Development of a Tool to Calculate the System Cost of Replacement Energy (SCoRE)

FWP Number: 1022402 Task 4

Amanda J. Harker Steele, Ph.D.
Energy Markets Analysis Team
Strategic Systems Analysis & Engineering

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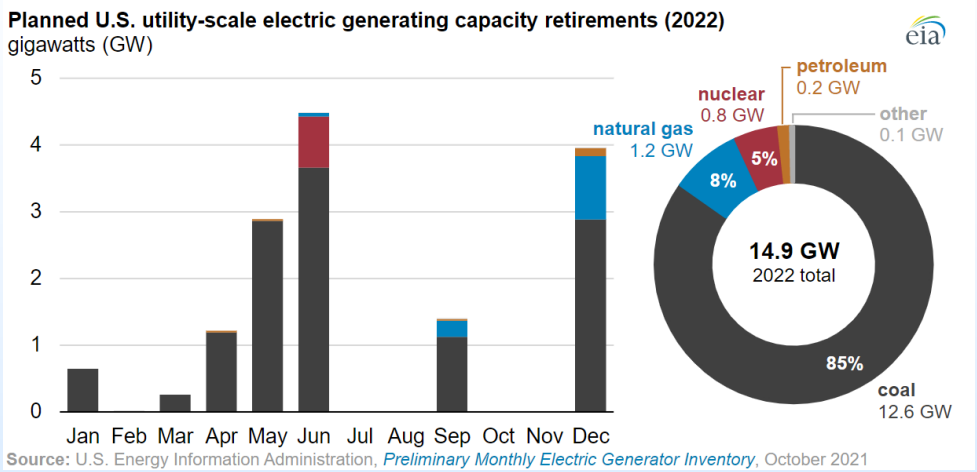
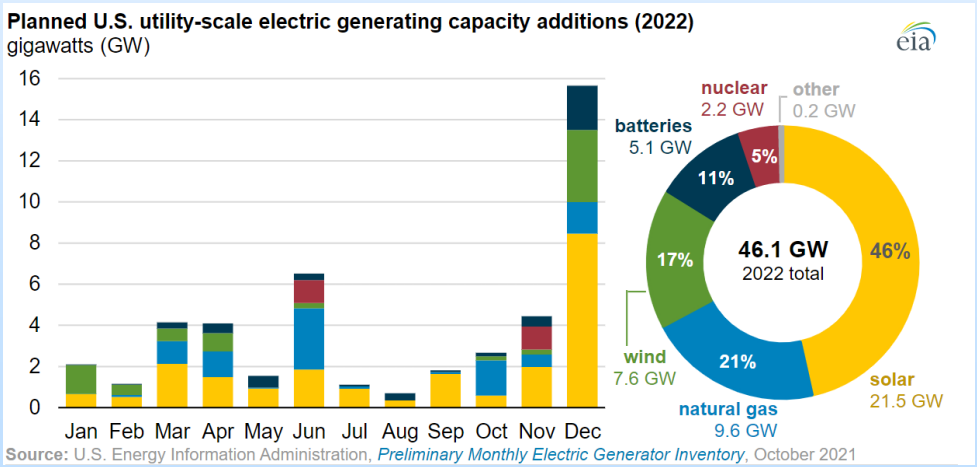
Problem Statement

- Electricity systems evolving in response to changing economic and environmental conditions (IEA, 2021)
- Modifications to the mix of power generation technologies – LHCT replaced by NLCA (Bartlett, 2019)
- Traditional cost metrics – LCOE – fail to capture the additional costs and values of grid services (Byrom et al. 2021)
- Need for a tool to assess the total systems cost (TSC) implications of modifications motivated by decarbonization requirements (Byrom et al. 2021)





Project Objective

- Develop a dynamic tool capable of producing estimates of the **System Cost of Replacement Energy (SCoRE)** for different technology substitution (or replacement) pathways motivated by deep decarbonization of the system

- Tool should be applicable to operating regions of the United States considering variable inputs – costs, available technology options, emissions, etc.

- Results can be used to discern potential least-cost technology pathways to decarbonization

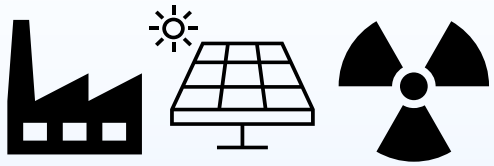
Project Overview

- Funding: $200K (no cost share)
- Project Performance Dates: March 2021-2022
- Project Participants: NETL & MESA Staff

Key Abbreviations

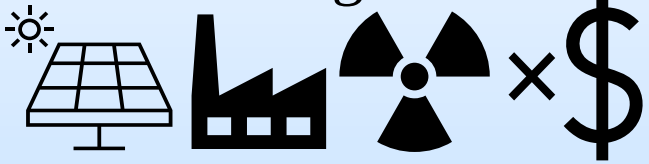
Term	Abbreviation
Legacy High Carbon Technology	LHCT
New Low Carbon Technology or Alternative	NLCT or NLCA
Coal Fired Power Plant	CFPP
Natural Gas Combined Cycle	NGCC
Natural Gas Combustion Turbine	NGCT
Maximum Fossil Replaceable Capacity	MAXFC
Variable Renewable Resources	VRE
Variable Renewable Resources Paired With Energy Storage	VRE-Storage
Firm Low Carbon Capacity	FLCC
Asymptotic Decarbonization Rate	ADR
Threshold Decarbonization Rate	TDR
Total Systems Cost	TSC

