Exploring Nuclear Fuel Cycle (NFC) Simulation using HTCondor

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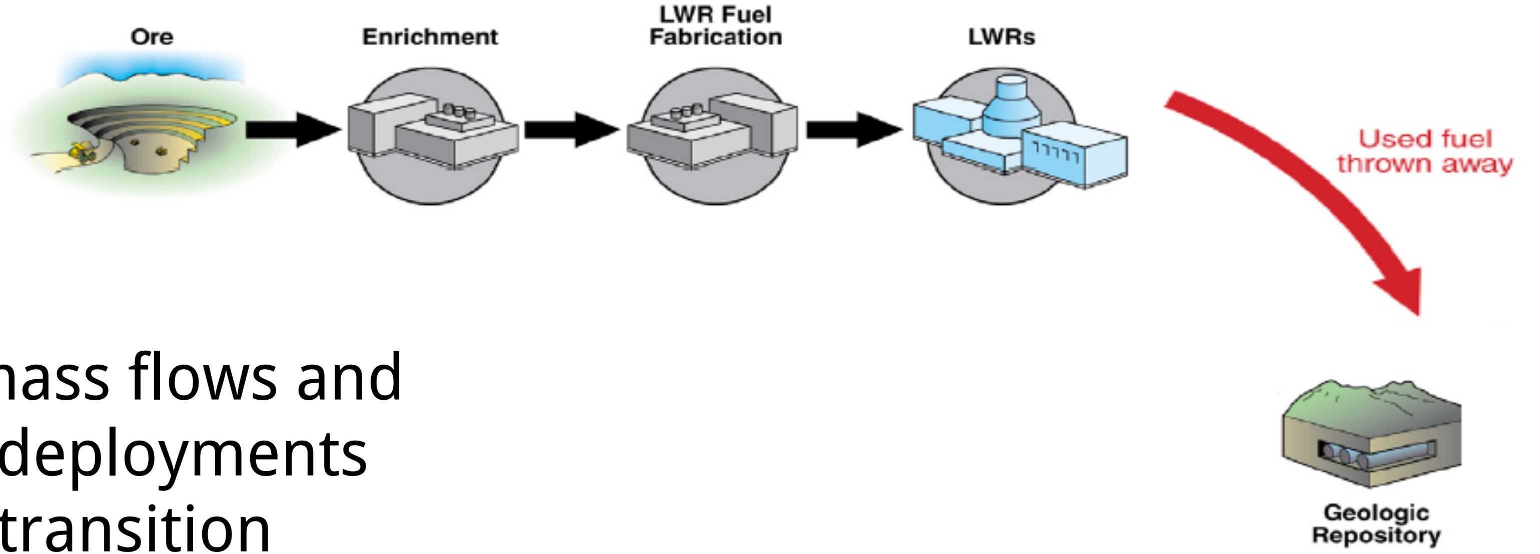
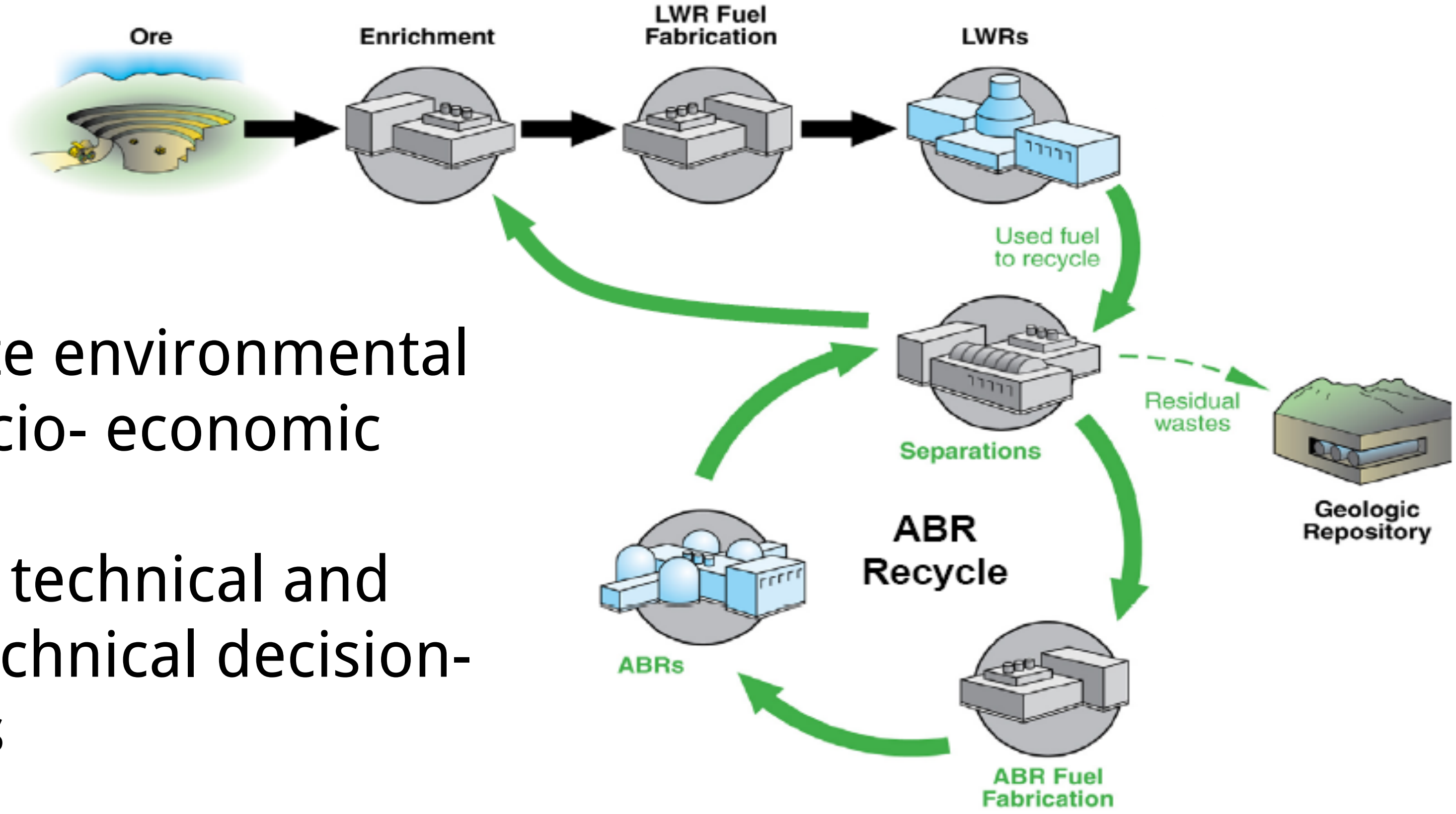
HTCondor Week, 05/21/15

