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Flexible Environments for Generation and Transmission Expansion Planning (GTEP) Analysis

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GTEP is Large; It Contains Multitudes

- **Expansion planning** optimizes the investment and operational decisions of the bulk power system (generation and transmission) over a long-term, multi-decade planning horizon

- Deployed to guide investment portfolios while considering evolving grid (e.g., retirements and decarb), dynamic technology, and economic conditions

- Problem scale rapidly explodes into intractability based on network size and discrete decision selection

Costs

- ❑ Which investments?
- ❑ Which operations?
- ❑ What objective?
- ❑ Which hazards?
- ❑ What (if any) recourse actions?

Time Horizon

- ❑ Decades?
- ❑ Years?
- ❑ Weeks?
- ❑ Days?
- ❑ Hours?
- ❑ Minutes?

Uncertainties

- ❑ Renewable forecasts?
- ❑ Load forecasts?
- ❑ Resource forecasts?
- ❑ Climate?
- ❑ Weather?
- ❑ Technologies?

The set of GTEP-related questions is already enormous and growing rapidly

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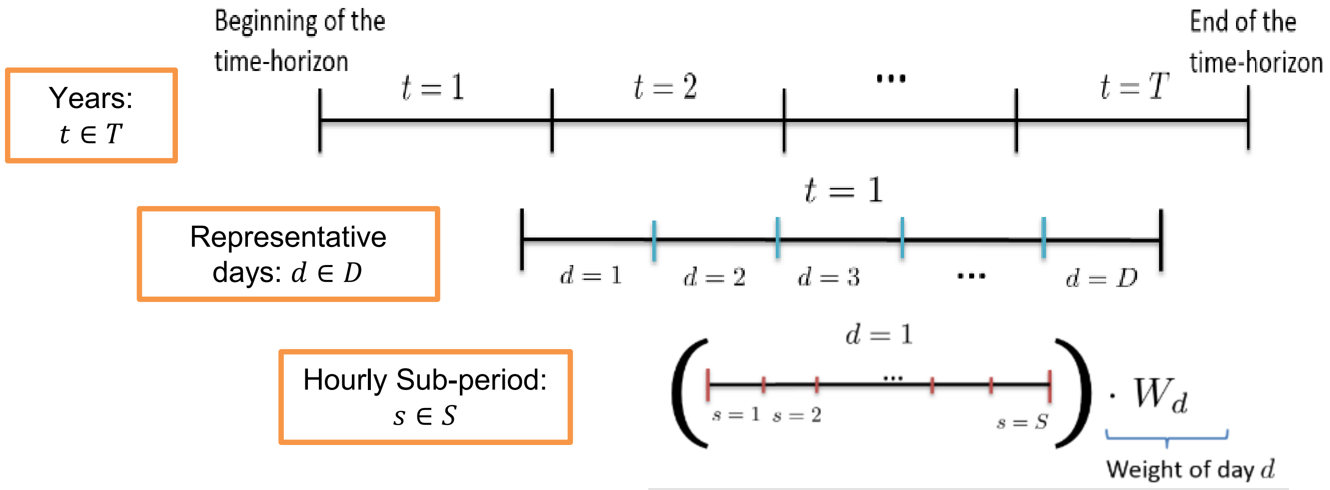
State-of-the-art (GTEP is hard)



Simplifying Assumptions:

- Reduced-network model
- Power flow approximations
- Scenario reduction
- Single-source uncertainty

Investments

- Either resilience or capacity, not both
- Either generation or transmission, rarely both
- Single timescale decisions

$\vee$

Objective

- Almost always pure **single** objective
- Rarely two competing objectives based on a tolerance trade-off parameter

$\vee$

Uncertainties

- At most one, often zero
- Typically modeled exogenously and abstractly
- Rarely geo-spatially located

Existing GTEP models are bespoke; i.e., highly individualized and tailored to specific questions or cases

Sample Models in Active Development

ReEDS

Features	
✓ Well-established ✓ Large scale functionality (CONUS) ✓ High level aggregation	❖ Relaxed model (LP) ❖ Limited disaggregation capability ❖ Rigid assumptions

GenX.jl

Features	
✓ Flexible scale ✓ Relatively high configurability ❑ Entirely in Julia	❖ Deterministic and/or myopic multi-stage optimization only ❖ Representative time periods repeatedly duplicated