Background: Total System Costs

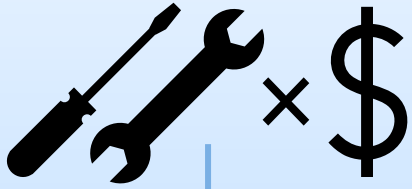


Energy System

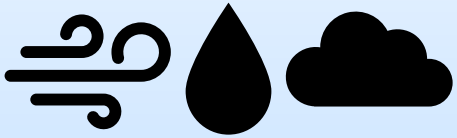
Capital Costs Plus Financing



O&M Costs

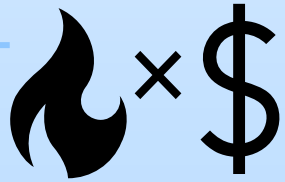


Site Characteristics



Annual Cost

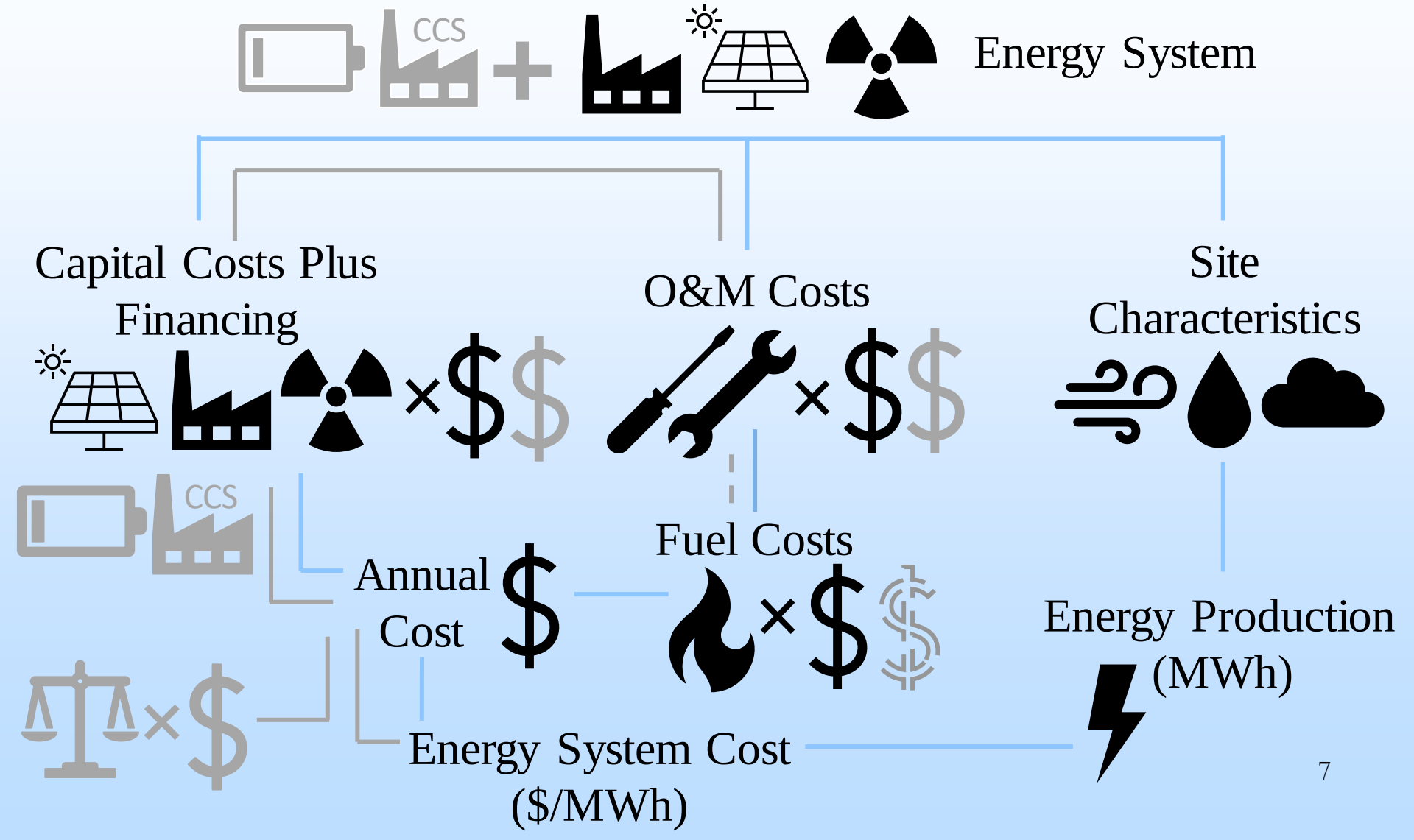
Fuel Costs



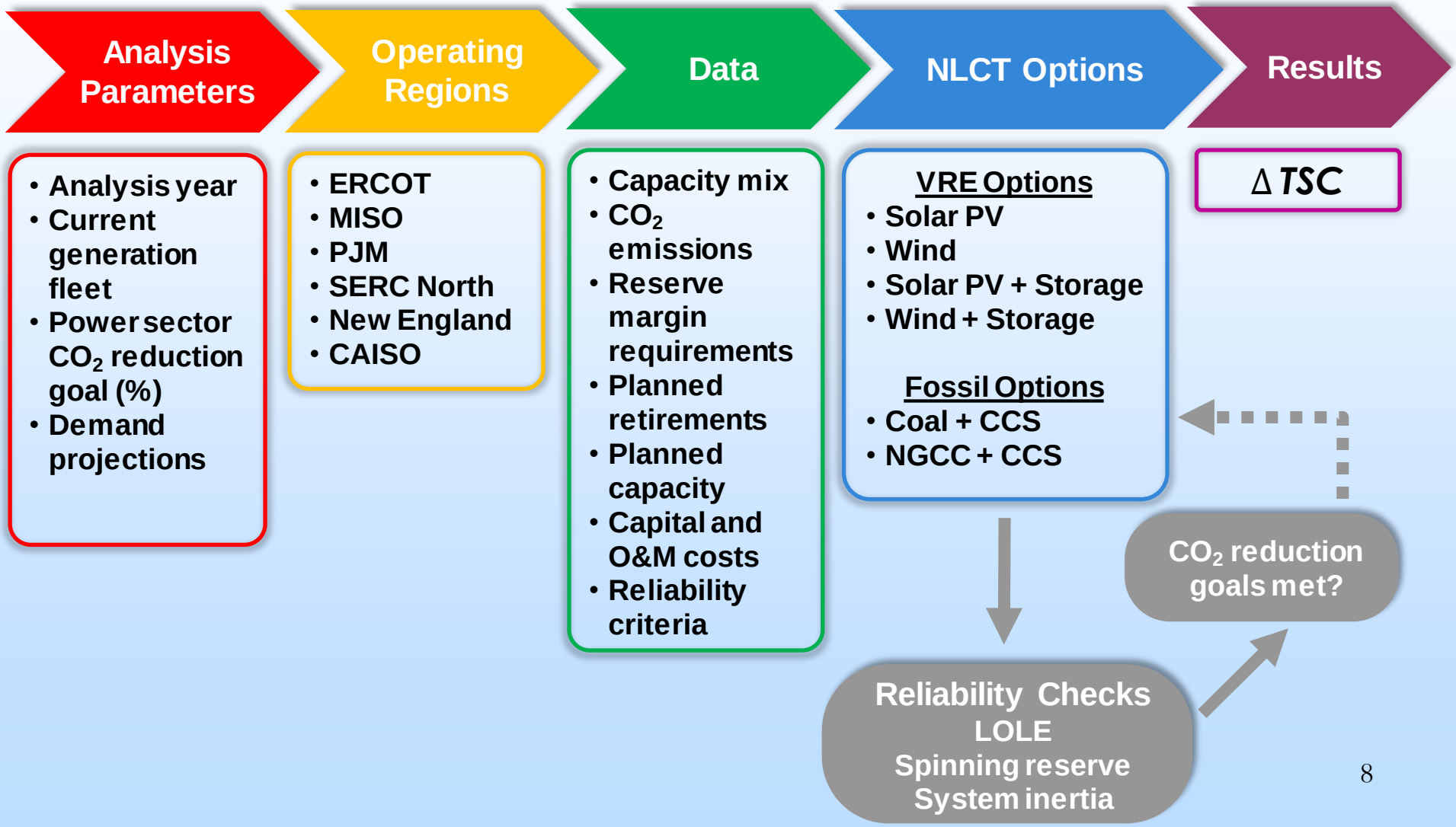
Energy Production (MWh)

Energy System Cost ($/MWh)

Background: Total System Costs



Project Scope: SCoRE Tool



Project Scope: Schedule & Success Criteria

SCHEDULE		
Identifier	**Expected Completion Date**	**Description (What, How, Who, Where)**
EY21.4.M	06/30/2021	SCoRE design basis document.
EY21.4.O	11/30/2021	SCoRE tool(s) delivery
EY20.4.K	03/01/2022	SCoRE journal paper submitted, or conference presentation delivered.

SUCCESS CRITERIA
Tool(s) for visualization and presentation of dynamic SCoRE values delivered.

