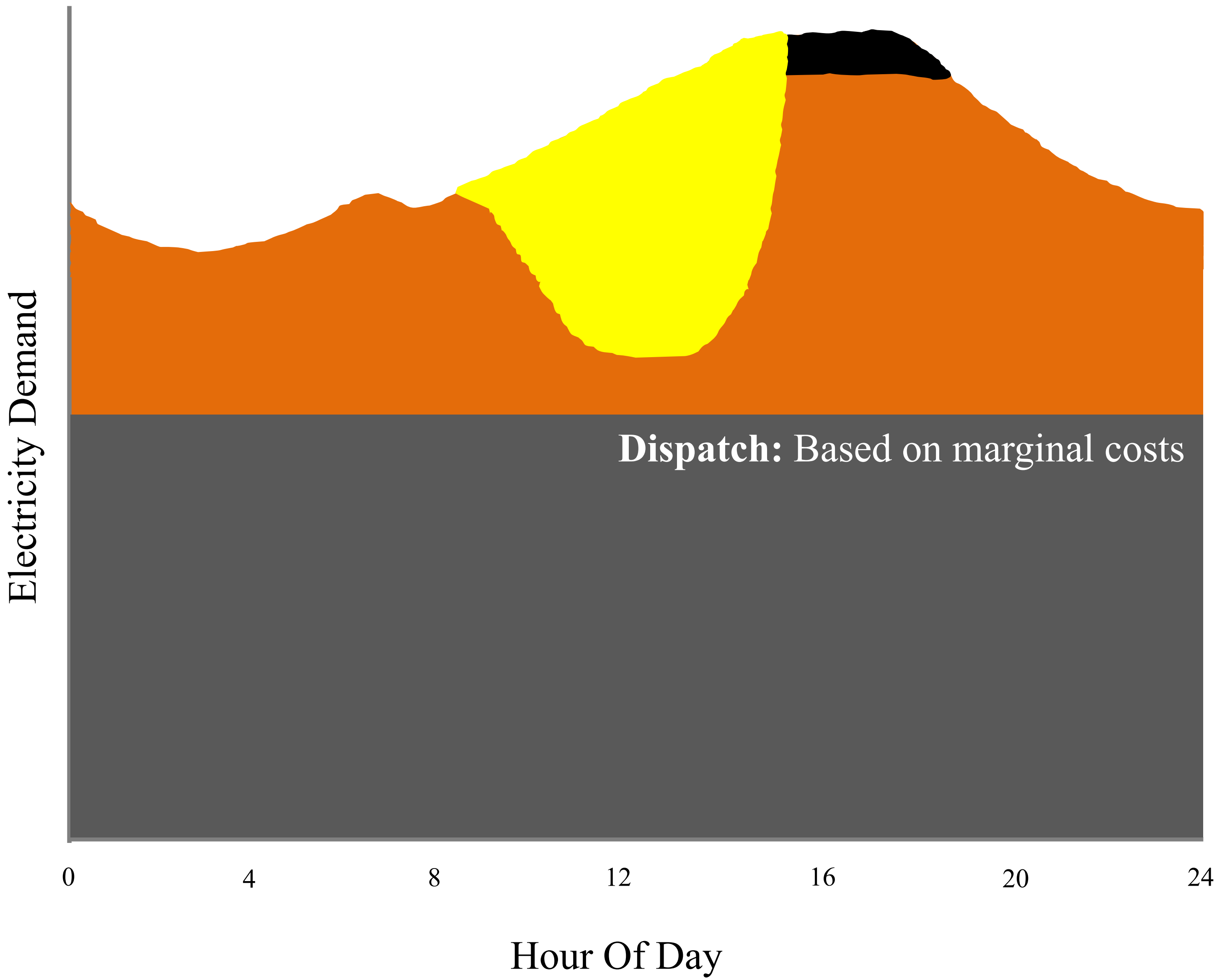
Direct CO_2 Emissions Reductions
(CO_2 sequestration)

What is the value of CO_2-BES for reducing CO_2 emissions?

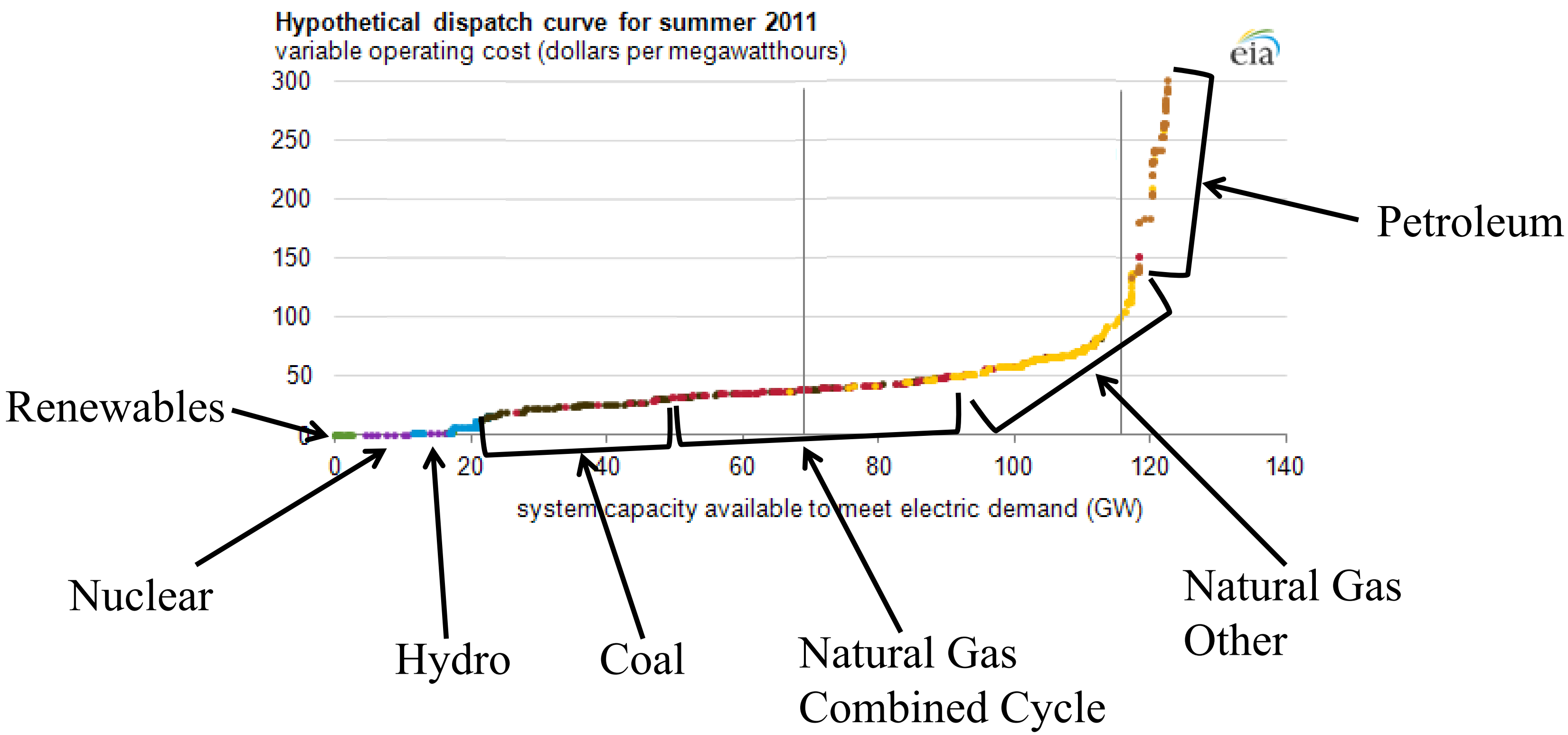
$$\text{Value}\left[\frac{\$}{\text{MWh}}\right] = \frac{\text{Monetary Value of } CO_2 \text{ Emission Reductions}}{\text{Energy Storage Capacity}}$$



Time-Shift
Electricity Demand
0
4
8
12
16
20
24
Hour Of Day



Electricity Demand
Dispatch: Based on marginal costs
0
4
8
12
16
20
24
Hour Of Day



http://www.eia.gov/todayinenergy/images/2012.08.17/DispatchCurve.png

$$\text{Value}\left[\frac{\$}{\text{MWh}}\right] = \frac{\text{Monetary Value of } CO_2 \text{ Emission Reductions}}{\text{Energy Storage Capacity}}$$

$$\text{Value}\left[\frac{\$}{\text{MWh}}\right] = f(\text{Price of } CO_2)$$

Changes in dispatch order due to differences in CO_2 intensity

Optimization Model

Choose generation from:

1. Nuclear
2. Coal
3. Natural Gas
4. Wind
5. CO_2-BES

- Diurnal operation
- Perfect foresight

Minimize:

$$\sum_{t=0}^{T} \left(\sum_i [Q_{i,t}(V_i + \Omega * \varsigma_i)) + \frac{(1+\eta) * Q_{B,t}}{\eta}(V_B + \Omega * \varsigma_B) + X_t * \left(\frac{E * V_B}{m} + K - \Omega\right)\right)$$

$$i \in \{1,2,3,4\}$$

subject to:

$$0 \pounds Q_{1,t} \pounds \overline{Q_1}$$

$$Q_{1,t} = Q_{1,t-1}$$

$$M_k \pounds Q_{k,t} \pounds \overline{Q_k}$$

$$k \hat{\text{I}} \ \{2,3\}$$

$$Q_{k,t} \ ^3 \ Q_{k,t-1} - R_k$$

$$Q_{k,t} \pounds Q_{k,t-1} + R_k$$

$$0 \pounds Q_{4,t} \pounds W_t$$

$$C_t = C_{t-1} + \sum_i [Q_{i,t}] - \left(D_t + \frac{X_t * E}{m}\right)$$

$$Q_{B,t} \pounds h \cdot C_{t-1}$$

$$D_t + \frac{X_t * E}{m} \leq \sum_i [Q_{i,t}] + Q_{B,t}$$

$$X_t \leq Q_{2,t} * \varsigma_2 + Q_{3,t} * \varsigma_3$$

Data

Electricity System Data: ERCOT

Variable Costs: Congressional Research Service

CO_2 Emissions Factors: Environmental Protection Agency

Electricity System Component	Capacity [MWh]	Ramp Rate [MWh]	Minimum Required Generation [MWh]	Variable Cost [$/MWh]	CO_2 Emission Rate [tCO_2/MWh]
Nuclear	1,240.00	0.00	N/A	8.23	0.00
Coal	3,644.00	0.00	1,356.00	17.31	0.91
Natural Gas	5,921.00	525.00	592.00	33.27	0.45
Wind	N/A	N/A	N/A	6.67	0.00
CO_2-BES	N/A	N/A	N/A	13.69	0.00