These tools are more flexible and can answer more questions than previous GTEP attempts, but are still *just models*

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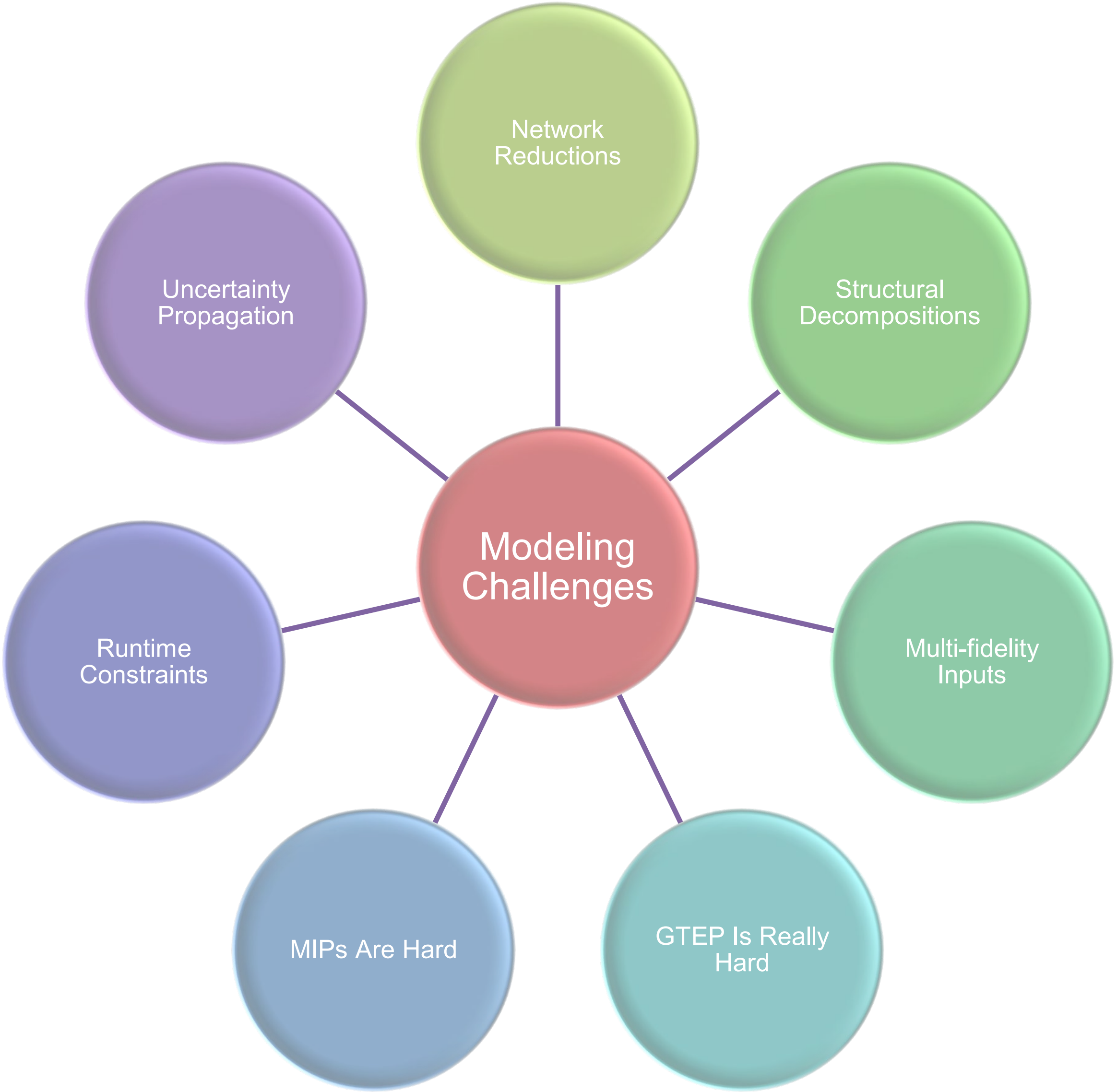
We Don't Want *A* Model



We need to identify the "right" model from a superset AND the "right" way to solve it

How do we do that when designing, building, testing, and evaluating *new* models is so expensive?

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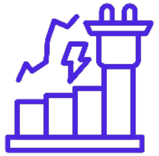
What is IDAES GTEP if Not a Model?