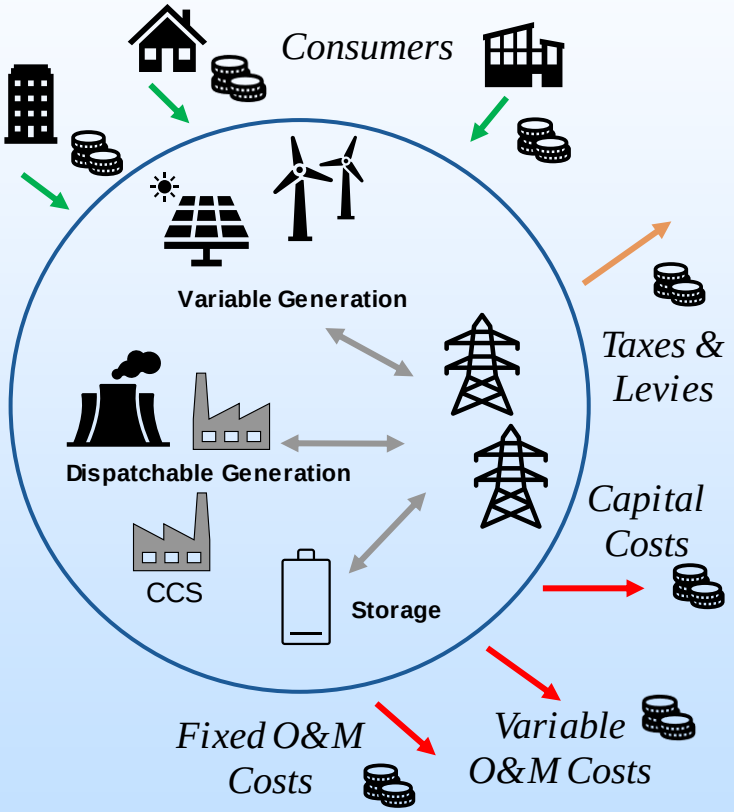
Project Scope - Technical Approach

- **Calculating SCoRE:**

$$\boldsymbol{SCoRE_{ij}^{a}} = \frac{TSC_j - TSC_i}{E_{ji}} = \frac{\Delta TSC_{j-i}}{E_{ji}}$$

$$\boldsymbol{TSC_{i,j}} = \sum_{a=1}^{a_{max}} \left(CAPX_{a,t} + FOM_{a,t} + VOM_{a,t} + FUEL_{a,t} + INT_{a,t}\right)$$

- TSC_i : TSC under a non-replacement
- TSC_j : TSC under a replacement
- E_{ji} : Generation from replacement
- $CAPX$: Capital costs
- FOM : Fixed O&M costs
- VOM : Variable O&M costs
- $FUEL$: Fuel costs
- INT : Integration costs
- a: Replaceable capacity
- a_{max} : Maximum replaceable capacity
- t : Year



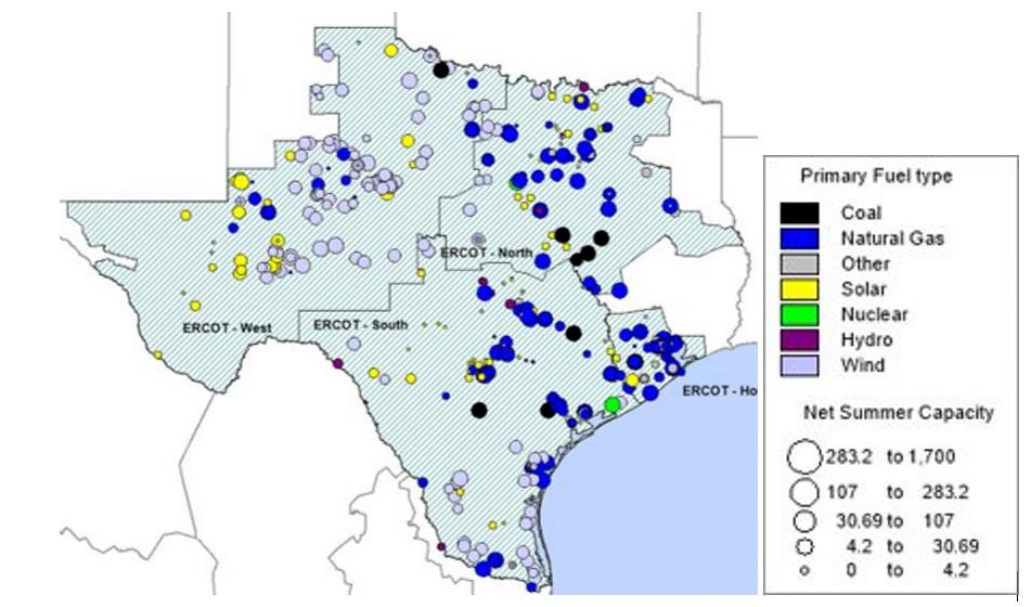
Total System

Source: Byrom, S, Bongers, G., Boston, A. and Garnett, A. (2021, April). Total System Cost: A better metric for valuing electricity in supply network planning and decision-making. *Journal of Environmental Informatics Letters*.