CO_2-BES Parameters

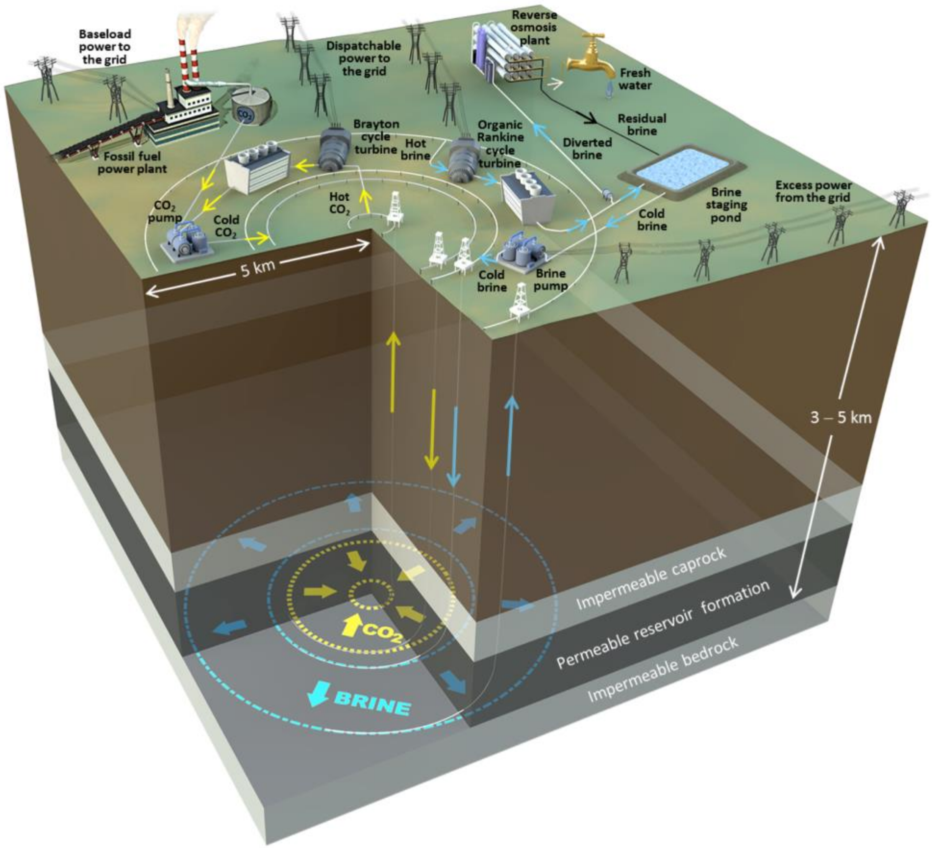
CO_2 Injection Pump Efficiency: 75%

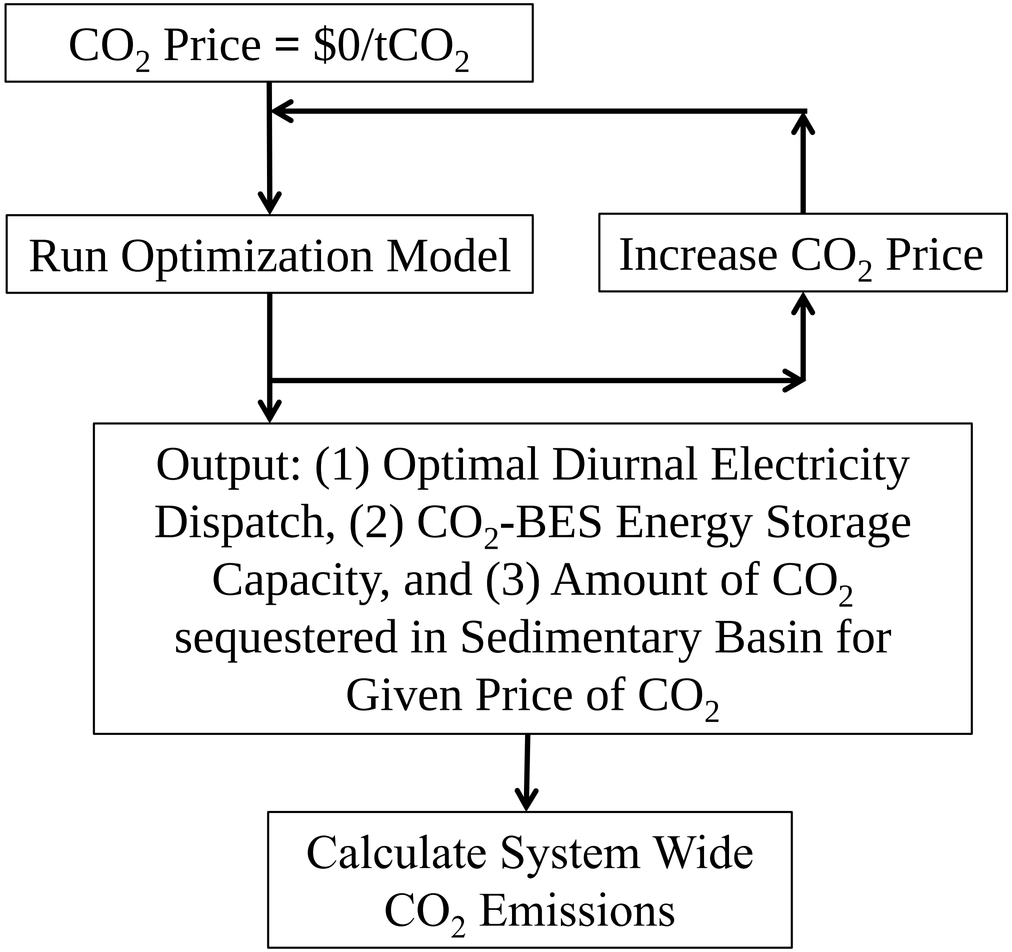
CO_2 Injection Rate: 120 kg/s

Reservoir Depth: 4 km

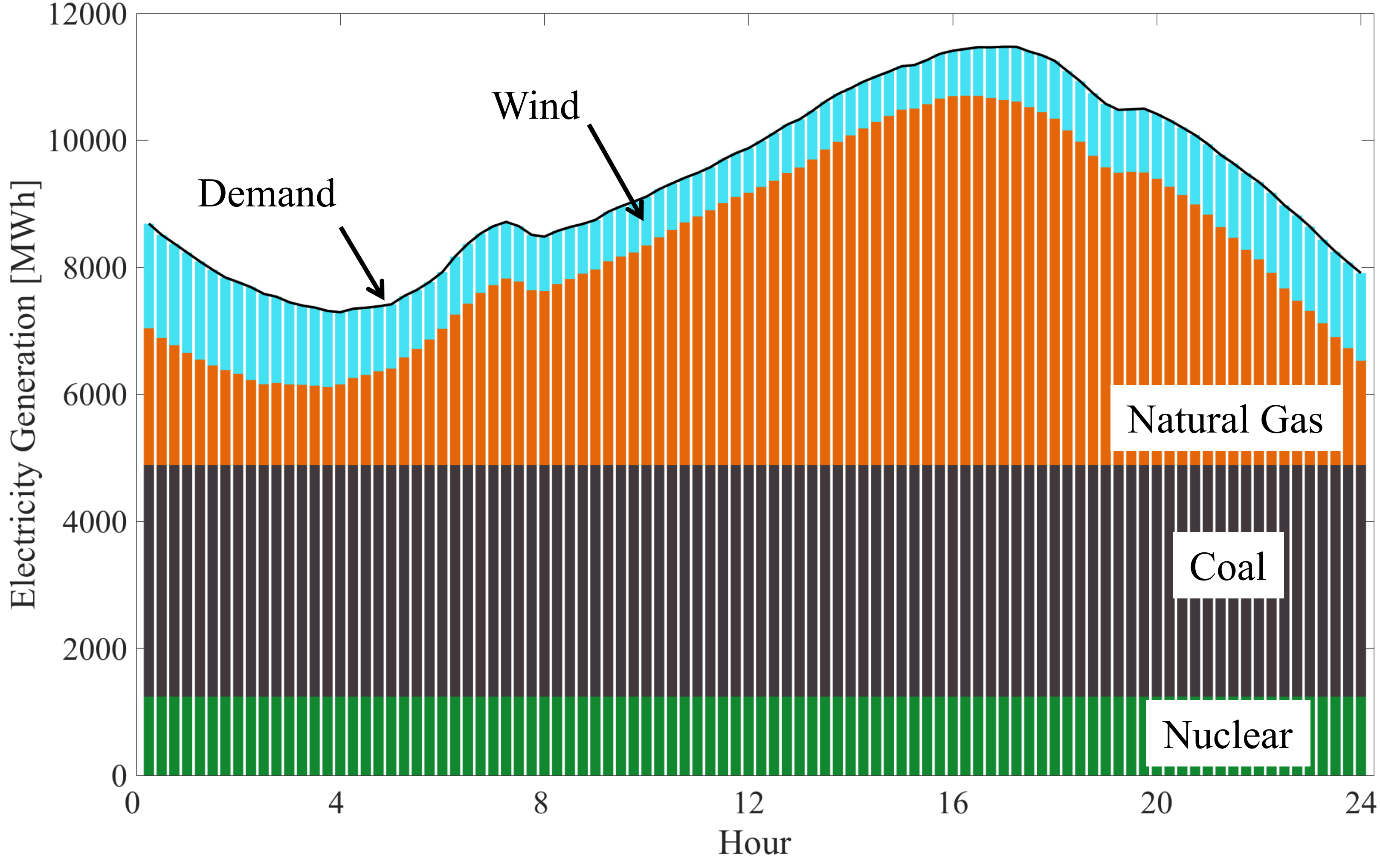
ΔP Between Production and Injection Well: 10 MPa

