Intelligent Power Scheduling on the Client Side

Design Of A Smart Grid Agent

Terry Zimmerman, Stephen F. Smith

The Robotics Institute
Carnegie Mellon University
Pittsburgh PA 15213

6th Annual Carnegie Mellon Conference
on the Electricity Industry

Carnegie Mellon

Intelligent Coordination and Logistics Laboratory

The Robotics Institute, Carnegie Mellon University

Stephen F. Smith, Research Professor and Director

Focus: *Scalable, execution-driven technologies for planning and scheduling*

- Distributed management of joint plans for coordinating disaster relief operations

– Data-Driven Congestion Management & Traffic Control

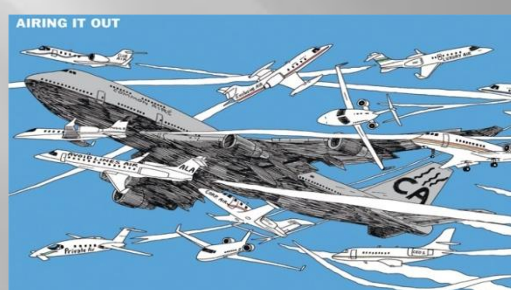


Illustration by Peter Arkle for the New York Times - 26 August 2007

– Dynamic airspace management

– Short-term Scheduling for the USAF Air Mobility Command

Revolutionary upgrades to the century-old power grid are underway… Major goals include:

- Improved grid reliability
- Reduced peak demand / Increased efficiency
- Integration of distributed energy resources (DER)

Centralized approaches for leveraging these improvements from the supplier side abound…

We present a distributed 'client-side' * approach that targets the system-wide goals, ***and*** *…*

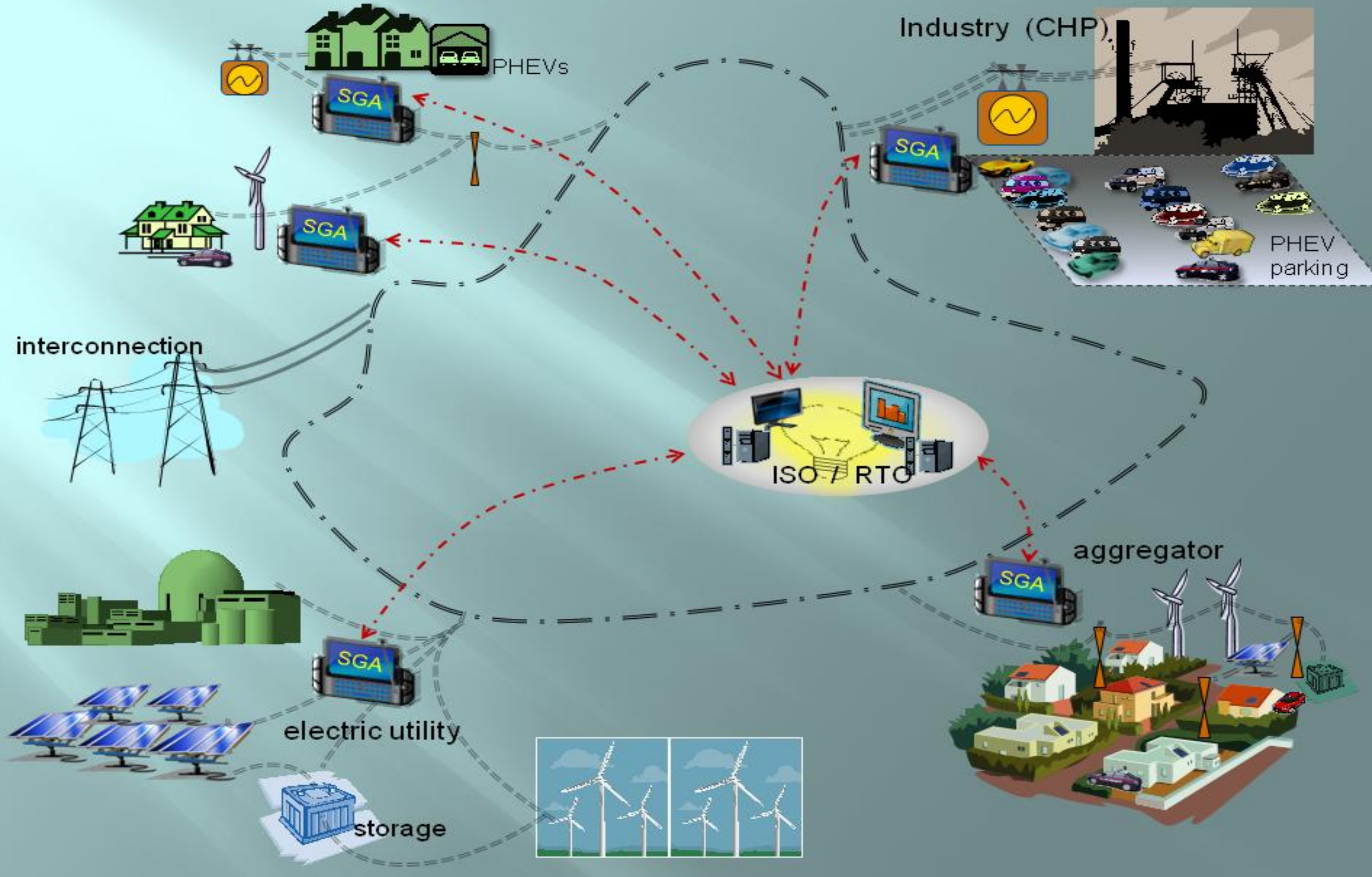
- Works autonomously to maximize client reward (minimize cost)
- Respects client preferences and constraints
- Maximizes client privacy
- Accommodates high levels of uncertainty and unexpected events