Project Status – ERCOT Application

- Interconnection, regional reliability entity, ISO, & BA
- Manages flow of electricity for more than 26 M customers in TX
  - 90% of the state's population
- 46.5 K miles of transmission lines
- > 700 generating units
  - LHCT, NLCA, and E. Storage
- CO_2 capture & storage potential
  - 1.4 trillion tons – Saline
  - 4.9 billion tons - EOR

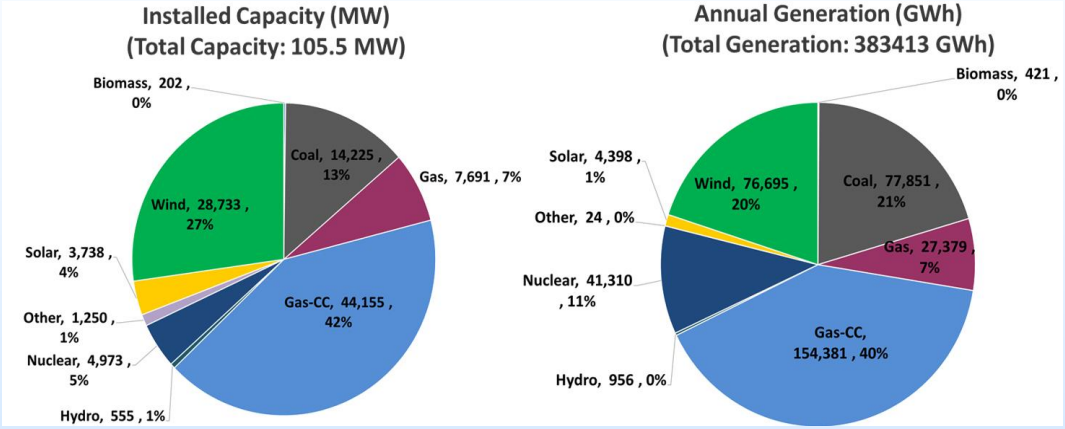
Geospatial location of the generation fleet by total capacity in the ERCOT in 2019

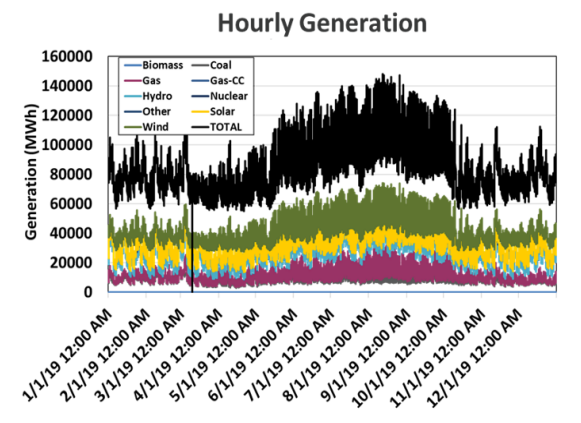


Source: Hitachi Energy Velocity Suite, 2021

ERCOT Application – Data Collection

- **Generation Data**
  - 15-minute interval - ERCOT Fuel Mix Report 2019 Grid Information Website
  - Capacity Factors
- Technology & Interconnection costs
  - Solar PV & Wind – EIA AEO 2021
  - CFPP & NGCC w/CCS – NETL Bituminous Baseline
  - Li-ion & flow battery storage – PNNL
  - Capital recovery factors – NREL & NETL Baseline
- Emission Factors for LHCT
  - Annual emission – Hitachi Energy Velocity Suite – 2019





Technology	Average Annual Capacity Factor in 2019
Biomass	23.8%
Coal	62.5%
Gas	40.6%
Gas-CC	39.9%
Hydro	19.7%
Nuclear	94.8%
Other	0.2%
Solar	13.4%
Wind	30.5%

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NLCT*	CAPX		FOM		VOM		Fuel	CFR
	$/kW	$/kWh	$/kW – year	$/MWh	$/kW – year	$/MWh	$/MWh	
Solar PV	1,214	-	15.33	-	0	-	-	0.0670
Wind	1,846	-	26.47	-	0	-	-	0.0670
Coal – CCS	4,654	-	-	16.1	-	14.0	24.1	0.0816
NGCC-CCS	2,412	-	-	8.58	-	5.63	31.65	0.0773
Li-Ion Battery Storage	3,565	356	8.82	-	0.5125	-	-	0.0670
Flow Battery Storage	3,994	399	11.3	-	0.5125	-	-	0.0670

NLCT**	Transmission Costs ($/MWh)
Coal – CCS	0.44
NGCC-CCS	0.40
Solar PV & Wind	5-10

Notes:*100 MW 10-hour discharge capacity, 80% depth of discharge, one cycle/day, and 5% downtime; **Coal with CCS and NGCC w/ CCS may use existing transmission lines when an existing coal or NGCC power plant is retrofitted, and in this case their associated transmission costs are negligible. This analysis considered only greenfield projects, with non-negligible transmission costs for Coal with CCS and NGCC w/ CCS.

ERCOT Application – Data Collection

- **Generation Data**
  - 15-minute interval - ERCOT Fuel Mix Report 2019 Grid Information Website
  - Capacity Factors
- Technology & Interconnection costs
  - Solar PV & Wind – EIA AEO 2021
  - CFPP & NGCC w/CCS – NETL Bituminous Baseline
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LHCT	Average Emission Factors (Metric tons/MWh-year)
CFPP	1.13
NGCC	0.55
Other Gas	0.69

Note: Natural Gas Combustion Turbines and other fossil-fuel-based power generators in ERCOT were precluded from replacement, and also operated as usual, since they provide essential ancillary services (e.g., black start and transient services) in the regions.