Cost of CO_2 Capture: $74/tCO_2$

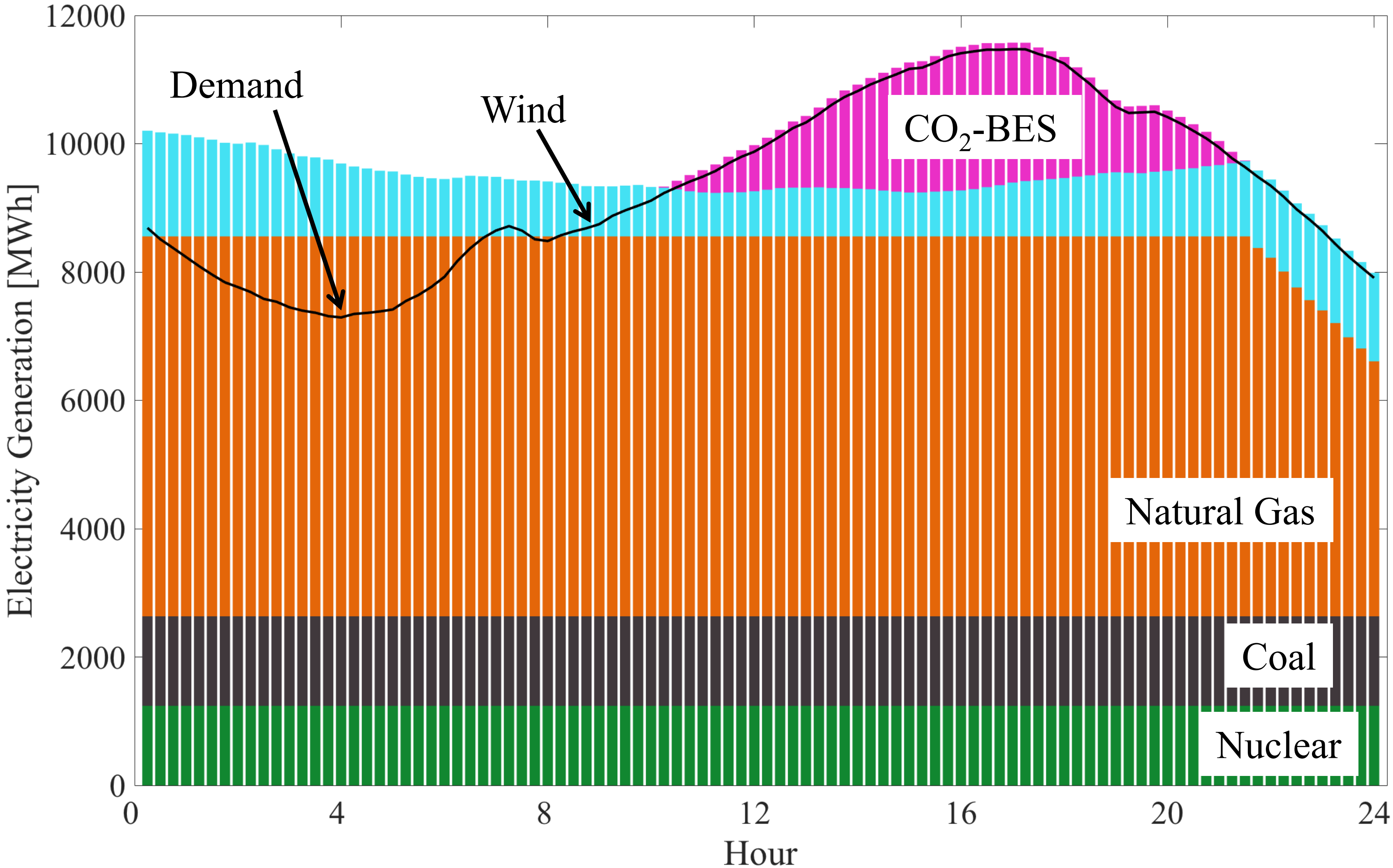


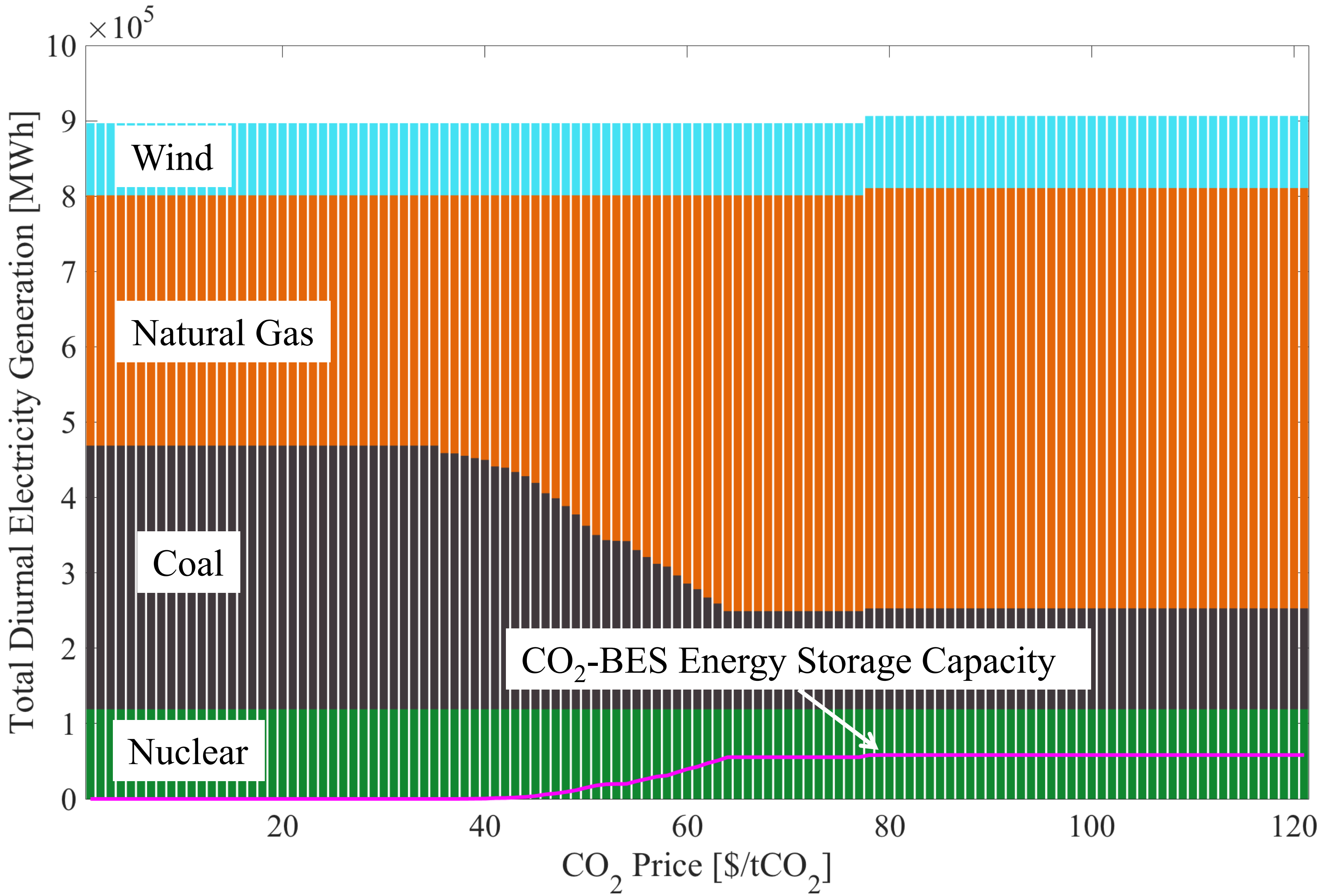

CO_2 Price = \$0/tCO_2
Run Optimization Model
Increase CO_2 Price
Output: (1) Optimal Diurnal Electricity Dispatch, (2) CO_2-BES Energy Storage Capacity, and (3) Amount of CO_2 sequestered in Sedimentary Basin for Given Price of CO_2
Calculate System Wide CO_2 Emissions