* *where electric grid 'clients' are increasingly likely to be producers as well as consumers.*

Overview

Core Ideas:

- Exploit ***scheduling*** technology to manage client-side energy usage, production and storage
  - Incorporate client constraints and preferences
  - Use communicated hourly price profiles to maximize client economic reward
  - Project usage profiles back to the grid operations to support demand forecasting
  - Adjust schedules in response to real-time pricing changes
- Combine with ***multi-agent coordination*** techniques to enable collaboration among clients within larger power cooperatives
  - Share projected supply and demand peaks
  - Negotiate joint scheduling commitments to maximize collective reward
  - Minimize need to expose private information
- Integrative concept: ***Smart Grid Agent (SGA)***



Smart Grid Agents situated in the electric power marketplace

Smart Home Example

Schedulable Loads	Power Sources	Storage
Ambient temp control, Water heater, Pool mgnt, PHEV charging, etc.	Photovoltaic, Wind turbine, Buy from grid	PHEV batteries

-- Constraints --		
Grid	System	Client
Projected 24 hr electricity price profile	Freezer defrost cycle must run once per mo. PHEV batteries must be fully charged at least once per week.	Keep room temp. in [min, max] range, Need ≥ 75% charge on vehicle by 8 AM, Only clean pool when price < x

Objective:	Construct daily schedule that maximizes economic return, subject to client constraints