Electrification

- ❑ Increased unpredictability
- ❑ Impact of inverter-based resources
  - ❑ Reliability
  - ❑ Valuation
  - ❑ Inertia

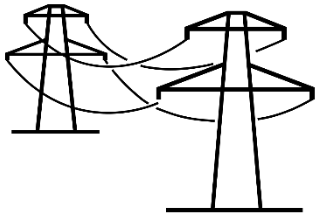


Regulation

- ❑ Decarbonization
- ❑ Renewable minima
- ❑ Technology restrictions
- ❑ FERC 1920

Modeling Choices

- ❑ Appropriate network reductions
- ❑ Improved temporal multi-fidelity
- ❑ Case study independence
- ❑ Flexible investment options
- ❑ Common & verified flow models (e.g., EGRET)
- ❑ Consistent Verification & Validation (e.g., PRESCIENT)



We need a *superstructure* to explore multiple GTEP questions without creating new models

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We Want A ***Superstructure***

Superstructure (metamodel design)

- What combination of input fidelities is necessary?
- How do we decompose the problem?
- How much can we simplify the network?

Model Design

- Uncertainties
- Regulations
- Investments

Algorithmic Decisions

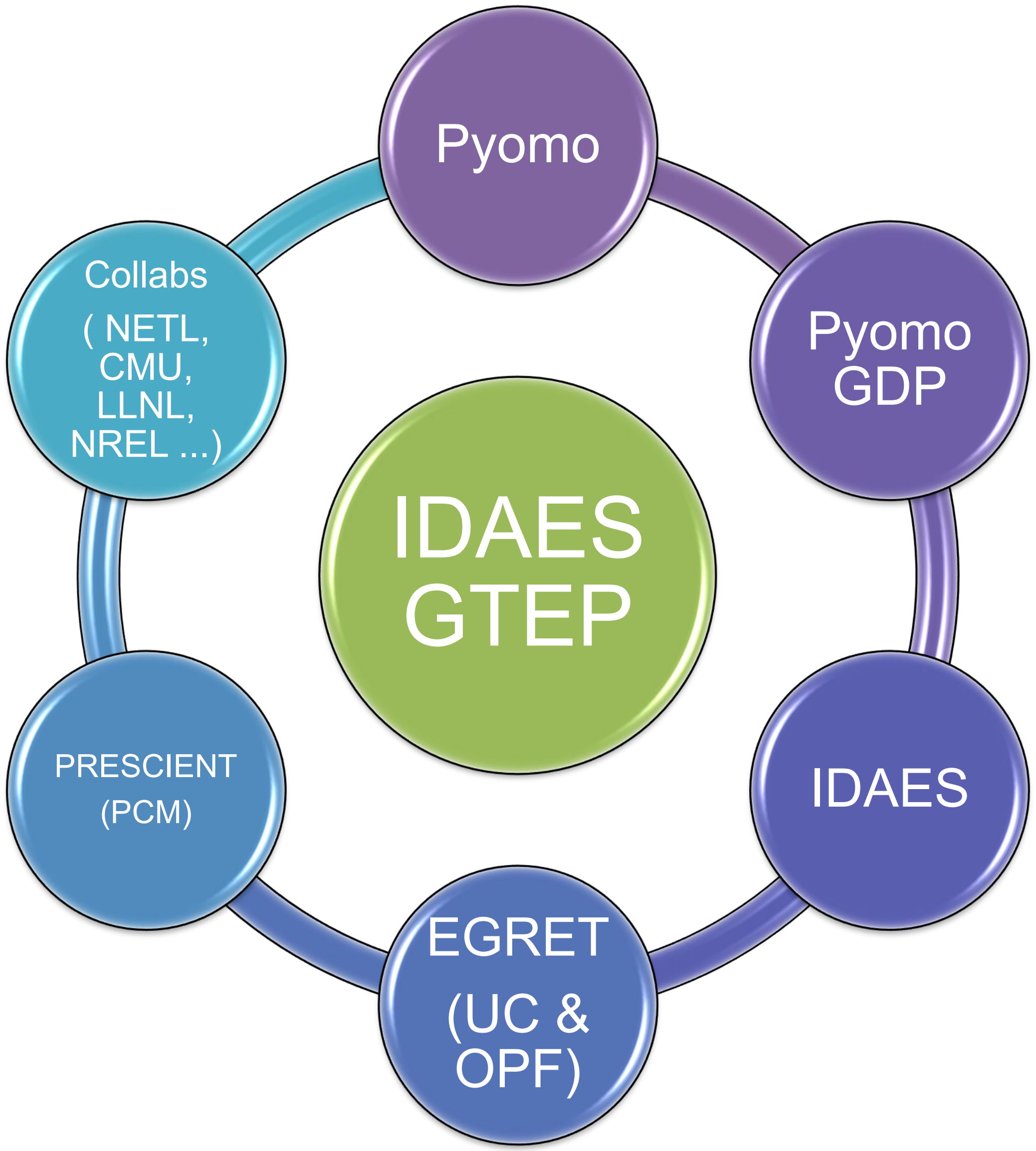
- Multi-fidelities
- Decomposition
- Simplified Network