Fuel Cycle Simulator - Purpose



- Track mass flows and facility deployments during transition between alternative nuclear fuel cycles

Fuel Cycle Simulator - Purpose



- Evaluate environmental and socio- economic impact
- Inform technical and non- technical decision- makers

Difficulties

- Reactor performance depends on fuel isotopics
- Commodities are fungible
- Supply chain with recycling
- "Unlimited" possible fuel cycles

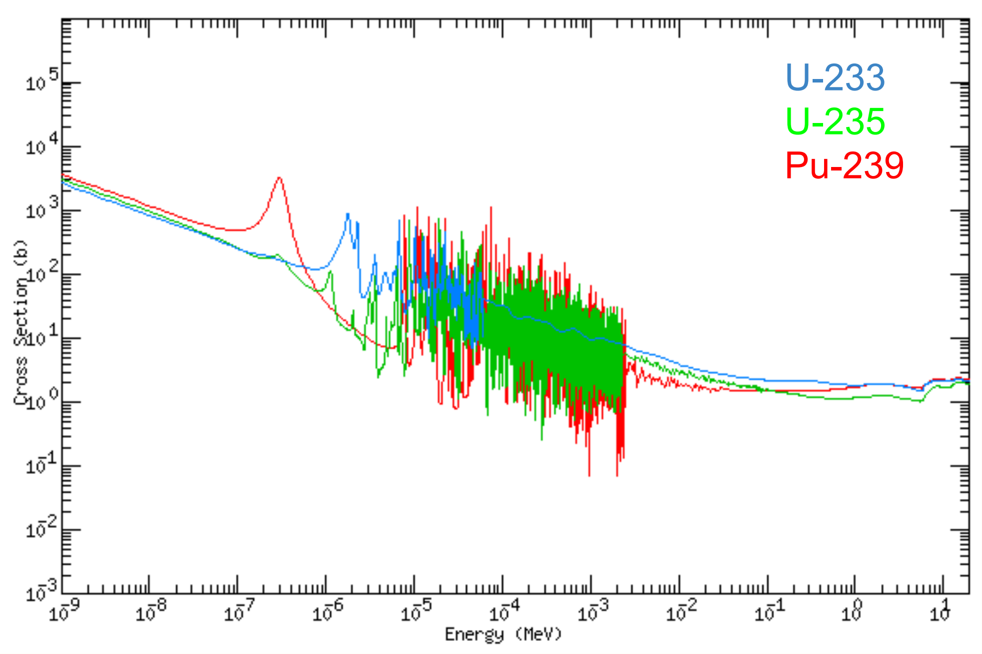
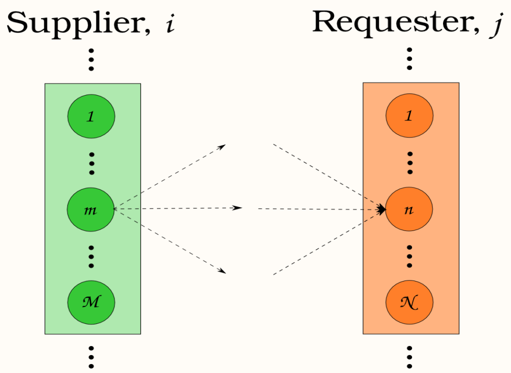
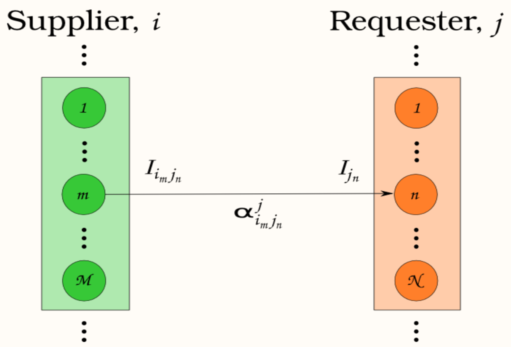


Fig: Fission Cross Section [1]

Dynamic Resource Exchange

- DRE: Core algorithm for fuel cycle simulation
- Supplier and requester agents
- Recomputed at each time step
- Solves economic problem dynamically; no hard-coded supply-demand behavior
- Enables complicated fuel cycles





DRE Phases

Request for Bids

Queries each requesting Agent in the simulation that ***demands*** a resource

Response to Request for Bids

Queries each responding Agent in the simulation that ***supplies*** a resource

Preference Adjustment

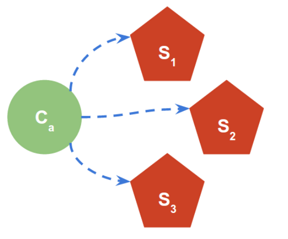
Agent ***reviews*** all matches; opportunity for preference adjustment

Solution

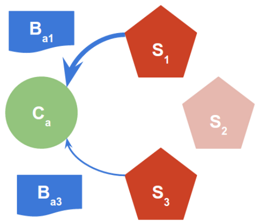
Matches ***selected*** for satisfiable requests

Trade Execution

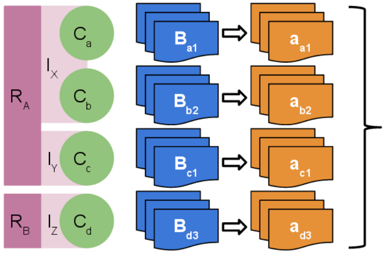
Material ***transaction*** takes place



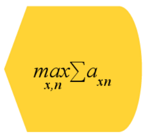
Phase 1: Request for bids



Phase 2: Response to request for bids



Phase 3: Preference Adjustment



Phase 4: Market Resolution

DRE Constraints

- Agents define conversion functions for constraint coefficients
  - input: proposed resource quality
  - output: unit capacity coefficient
- Allows arbitrary physics/chemistry fidelity