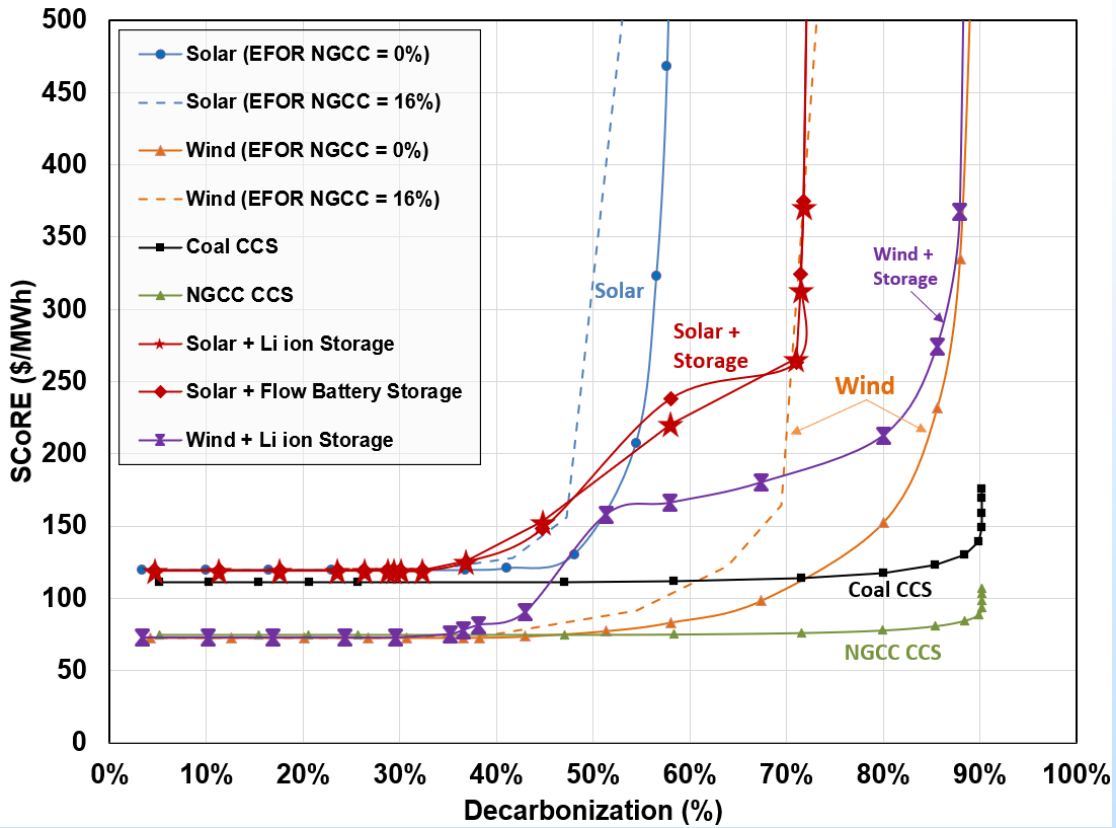
ERCOT Application - Scenarios

Scenario	NLCT	Label
1	Solar PV	**Solar**
2	Land-based Wind	**Wind**
3	CFPP with CCS	**Coal + CCS**
4	NGCC with CCS	**NGCC + CCS**
5	Solar PV + Li-ion Battery Storage	**Solar + Li-ion**
6	Solar PV + Flow Battery Storage	**Solar + Flow Battery**
7	Land-based Wind + Li-ion Battery Storage	**Wind + Li-ion**

- For each scenario, the NLCT was assumed to replace coal first and natural gas second

ERCOT Application - Results

- **SCoRE** = ΔTSC_j
- **TDR:** Decarbonization target where SCoRE begins to increase exponentially
- **ADR:** Maximum decarbonization target



ERCOT Application - Results

Least Cost Technology Pathway To Decarbonization in ERCOT

NGCC w/ CCS

SCoRE = ~ $75/MWh

TDR = 88%

ADR = 90%

Scenario	Label	LHCT Replaced (%)	MAXFC (GW)	Threshold Decarb Rate [TDR] (%)	New Capacity at TDR (GW)	Asymptotic Decarb Rate [ADR] %
1	Solar	24%	15.9	48	50	58
2	Wind	23%	15.5	68	78	90
3	**Coal + CCS**	**100%**	**58.4**	**88**	**41**	**90**
4	**NGCC + CCS**	**100%**	**58.4**	**88**	**41**	**90**
5	Solar + Li-ion	24%	15.9	45	64	72
6	Solar + Flow Battery	24%	15.9	45	64	72
7	Wind + Li-ion	23%	15.5	43	26	88

Performance Levels Compared to Project Goals

- Successful demonstration of dynamic SCoRE for ERCOT ☑
- Submission of journal article detailing SCoRE tool development, application, and results ☑
- Showcase impacts on the overall system of deep decarbonization technologies ☑
- Inform critical topics concerning energy policy ☑