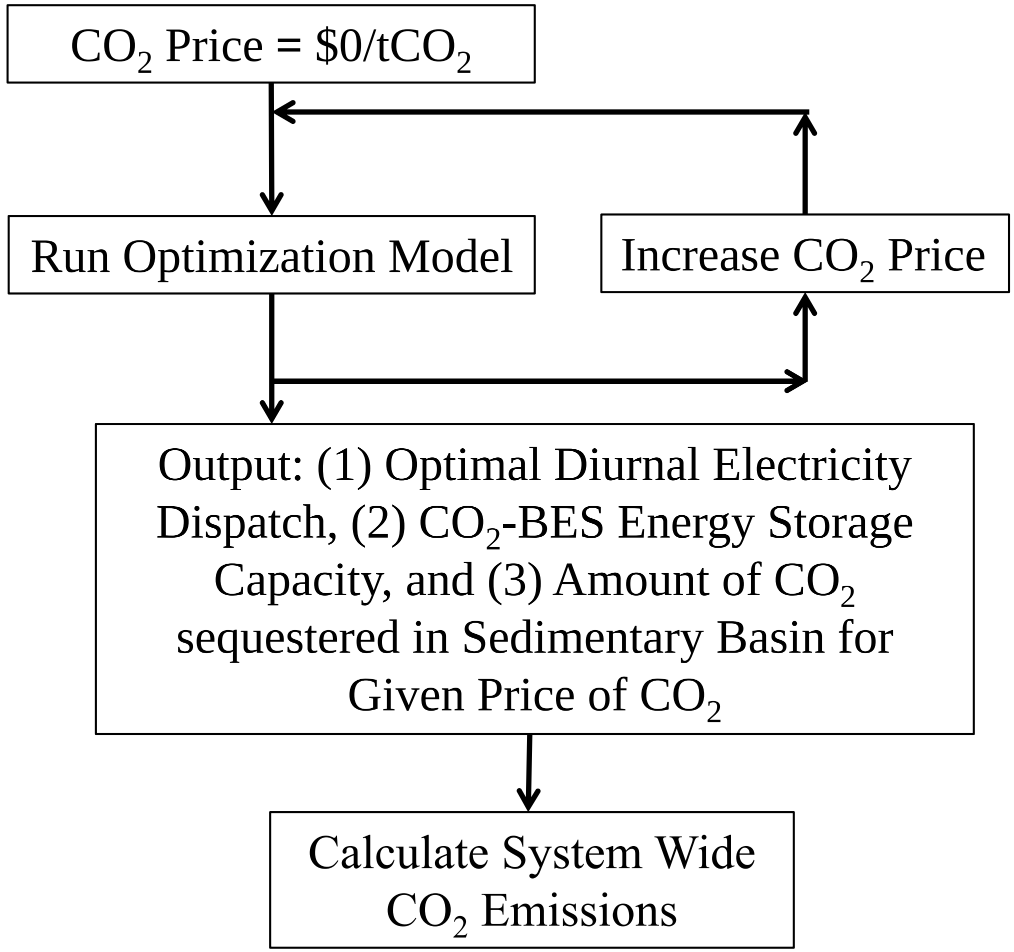
Price of CO_2 = \$0/tCO_2

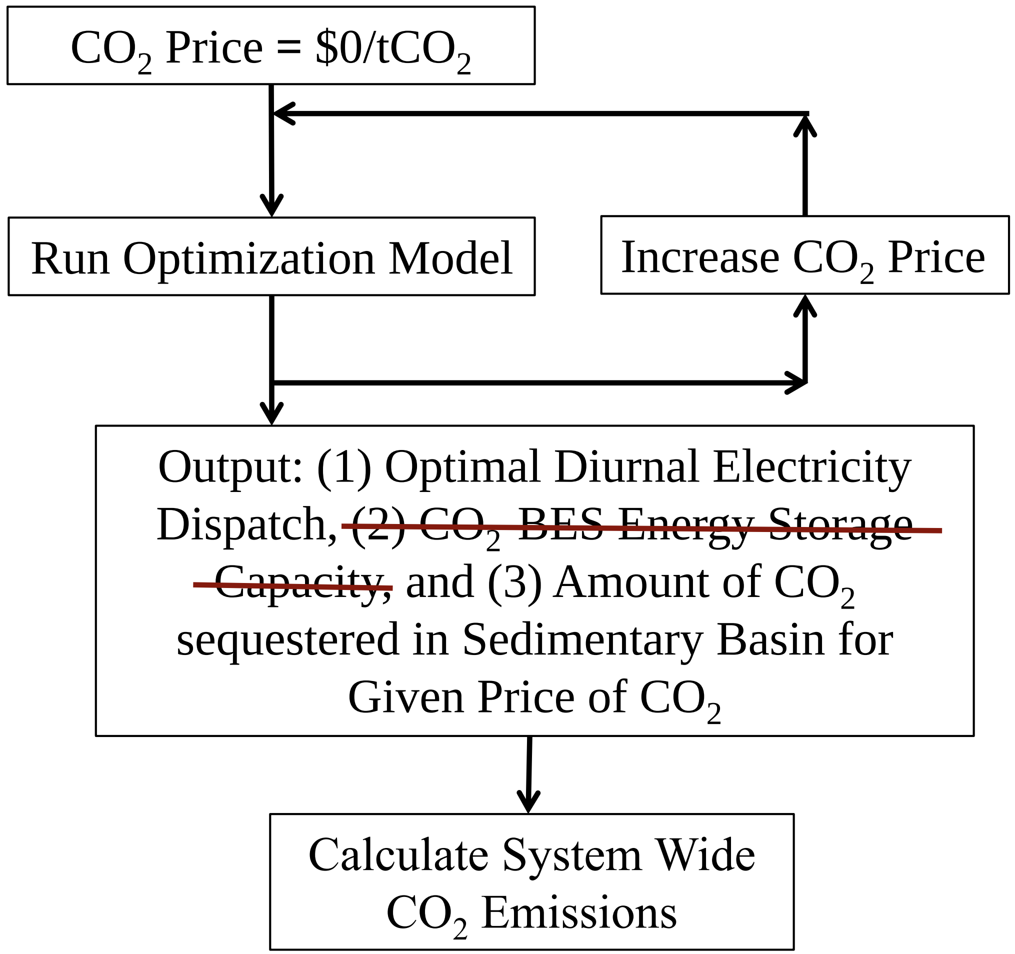


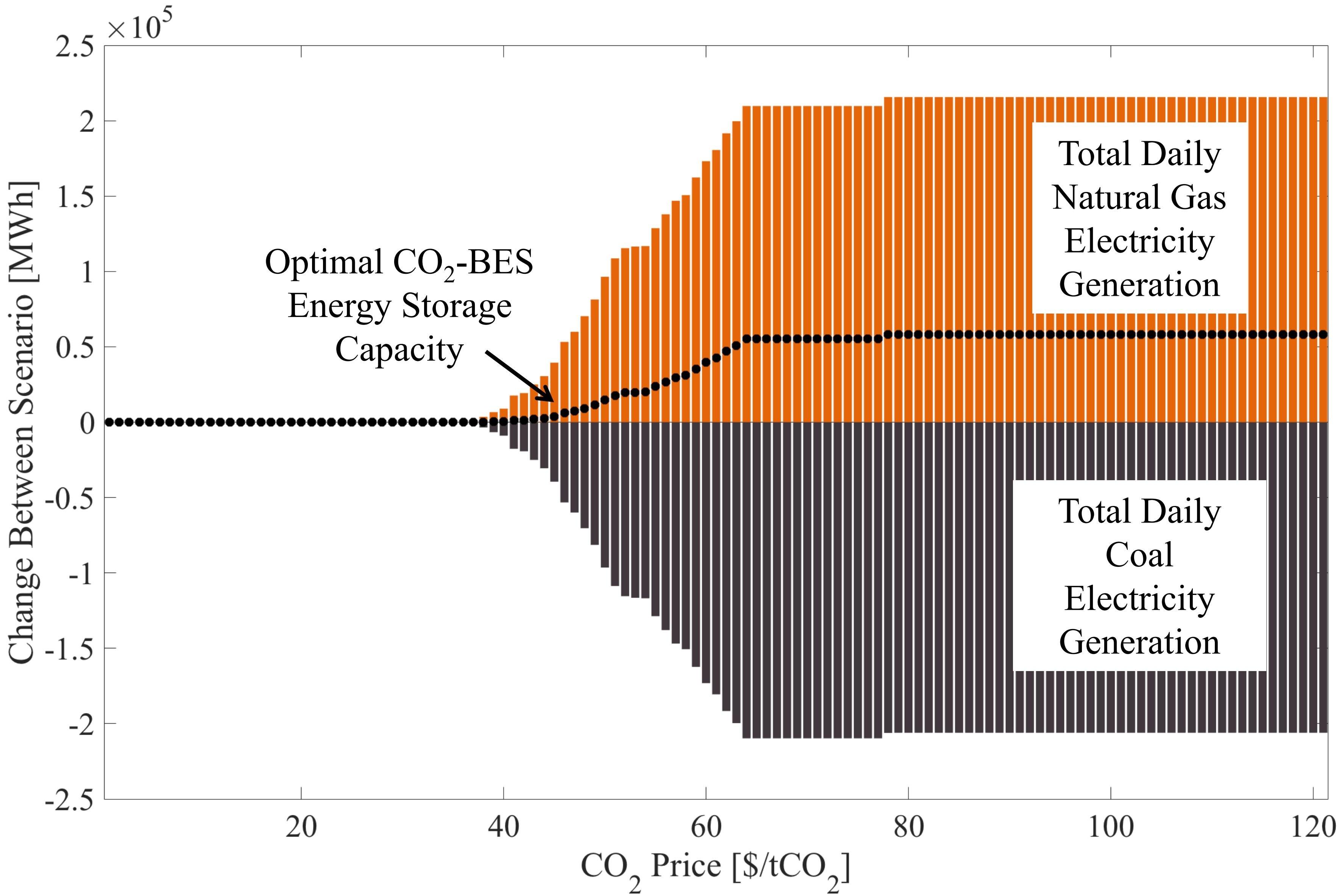
Price of CO_2 = \$120/tCO_2

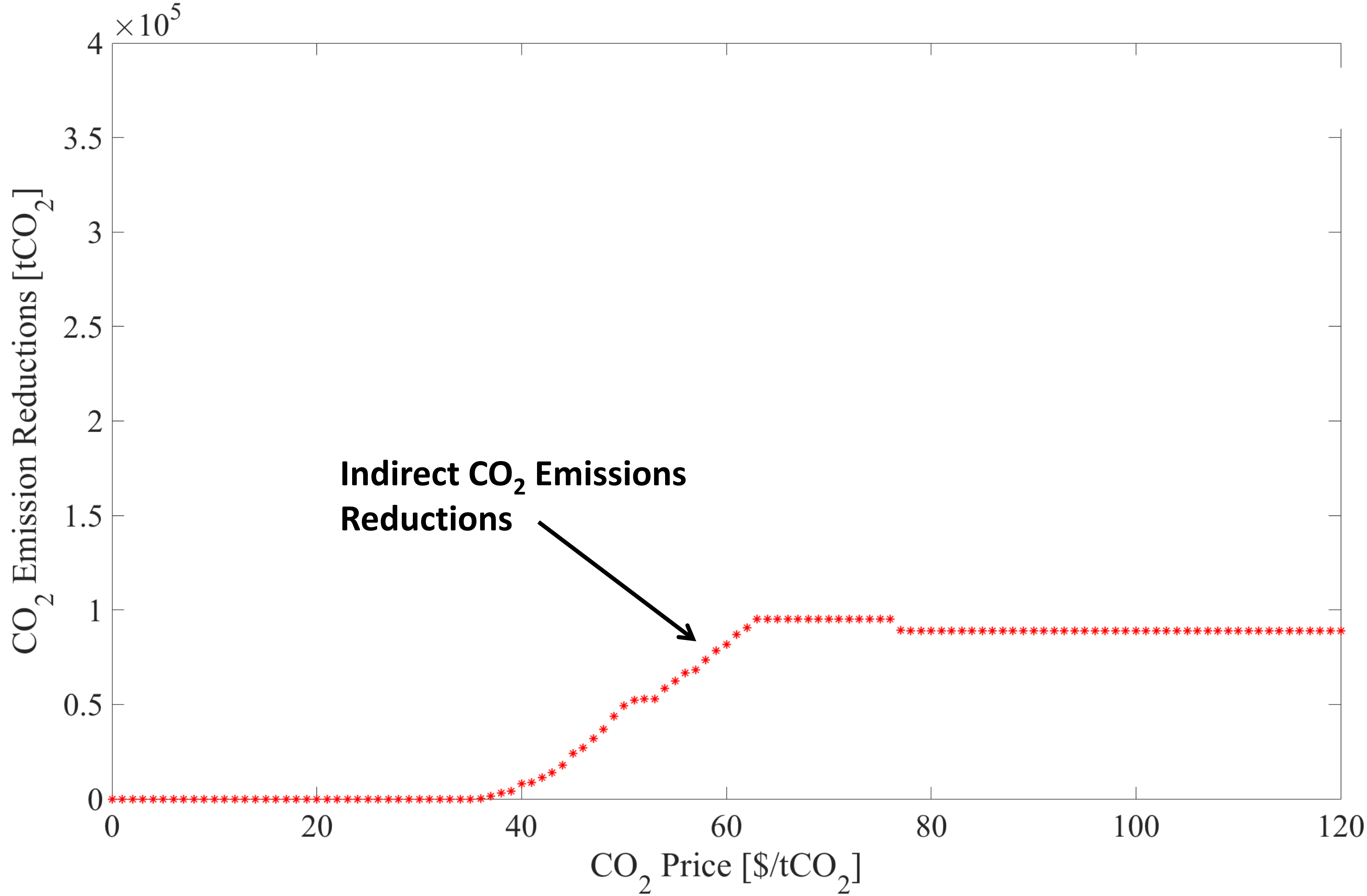


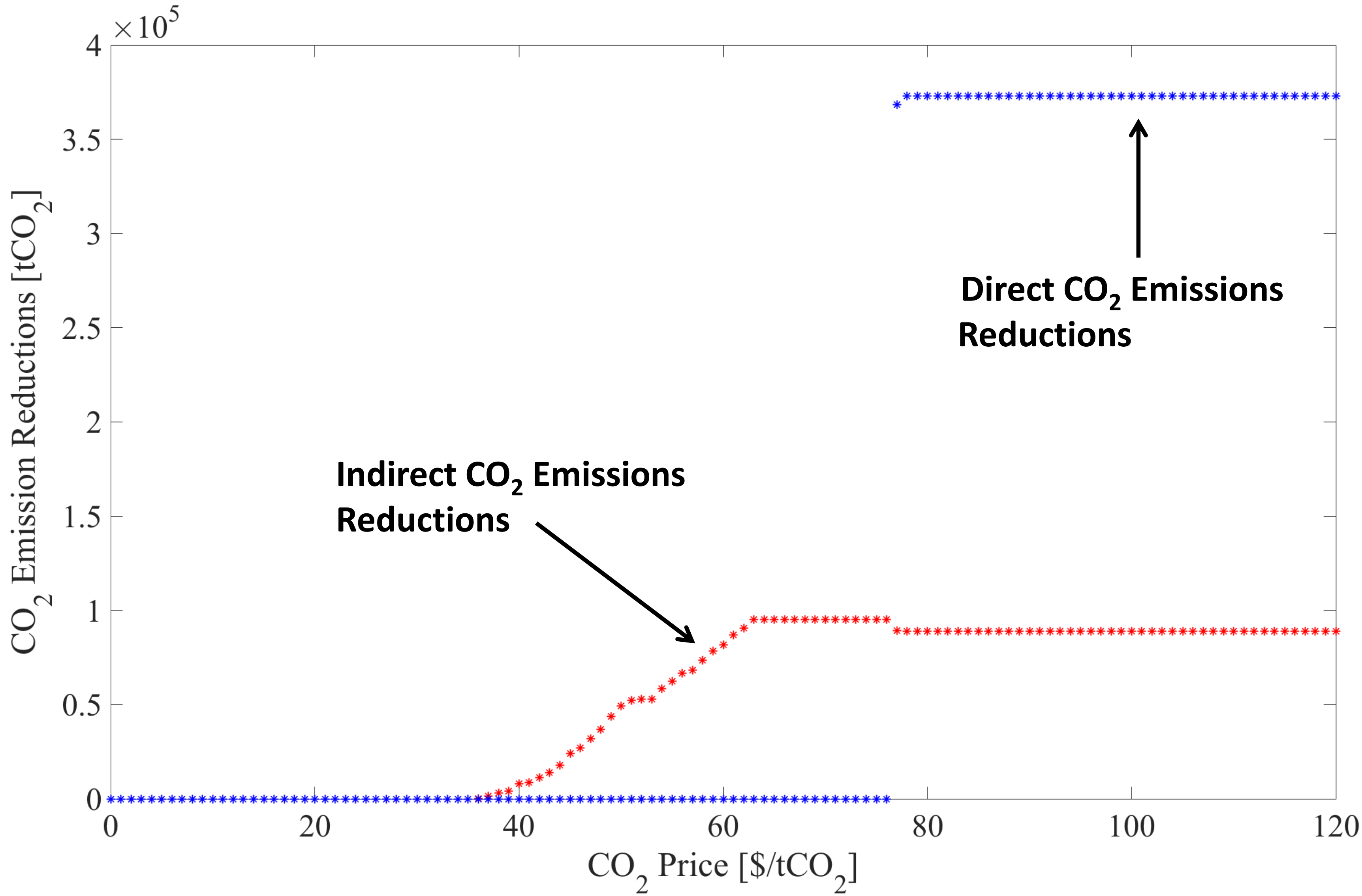

×10^5
10
9
8
7
6
5
4
3
2
1
0
Total Diurnal Electricity Generation [MWh]
20
40
60
80
100
120
CO2 Price [$/tCO2]
Wind
Natural Gas
Coal
CO2-BES Energy Storage Capacity
Nuclear

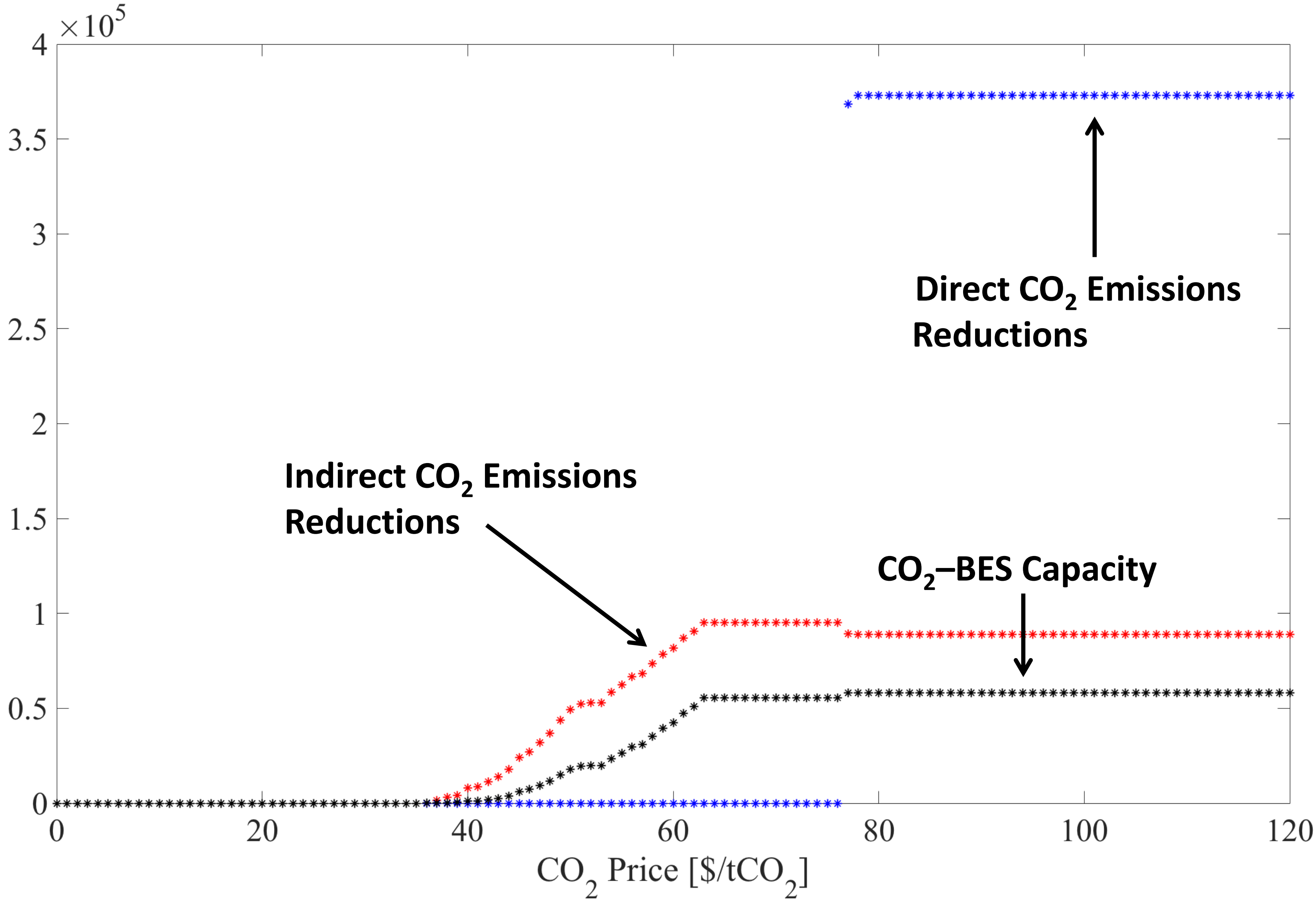

CO_2 Price = \$0/tCO_2
Run Optimization Model
Increase CO_2 Price
Output: (1) Optimal Diurnal Electricity Dispatch, (2) CO_2-BES Energy Storage Capacity, and (3) Amount of CO_2 sequestered in Sedimentary Basin for Given Price of CO_2
Calculate System Wide CO_2 Emissions


CO_2 Price = $0/t$CO_2$
Run Optimization Model
Increase CO_2 Price
Output: (1) Optimal Diurnal Electricity Dispatch, ~~(2) CO_2 BES Energy Storage Capacity,~~ and (3) Amount of CO_2 sequestered in Sedimentary Basin for Given Price of CO_2
Calculate System Wide CO_2 Emissions