$$\sum_{j \in J} f_{SWU}(\varepsilon_j) x_{i,j}^{EU} \leq s_{i,SWU}$$

$$\sum_{j \in J} f_{NU}(\varepsilon_j) x_{i,j}^{EU} \leq s_{i,NU}$$

→

$$\sum_{j \in J} \beta_{i,k}(q_j^h) x_{i,j}^h \leq s_{i,k}$$

NFC LP Formulation

Variable	Description
H, h	Commodities
I, i	Bids
J, j	Requests
K, k	Capacities
c	Cost of commodity
x	Decision variable
β	Capacity coefficient
s	Supply capacity
d	Demand capacity

$$\min_{x} \quad z = \sum_{i \in I} \sum_{j \in J} \sum_{h \in H} c_{i,j}^{h} x_{i,j}^{h}$$

$$\text{s.t.} \quad \sum_{j \in J} \sum_{h \in H} \beta_{i,k} x_{i,j}^{h} \leq s_{i,k} \qquad \forall\, k \in K_I, \forall\, i \in I$$

$$\sum_{i \in I} \sum_{h \in H} \beta_{j,k} x_{i,j}^{h} \geq d_{j,k} \qquad \forall\, k \in K_J, \forall\, j \in J$$

$$x_{i,j}^{h} \geq 0 \qquad \forall\, x \in X$$

NFC MILP Formulation

Variable	Description
H, h	Commodities
I, i	Bids
J, j	Requests
K, k	Capacities
c	Cost of commodity
x, y	Decision variable
β	Capacity coefficient
s	Supply capacity
d	Demand capacity

$$\min_{x,y} \; z = \sum_{h \in H} \sum_{i \in I} \sum_{j \in J_p} c_{i,j}^h x_{i,j}^h + \sum_{h \in H} \sum_{i \in I} \sum_{j \in J_e} c_{i,j}^h y_{i,j}^h \tilde{x}_j^h$$

$$\text{s.t.} \quad \sum_{j \in J_p} \beta_{i,k}(q_j^h) x_{i,j}^h + \sum_{j \in J_e} \beta_{i,k}(q_j^h) y_{i,j}^h \tilde{x}_j^h \leq s_{i,k}^h$$

$$\forall\, i \in I,\ \forall\, k \in K_i^h, \forall\, h \in H$$

$$\sum_{i \in I} \sum_{h \in H_j} \beta_{i,k}(q_j^h) x_{i,j}^h \geq d_j(H_j) \qquad \forall\, k \in K_j,\ \forall\, j \in J_p$$

$$\sum_{i \in I} \sum_{h \in H_j} \beta_{i,k}(q_j^h) y_{i,j}^h \tilde{x}_j^h \geq d_j(H_j) \qquad \forall\, k \in K_j,\ \forall\, j \in J_e$$

$$\sum_{h \in H} \sum_{i \in I} y_{i,j}^h = 1 \qquad \forall\, j \in J_e$$

$$x_{i,j}^h \geq 0 \qquad \forall\, x \in X$$

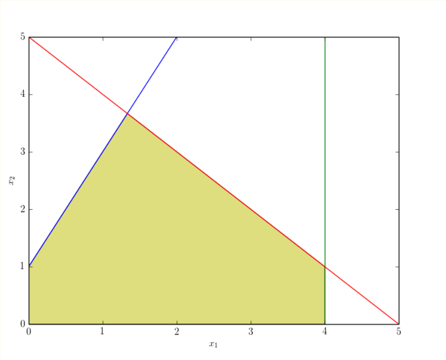
$$y_{i,j}^h \in \{0, 1\} \qquad \forall\, y \in Y$$

Simulation Behavior on Run Time

- Dynamic
  - population (problem size)
  - reactor fuel requirements (problem instance)
  - available fuel types (connectivity)
- Different fuel cycles
- Different solution techniques
  - Optimal solution
  - Relaxations
  - Heuristics

An Exploratory Tool

- mattgidden.com/cyclopts/
- Define bounds and discretization of parameter space
- Define a parameter->simulation->instance translation
- Provide a suite of solvers
- Can run locally or...