IDEAS GTEP Superstructure is Built on an Ecosystem

IDAES GTEP builds on and interacts with established, trusted systems

PYOMO

PYOMO GDP



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How Do We Build a Superstructure?

Extensive Use of *Generalized* Disjunctive Programming

- Unit Commitment
- Investment
- Storage

Make Case Study and Model Independent

- Generation decisions (technologies, locations, sizes, etc.)
- Transmission decisions
- Storage decisions
- Regional requirements
- Time periods

Select from a Menu of Relevant Assumptions

Investment Periods
- Decadal
- Annual
- Monthly
- Other

Representative Periods
- Daily
- 72-hourly
- Weekly
- Other

Power Flow Model
- Transport
- DCPF
- ACPF
- LPAC

Commitment Periods
- Hourly
- Sub-hourly
- Other

Dispatch Periods
- Hourly
- 15-minutely
- 5-minutely
- Other

GDP as a modeling framework enables easy selection of "menu items" to model – in isolation or jointly

GDP Defined

There is no such thing as a *BINARY* variable for yes/no decisions.

Variable Types:

- Real
- Integer

- ***Boolean***

Enables Logical Constraints:

$$Y_{ik} \Rightarrow \begin{cases} M_{ik}x + N_{ik}z \leq e_{ik} \\ r_{ik}(x,z) \leq 0 \end{cases}$$

Problems naturally described by GDP:

- Yes/no decision sets
- No-overlap
- Equipment selection
- State alternatives
- “Choose exactly *n* of”

GDP formulation admits a common logical structure for any Boolean decision variables

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PYOMO GDP

Example of GTEP as GDP

$$Y_{gT}\left[\begin{bmatrix} U_{g\tau}^{ON} \\ \underline{p}_g \le p_{gt} \le \overline{p}_g \end{bmatrix} \vee \begin{bmatrix} U_{g\tau}^{SU} \\ 0 \le p_{gt} \le \underline{p}_g \end{bmatrix} \vee \begin{bmatrix} U_{g\tau}^{SD} \\ 0 \le p_{gt} \le \underline{p}_g \end{bmatrix}\right]$$

Disjuncts

Disjunctions

GDP nests and isolates menu items, handling them consistently and independently

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GDP Gives Significant Advantages

- **Flexibility**
  - Abstracts modeling decisions from specific case studies or implementations
- **Modularity**
  - Enables easy inclusion/exclusion of modeling subcomponents (e.g., storage, transmission investment, power flow approximation, etc.)
- **Comprehensibility**
  - Results in cleaner, easier to understand codebase

Sample Menu Items

Decisions	Flow Models	Temporal Scale
Generation	DCOPF	Identical Length
Transmission	Copperplate	Any Number
Storage		Non-uniform Length
Switching	ACOPF	
Reconductoring		

Any case study in a standard format (e.g., RTS-GMLC) can be modeled with any set of assumptions *without* modifying data

Clean Math ⇔ Clean Code

```
@b.Disjunct(m.thermalGenerators)
    def genOn(disj, generator):
        # operating limits
        b = disj.parent_block()

        # Minimum operating Limits
        @disj.Constraint(b.dispatchPeriods)
        def operating_limit_min(d, dispatchPeriod):
            return (
                m.thermalMin[generator]
                <= b.dispatchPeriod[dispatchPeriod].thermalGeneration[generator]
            )

        # Maximum operating limits
        @disj.Constraint(b.dispatchPeriods)
        def operating_limit_max(d, dispatchPeriod):
            return (
                b.dispatchPeriod[dispatchPeriod].thermalGeneration[generator]
                + b.dispatchPeriod[dispatchPeriod].spinningReserve[generator]
                <= m.thermalCapacity[generator]
            )
```

$$\begin{bmatrix} U_{g\tau}^{ON} \\ \underline{p}_g \leq p_{gt} \leq \overline{p}_g \end{bmatrix} \vee$$