CHP Example

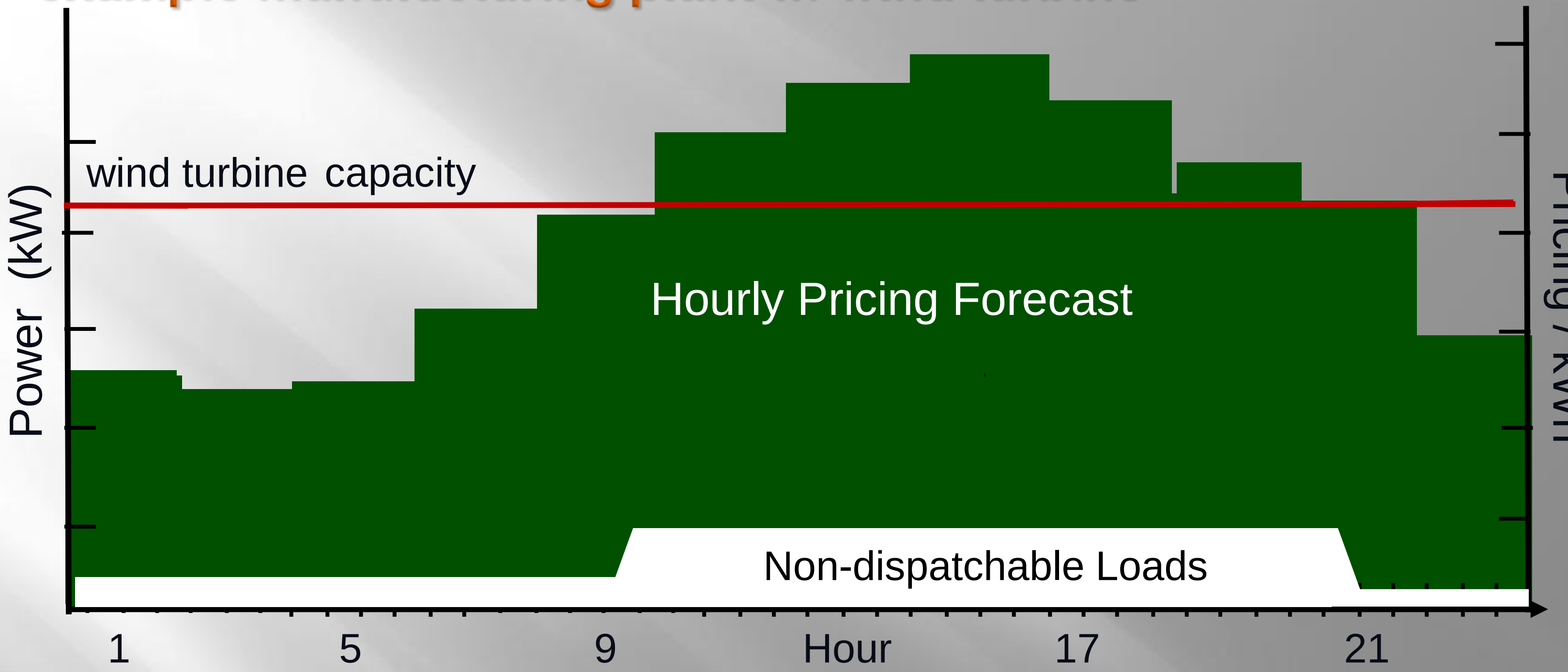
Schedulable Loads	Power Sources	Storage
Ambient Heating, Metal hot roll –lot D, Metal coating –lot D	Cogeneration: gas turbine heat/power, Buy from grid	PHEV batteries in employee parking lot

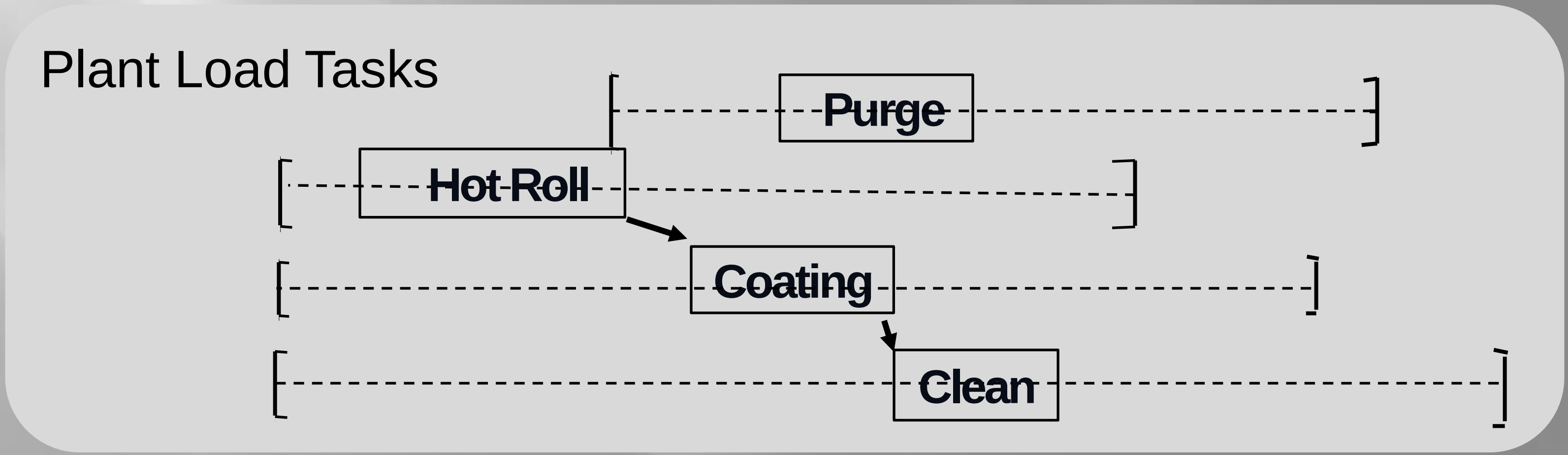
-- Constraints --		
Grid	System	Client
Projected price profile (24 hours)	Hot rolling process precedes coating process - 1 hour max. separation	Keep room ambient temp. for staff in [min, max] range, Coating window: 4 PM-midnight

Objective:	Construct daily schedule that maximizes economic return, subject to client constraints