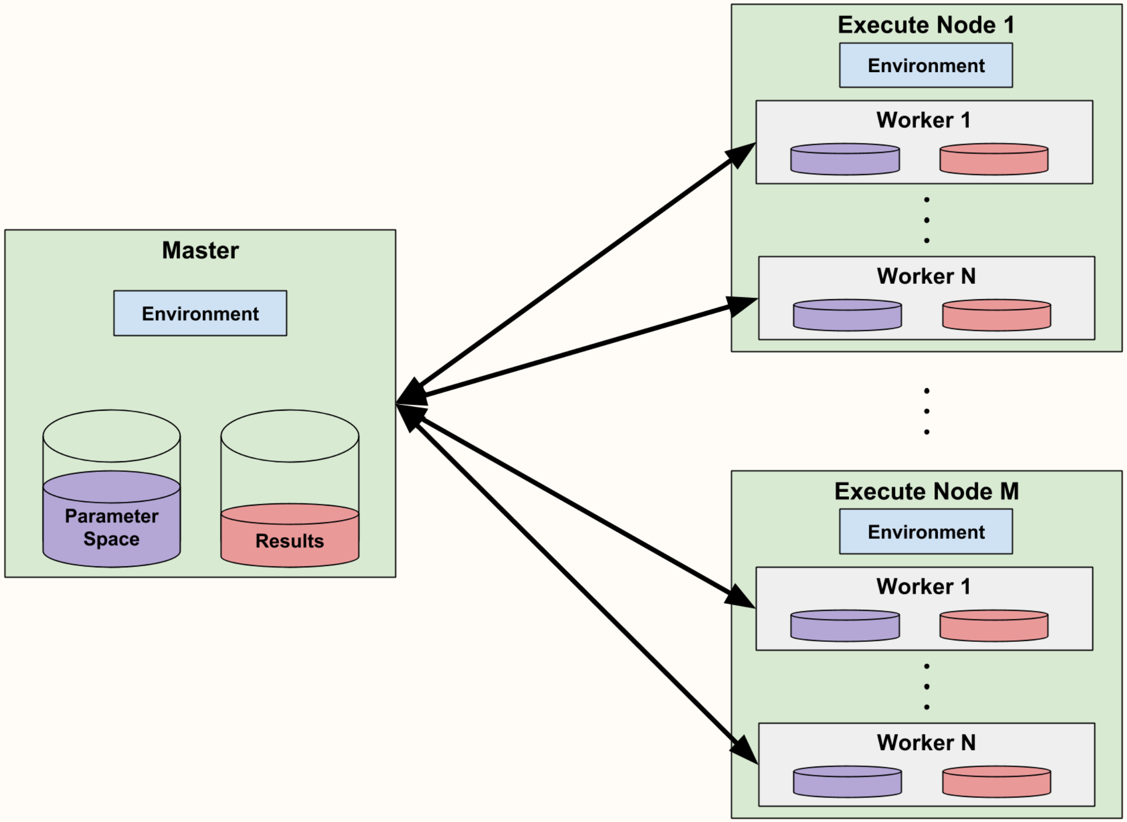
$$\min_{x} \; z = c^\top x \quad \text{s.t.} \; Ax \geq b, \quad x \geq 0$$