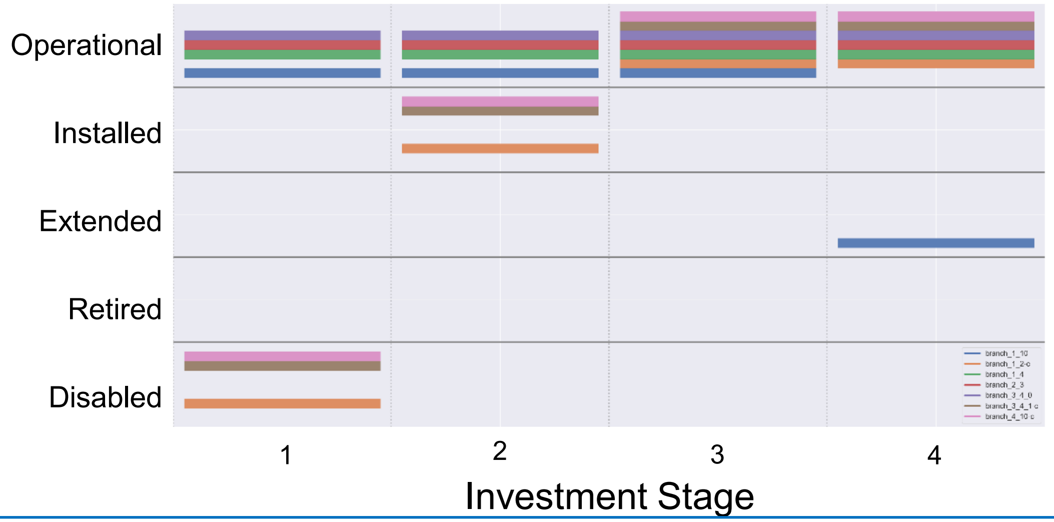
```
@b.Disjunction(m.thermalGenerators)
    def genStatus(disj, generator):
        return [
            disj.genOn[generator],
            disj.genStartup[generator],
            disj.genShutdown[generator],
            disj.genOff[generator],
        ]
```

GDP permits direct translation between abstract math formulations and concrete code implementations

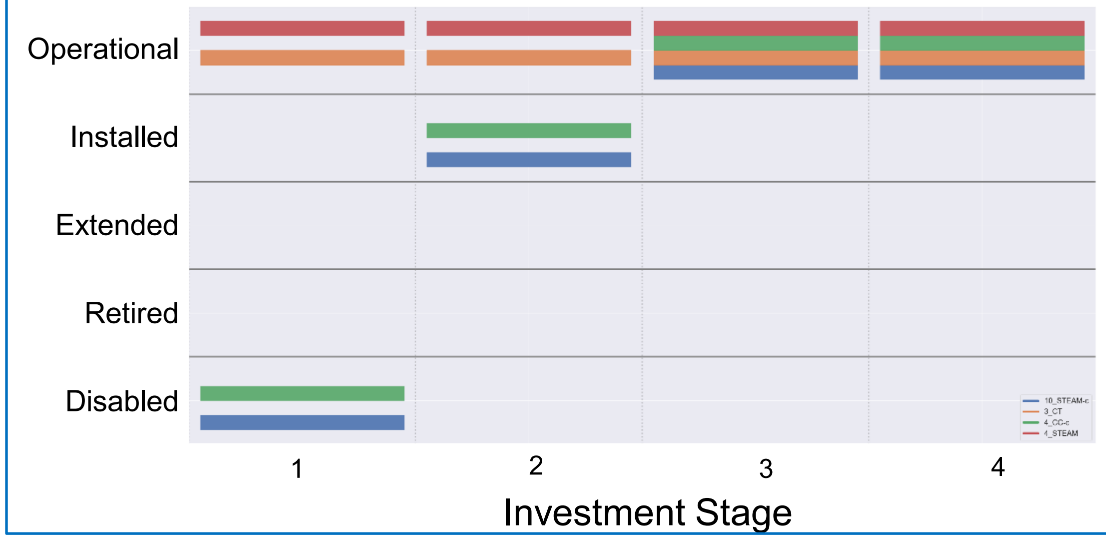
The whole IDEAS GTEP architecture can be built on trusted, unit-tested components (e.g., EGRET, PRESCIENT, etc.) in a plug-and-play fashion