Real-Time Power Scheduling

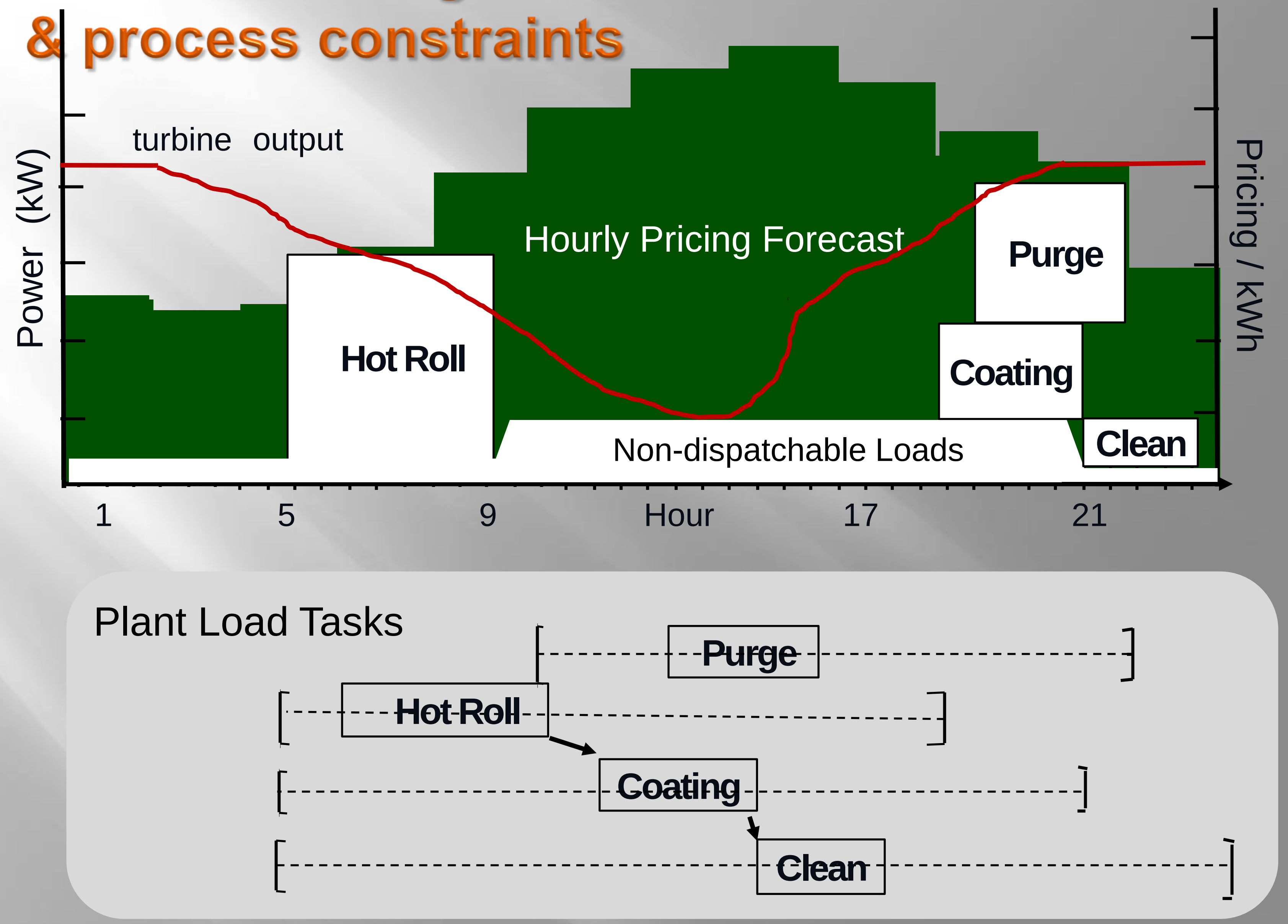
- - example manufacturing plant w/ wind turbine