$$z^* = c^\top x^*$$

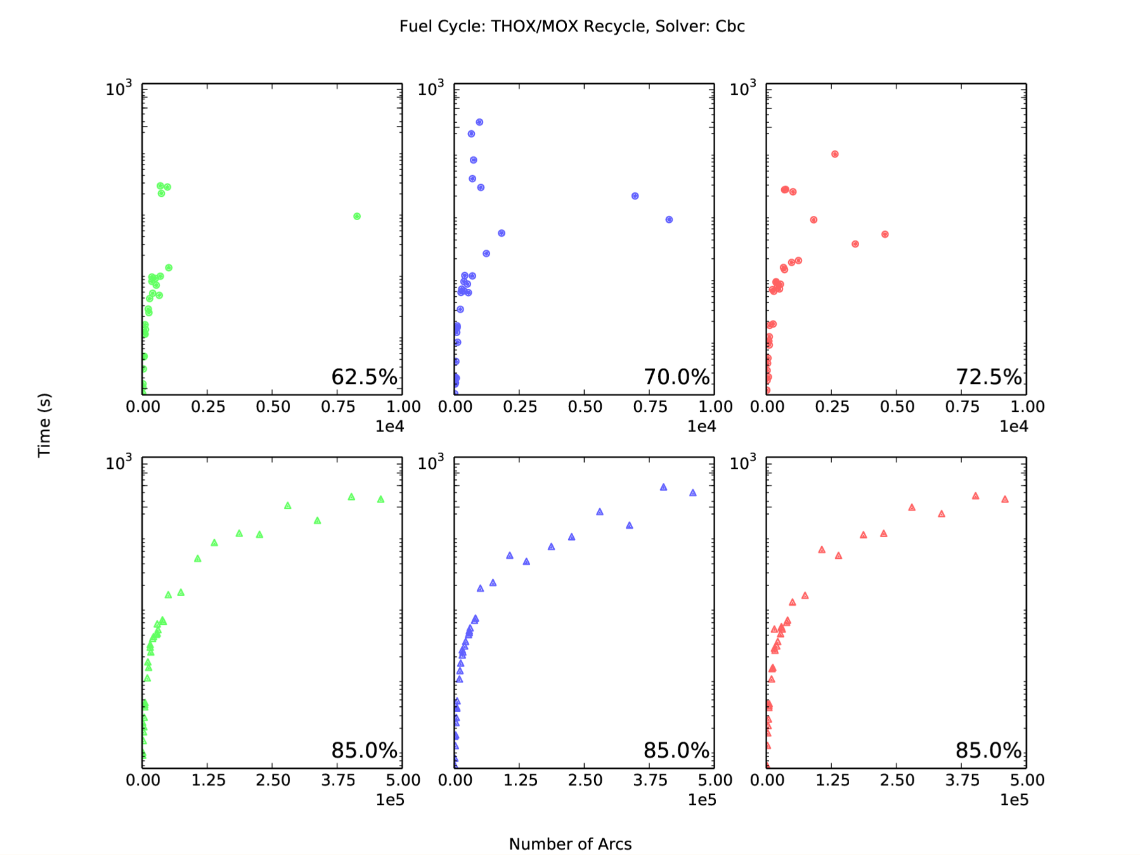
Using HTCondor

- Specify non-multithreaded nodes if timing study
- workqueue master-worker framework
- Master
  - parameter space database
  - CDE environment
  - queue of parameter points to solve
- Workers
  - translate point to simulation state and optimization instance
  - solve instance
  - send back state, instance, and solution