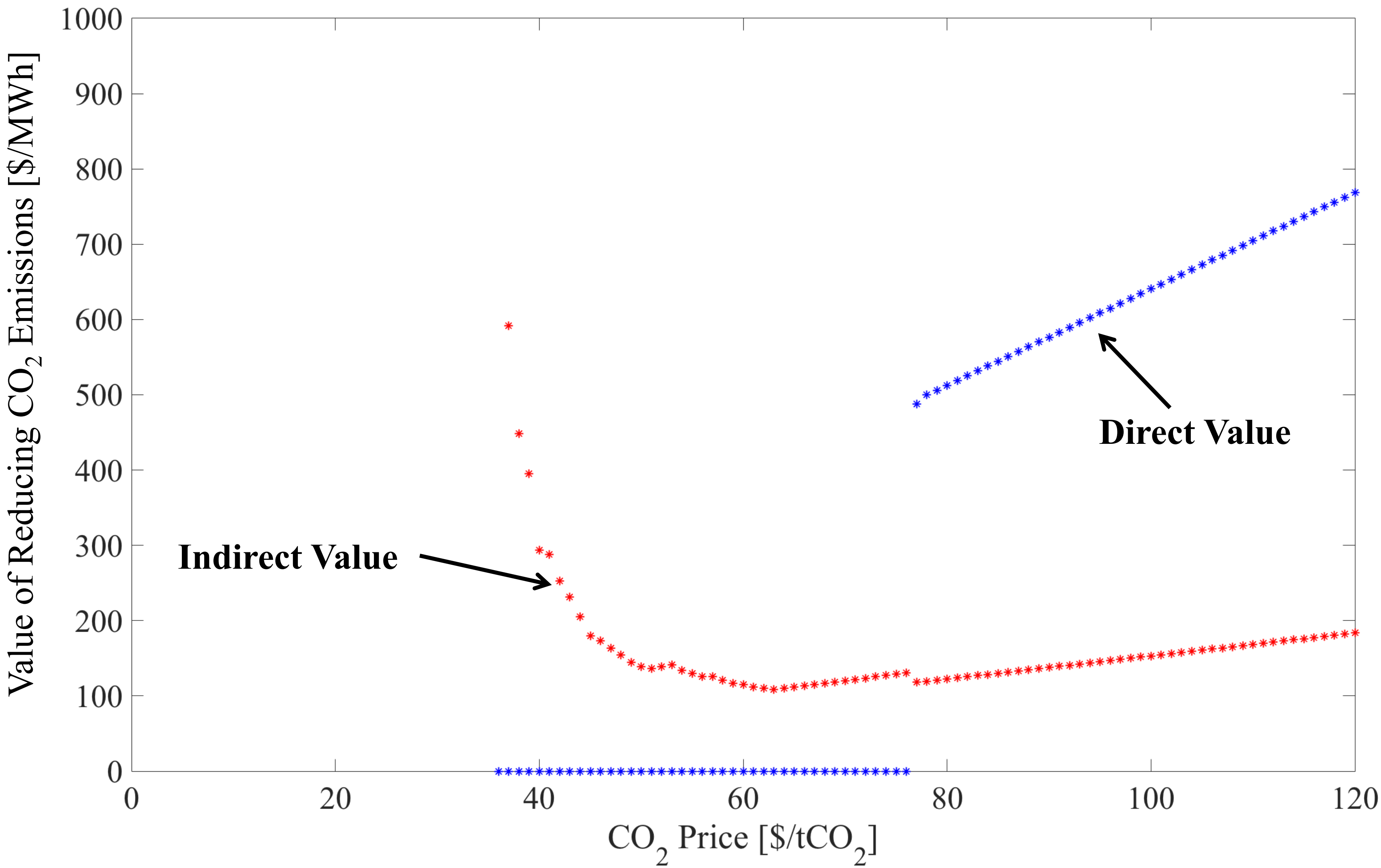

$\times 10^5$
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
Change Between Scenario [MWh]
20
40
60
80
100
120
CO_2 Price [\$/tCO_2]
Optimal CO_2-BES Energy Storage Capacity
Total Daily Natural Gas Electricity Generation
Total Daily Coal Electricity Generation


×10^5
4
3.5
3
2.5
2
1.5
1
0.5
0
CO2 Emission Reductions [tCO2]
Indirect CO2 Emissions Reductions
0
20
40
60
80
100
120
CO2 Price [$/tCO2]

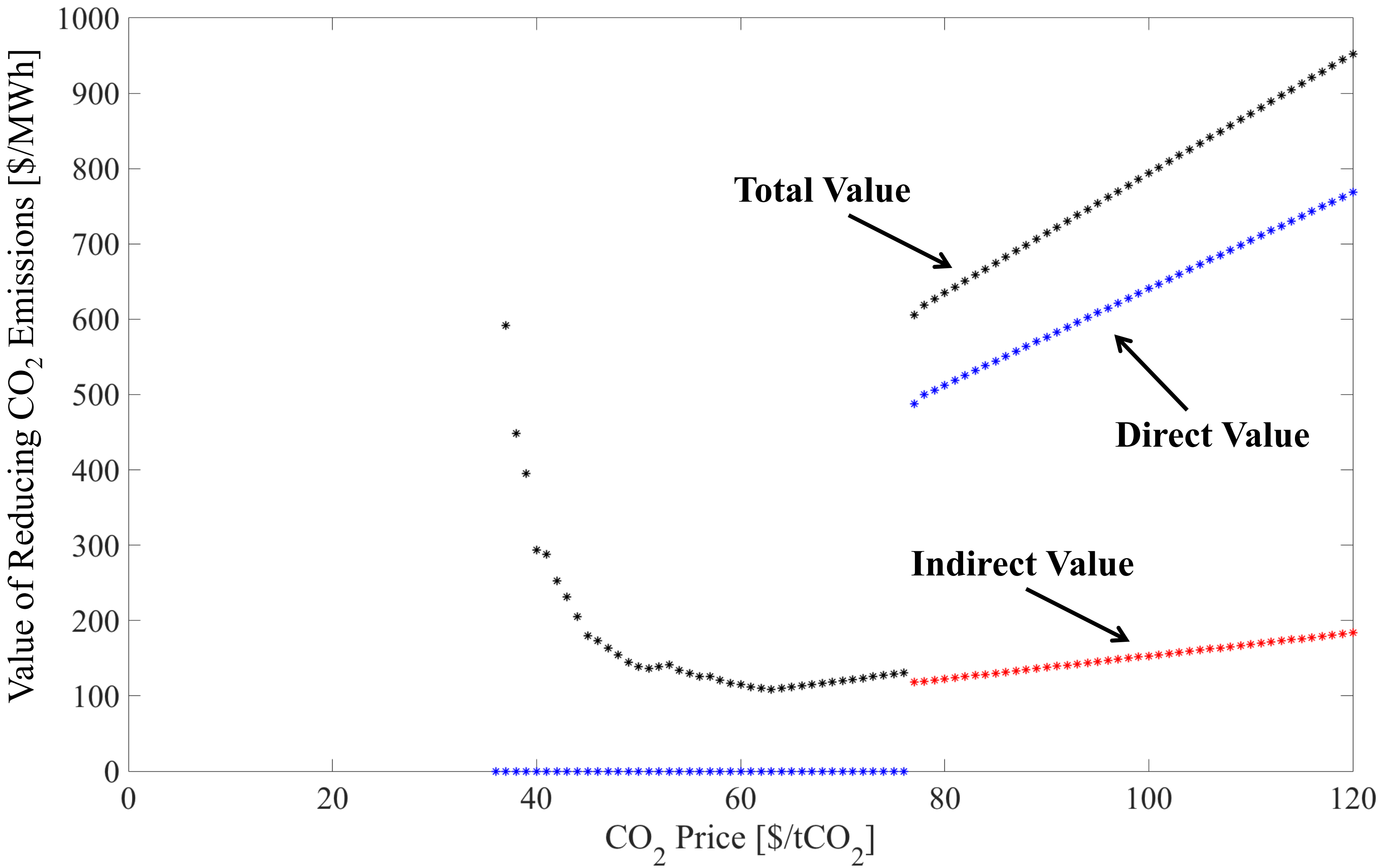

×10^5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120
CO2 Emission Reductions [tCO2]
CO2 Price [$/tCO2]
Direct CO2 Emissions Reductions
Indirect CO2 Emissions Reductions