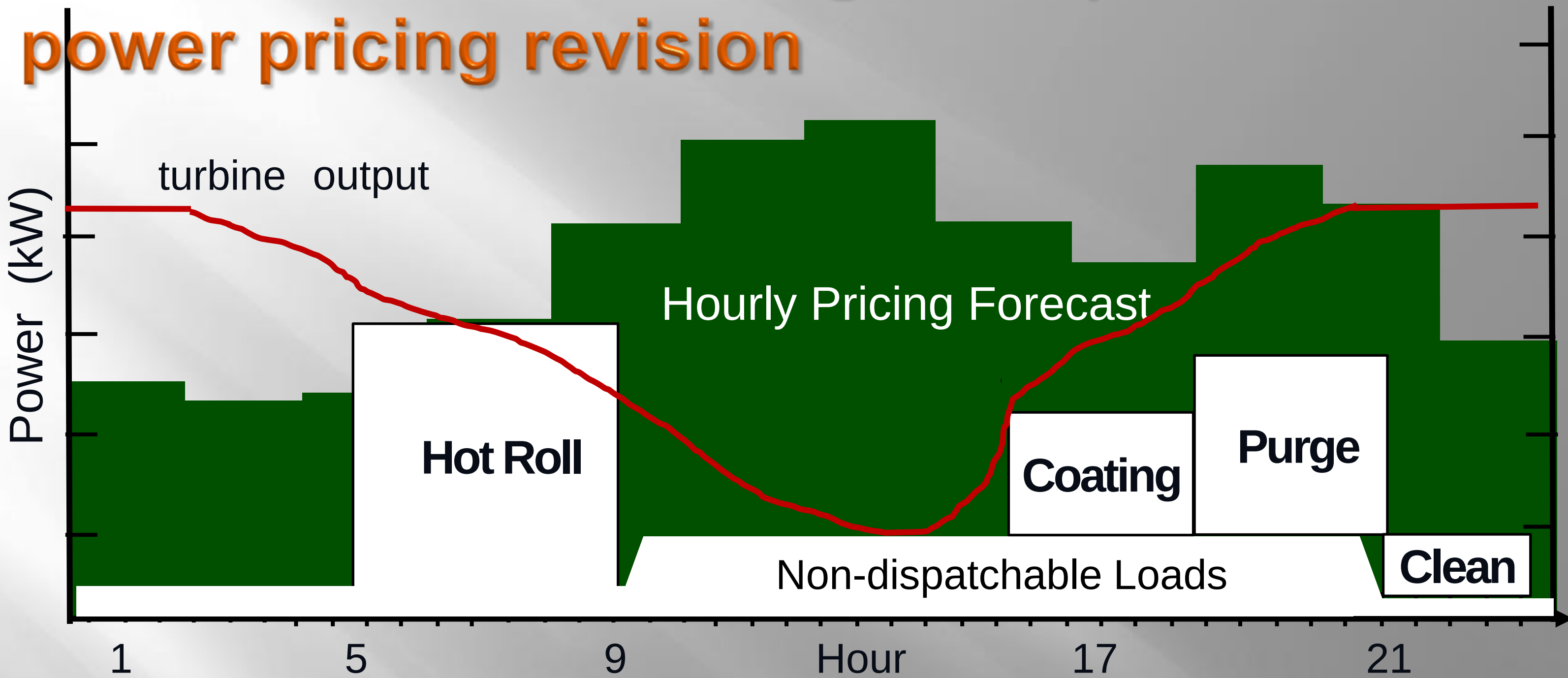
Real-Time Power Scheduling

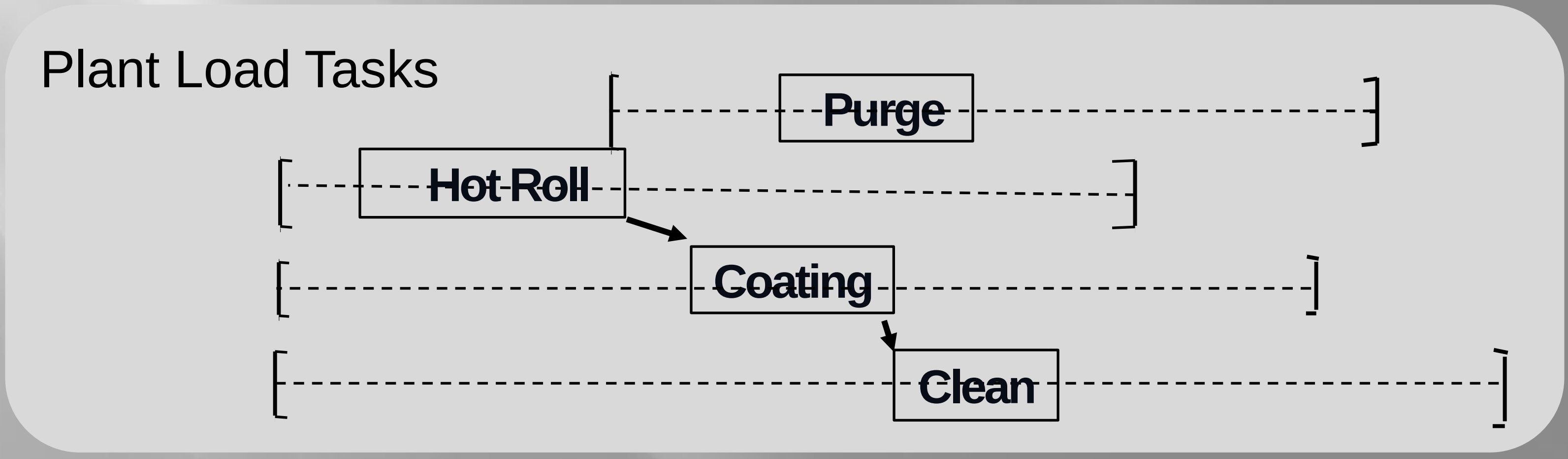
Profit-maximizing schedule consistent with client & process constraints