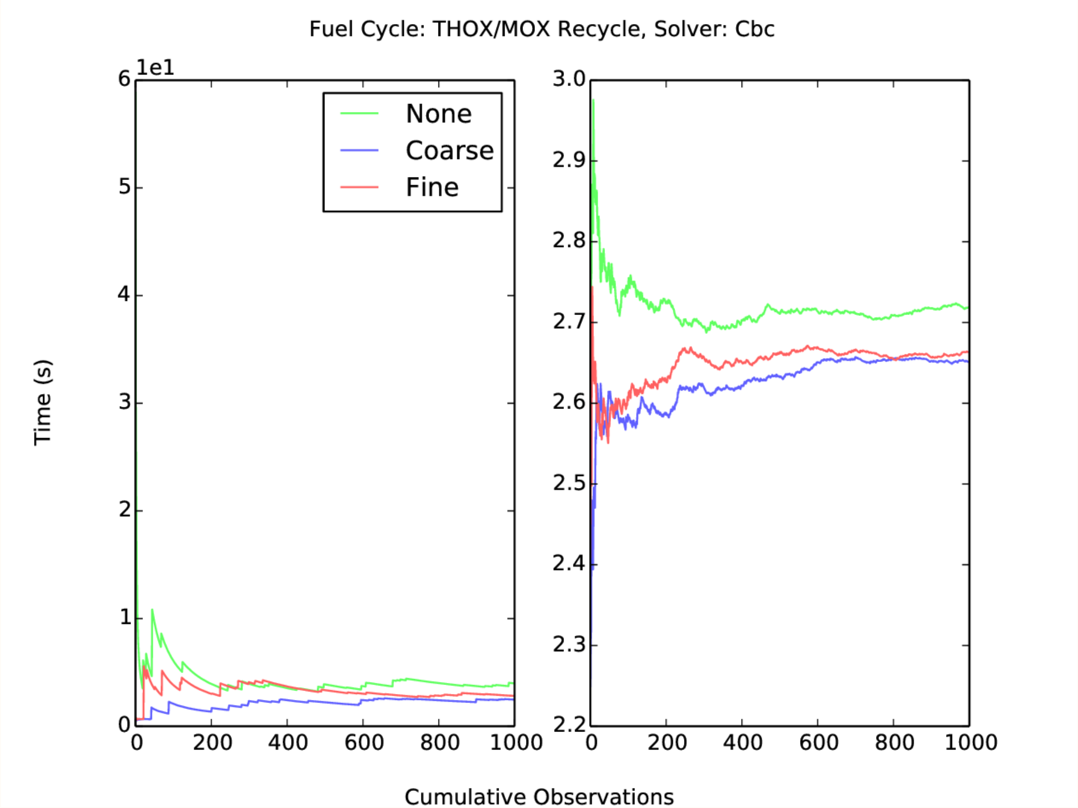
Using HTCondor



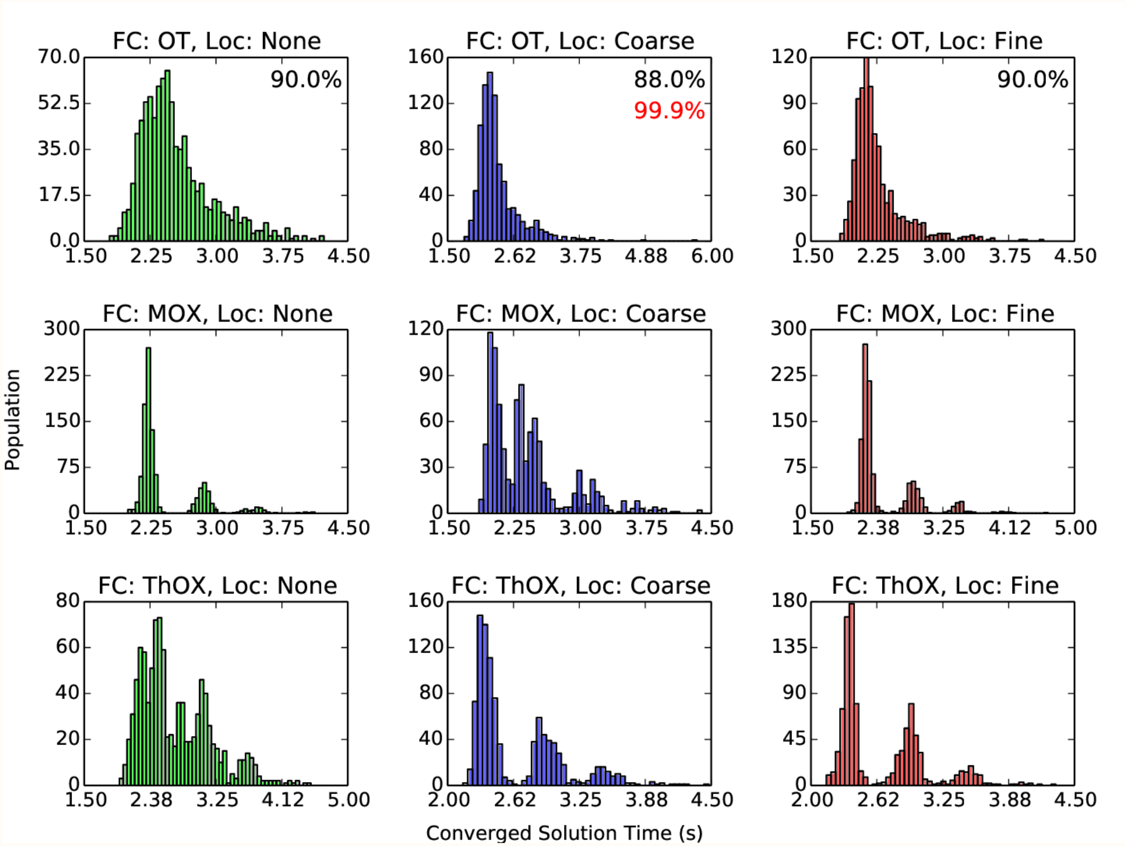
Scalability



Stochasticity



Stochasticity



Questions?

fuelcycle.org

Citations

[1] Korea Atomic Energy Institute Table of Nuclides, http://atom.kaeri.re.kr/, accessed 29-10-2014