Future Plans & Next Steps

Short-term

- Social Cost of Carbon (SCC) – tax on emissions
- Consider low solar/wind year – relative to system demand
- Regional extension - imports and exports
- Extend list of NLCT - biomass
- Compute SCoRE for a future year (2035) - with an existing demand projection

Long-term

- Modeling demand projection –high electrification scenarios with shifting load peaks and demand response
- Household energy burden impacts
- Translate to a Python based tool
- Integrate SCoRE with other modeling frameworks

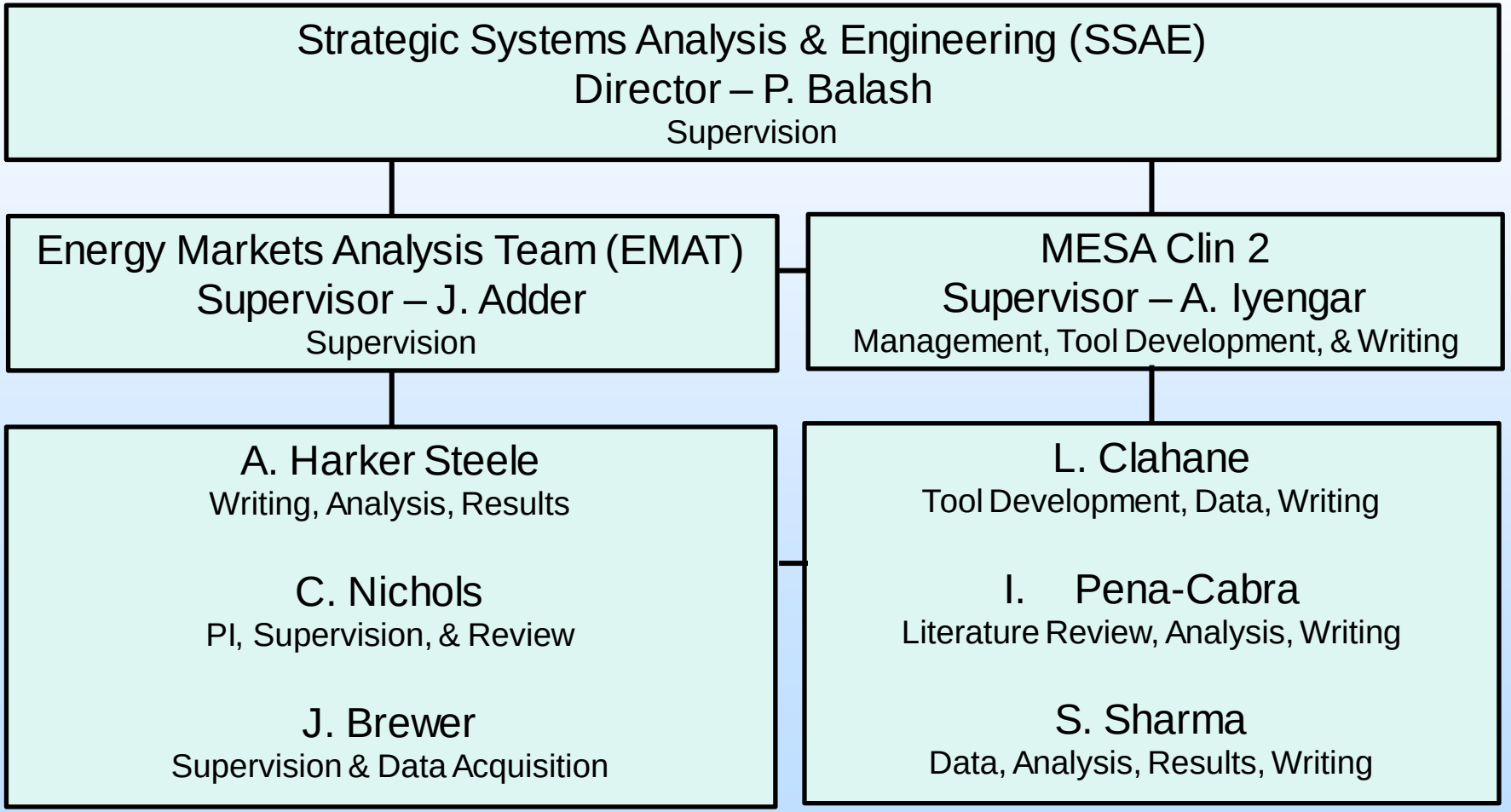
Summary Slide

- Spreadsheet based tool developed for computing SCoRE
  - Applied to ERCOT 2019
  - General methodology – currently tool can accept data from any year (leap year implementation pending)
- SCoRE evaluated for decarbonization through exclusive paths
  - Solar only
  - Wind only
  - Coal w/ CCS
  - **NGCC w/ CCS – Lowest SCoRE, TDR = 88%, ADR = 90%**
  - Solar + Li-ion Storage
  - Solar + Flow Battery Storage
  - Wind + Li-ion Storage
- SCoRE values are similar for some NLCT but beyond 40% decarbonization NGCC with CCS appears to be the least cost pathway to decarbonization in ERCOT