Real-Time Power Scheduling

Incremental rescheduling in response to real-time power pricing revision



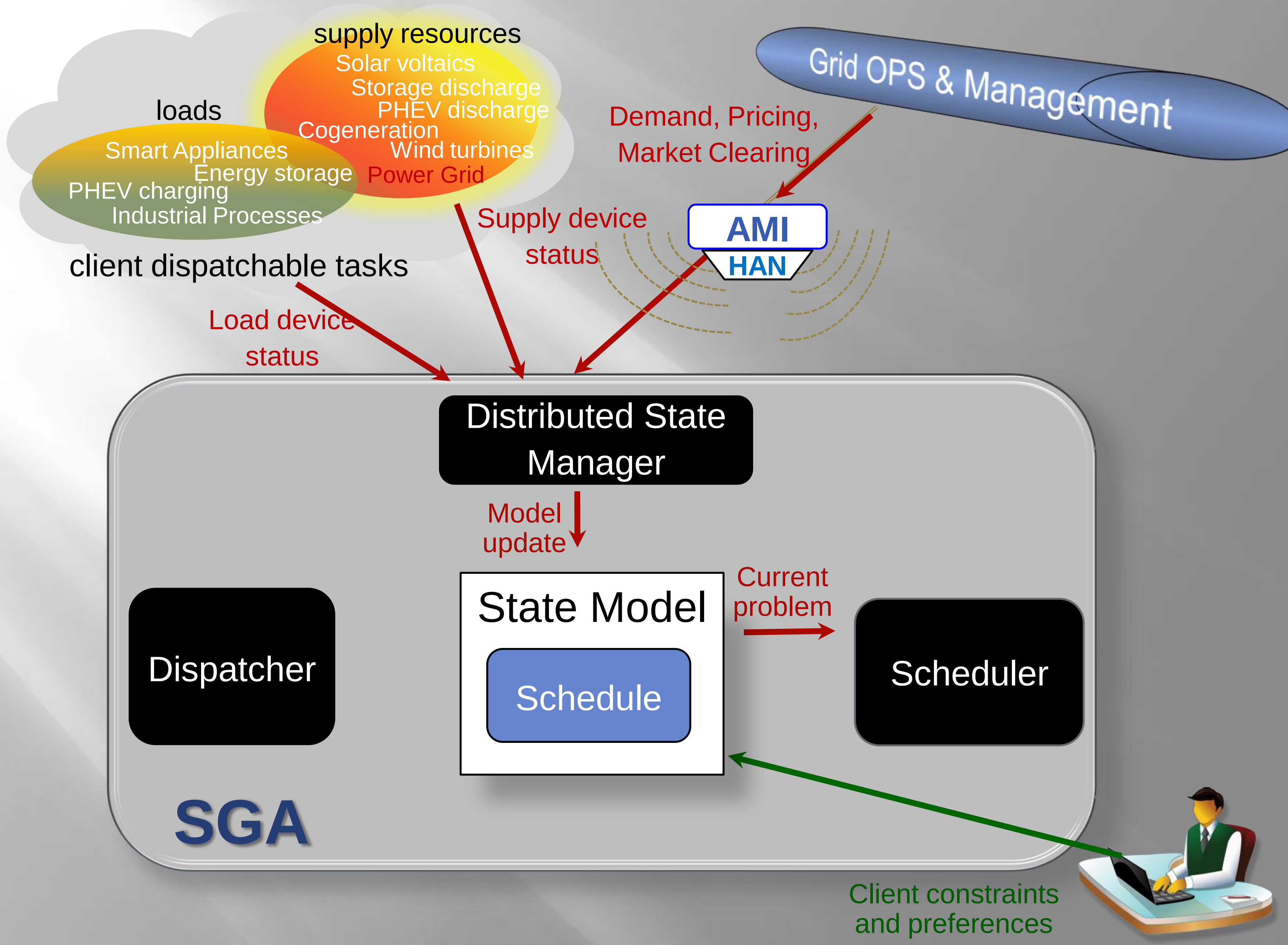


Power Management Approach

- Compute start and end times for power consumption, production and storage activities that optimize client’s economic return
- Treat collaborative commitments as additional constraints on activity start and end times
- Use this schedule to drive real-time dispatch decisions (i.e., initiation of energy transfer actions)
- Exploit *robust scheduling* techniques to hedge against uncertainty in price profiles and retain dispatch flexibility
- Exploit *incremental optimization* techniques to respond to price profile changes while respecting established collaborative commitments