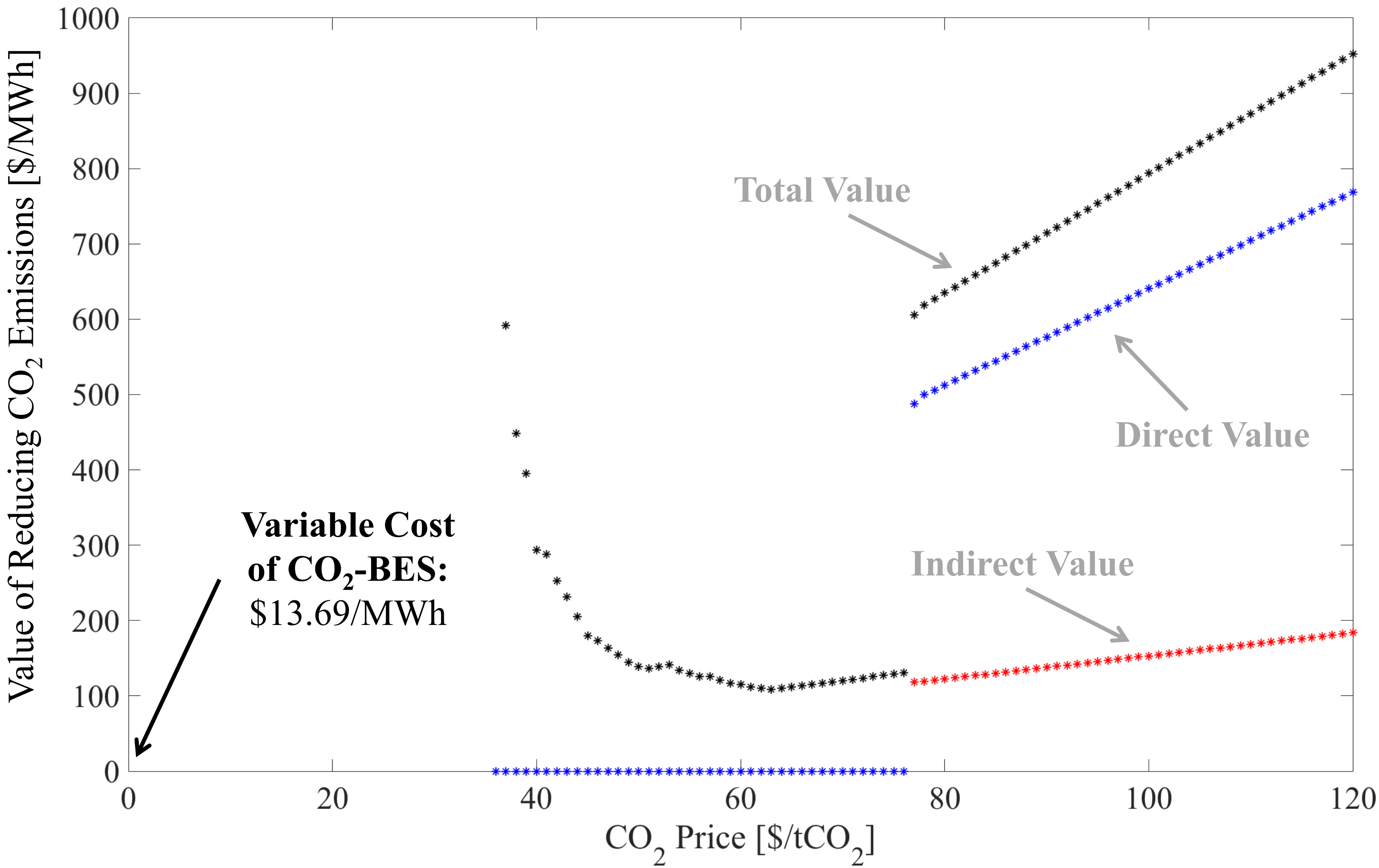


×10^5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120
CO2 Price [$/tCO2]
Direct CO2 Emissions Reductions
Indirect CO2 Emissions Reductions
CO2–BES Capacity



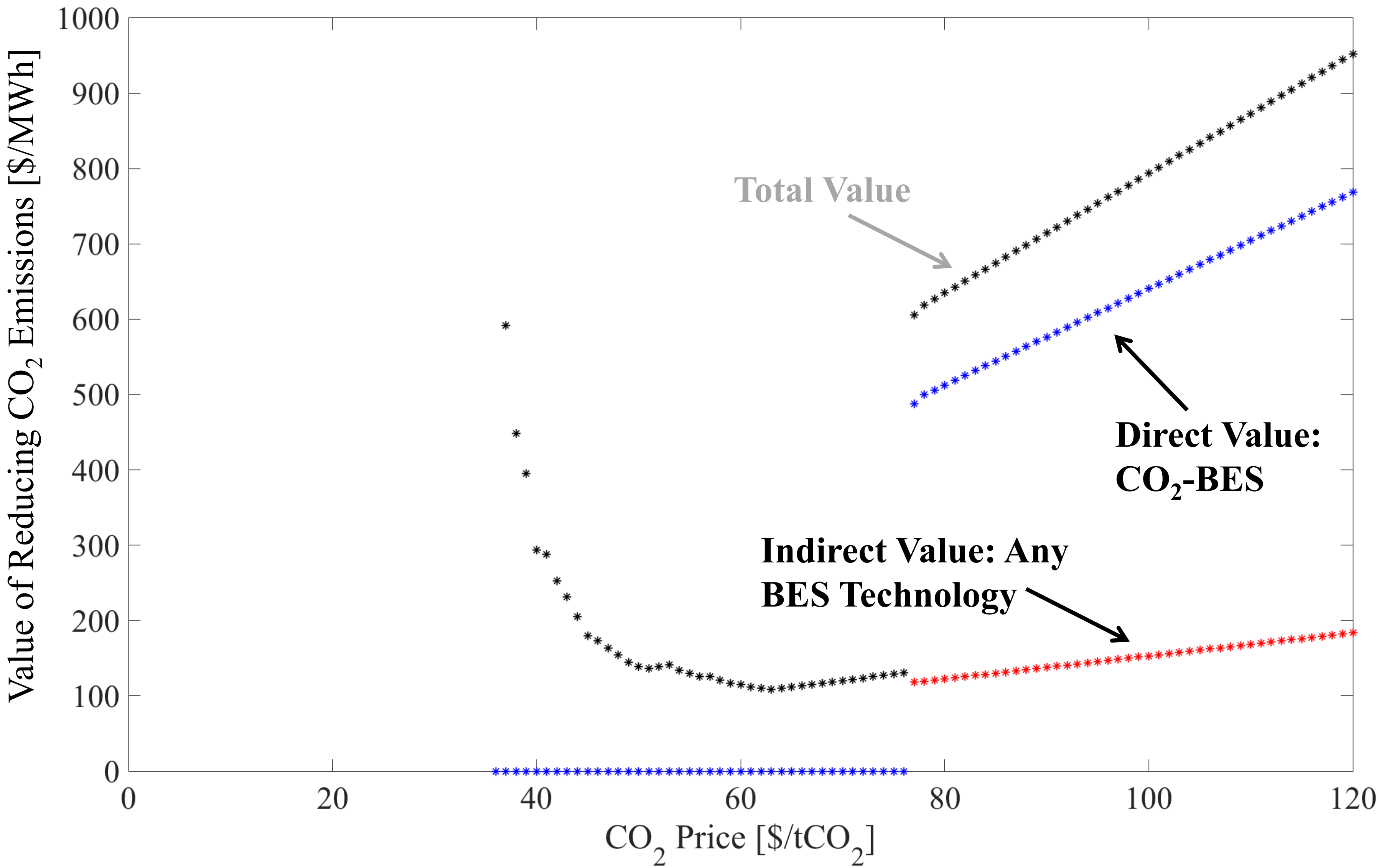
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
Value of Reducing CO2 Emissions [$/MWh]
CO2 Price [$/tCO2]
Direct Value
Indirect Value


Total Value
Direct Value
Indirect Value
Value of Reducing CO_2 Emissions [$/MWh]
CO_2 Price [$/t$CO_2$]
0
100
200
300
400
500
600
700
800
900
1000
0
20
40
60
80
100
120



THE OHIO STATE UNIVERSITY

Energy Sustainability Research Laboratory


Value of Reducing CO_2 Emissions [$/MWh]
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
CO_2 Price [$/t$CO_2$]
Total Value
Direct Value:
CO_2-BES
Indirect Value: Any
BES Technology

Lessons

Bulk Energy Storage (BES):

- time-shift electricity production
- indirectly reduce CO_2 emissions

Lessons

Bulk Energy Storage (BES):

- time-shift electricity production
- indirectly reduce CO_2 emissions

CO_2-BES:

- *directly and* indirectly reduce CO_2 emissions
- generation and value influenced by price on CO_2 emissions
- potential value of reducing CO_2 emissions is greater than operating cost
- direct benefits are greater than indirect benefits

Lessons

Bulk Energy Storage (BES):

- time-shift electricity production
- indirectly reduce CO_2 emissions

CO_2-BES:

- *directly and* indirectly reduce CO_2 emissions
- generation and value influenced by price on CO_2 emissions
- potential value of reducing CO_2 emissions is greater than operating cost
- direct benefits are greater than indirect benefits

CO_2-BES may be more attractive for energy storage than CAES or PHES

Jonathan D. Ogland-Hand

PhD Student

Environmental Science Graduate Program

The Ohio State University

ogland-hand.1@osu.edu