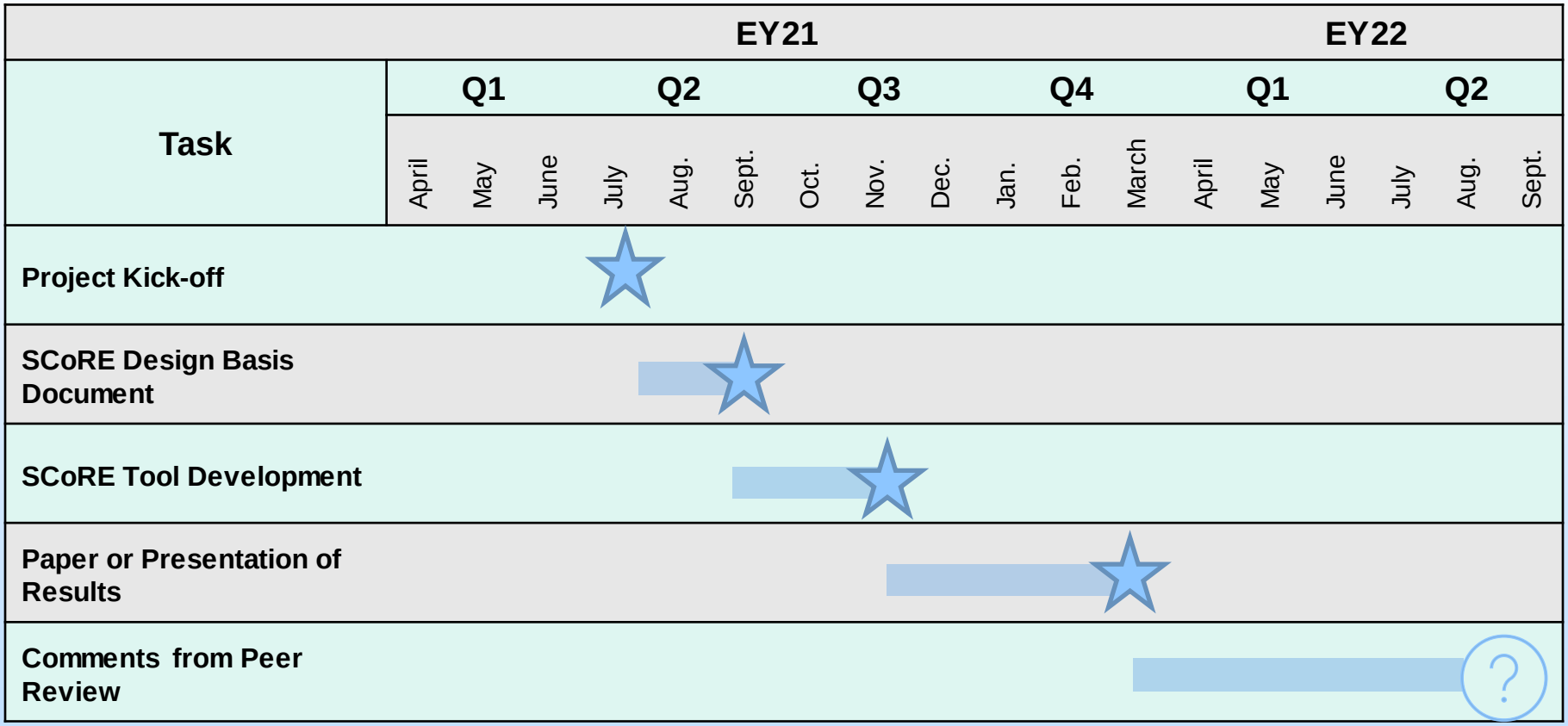
Legal Disclaimer

Appendix

Organization Chart



Gantt Chart


EY21
EY22
Task
Q1
Q2
Q3
Q4
Q1
Q2
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
March
April
May
June
July
Aug.
Sept.
Project Kick-off
SCoRE Design Basis Document
SCoRE Tool Development
Paper or Presentation of Results
Comments from Peer Review
?

Levelized Cost of Electricity*

- Measures lifetime costs of a power generating technology per unit of electricity produced (e.g., kWh)
  - Lifetime costs = capital + O&M + disposition
- Present value of the total cost to build, operate, and retire a plant
- Used to compare different generating technology options (1:1)
- Minimum price at which the electricity generated by the power generating technology can be sold for to offset the costs
- Assumes maximum capacity factor
- Assumes electricity generated is the only product of value
  - Doesn't consider non-electricity generating technology needs

$$\boldsymbol{LCOE} = \frac{\sum_{t=0}^{T} \frac{PC_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{E_t}{(1+r)^t}}$$

where:

- PC : Production costs including capital, O&M, fuel, disposition/disposal
- r : Discount rate
- t : Time period (year)
- T : Total life of the generating technology (years)
- E_t : Electricity generated (e.g., kWh)

*Sometimes referred to as Levelized Cost of Energy