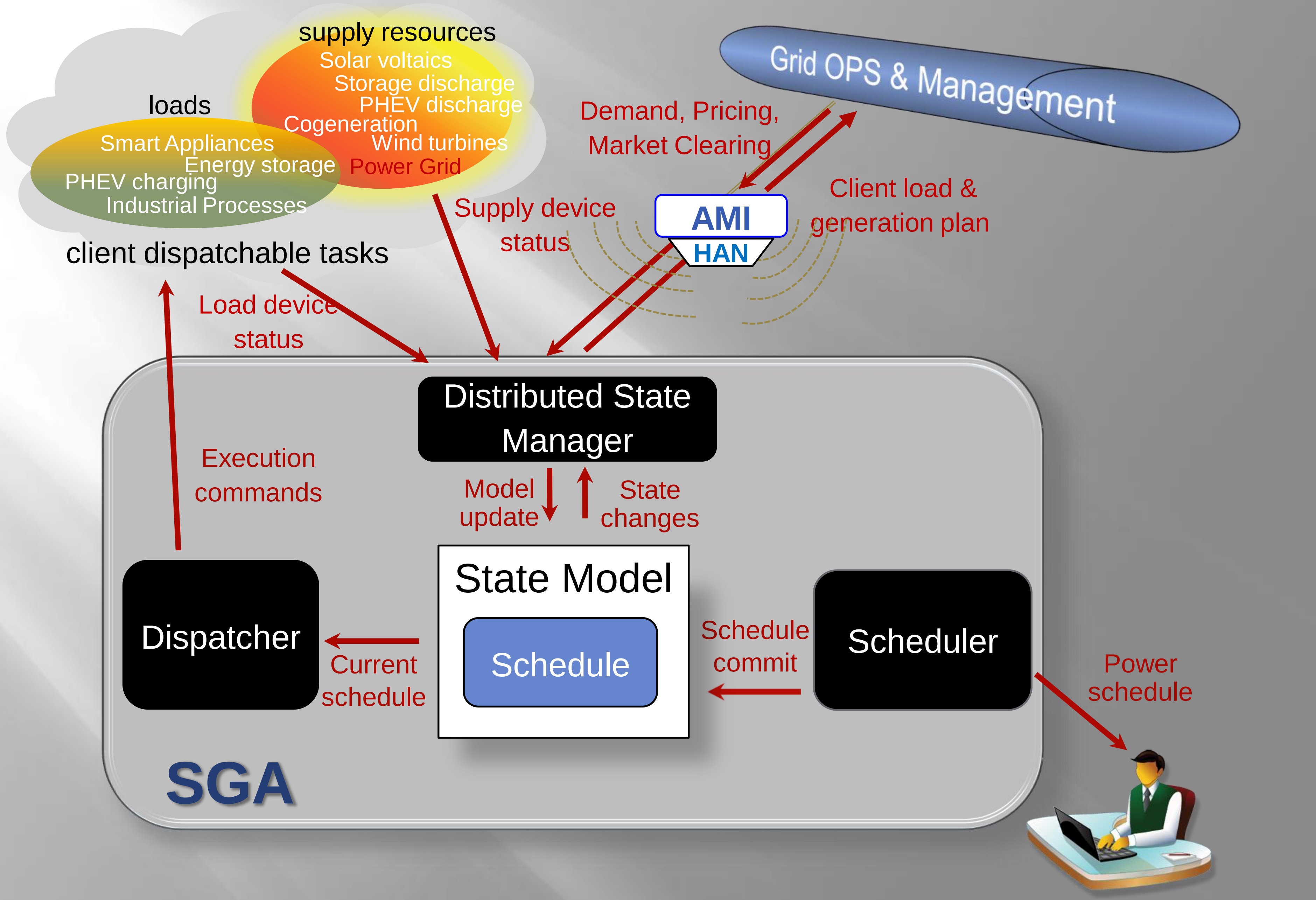
Smart Grid Agent

Problem constraints



Smart Grid Agent