Generalized Viz

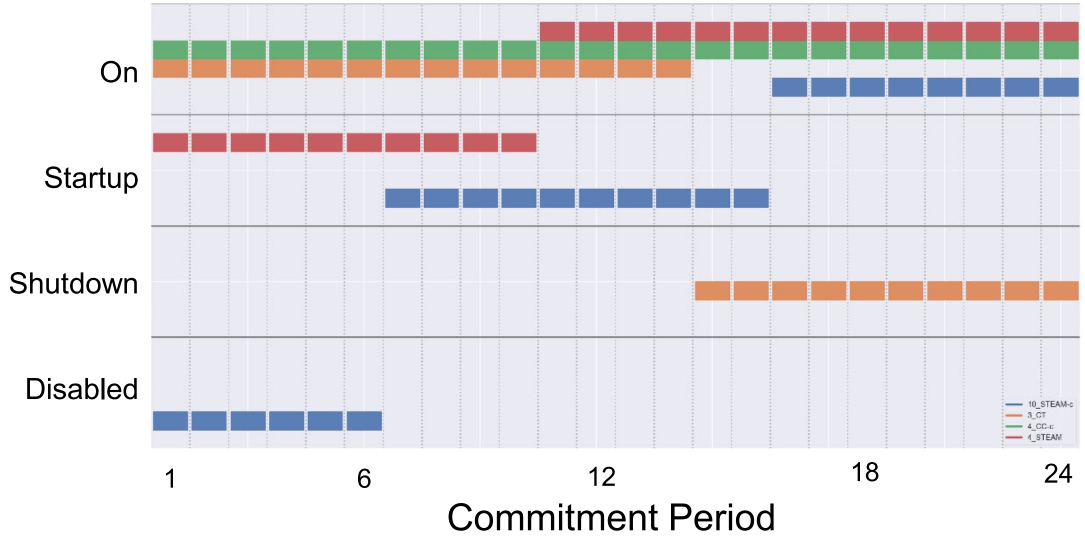
TRANSMISSION INVESTMENT STATUS



GENERATION INVESTMENT STATUS



UNIT COMMITMENT STATUS



Consistent architecture means visualization & analysis are straightforward for any questions about sets of Boolean decision variables

What IDAES GTEP Is ***NOT***

Simulation Tool

Policy Predictor

Stability Analysis

Market Model

What IDAES GTEP *IS*

Model Selection Optimization

Infrastructure Planning Optimization

Plant-Grid Interaction Optimization

Reliability / Resilience Optimization

Capabilities

Present and Accessible

- Planning Decisions
  - Generation
  - Transmission
- Flow Models
  - Copperplate
  - DCOPF
- Temporal Scale
  - Hourly UC
  - Hourly ED
  - Daily Rep. Periods
  - Yearly GTEP
- Test Cases
  - 5 Bus
  - 11 Bus
  - 31 Bus

Present and Guide-able

- Planning Decisions
  - Storage
- Temporal Scale
  - Arbitrary and consistent
- Test Cases
  - 133 Bus
- Visualization Tools
- Validation and Verification via Prescient

Near Future (<6 months)

- Planning Decisions
  - Undergrounding
  - Reconductoring
  - Reliability
- Algorithmic
  - Stochastic
  - Decomposition
- Temporal Scale
  - Arbitrary and inconsistent
- Test Cases
  - 2000/7000 Bus

Mid Future (<2 years)

- Planning Decisions
  - Resilience
- Algorithmic
  - AOS
  - Automated (Dis-) Aggregation
- Flow Models
  - ACOPF
- Test Cases
  - 10,000 Bus Geolocated [including line paths] CA

Where do I find IDAES GTEP?

REPO

https://github.com/IDAES/idaes-gtep

DOCS

https://idaes-gtep.readthedocs.io/en/latest/

QUESTIONS/CONTACT

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