Scheduling, Execution and Iteration

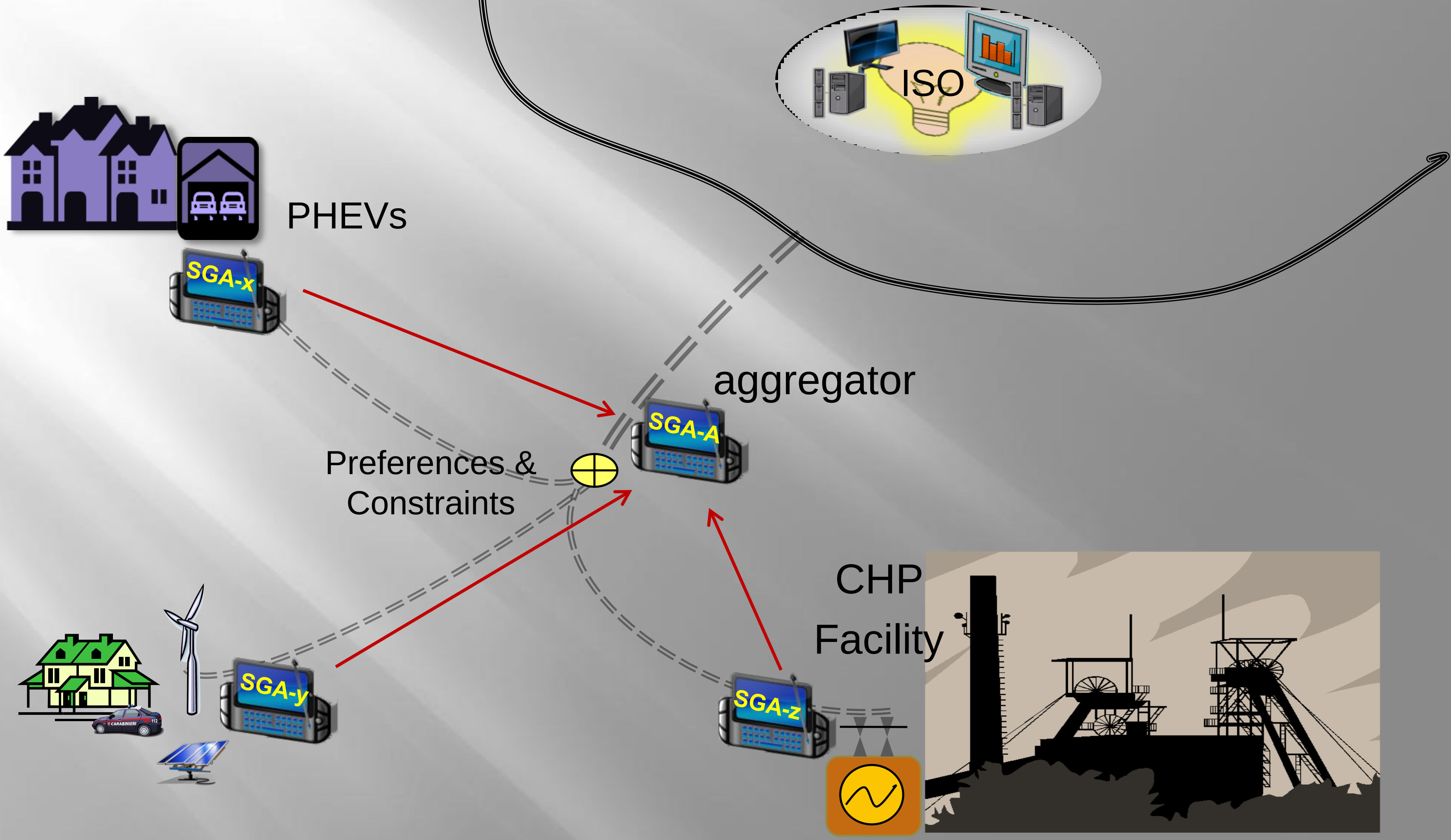


The Smart Grid Agent: One of Many

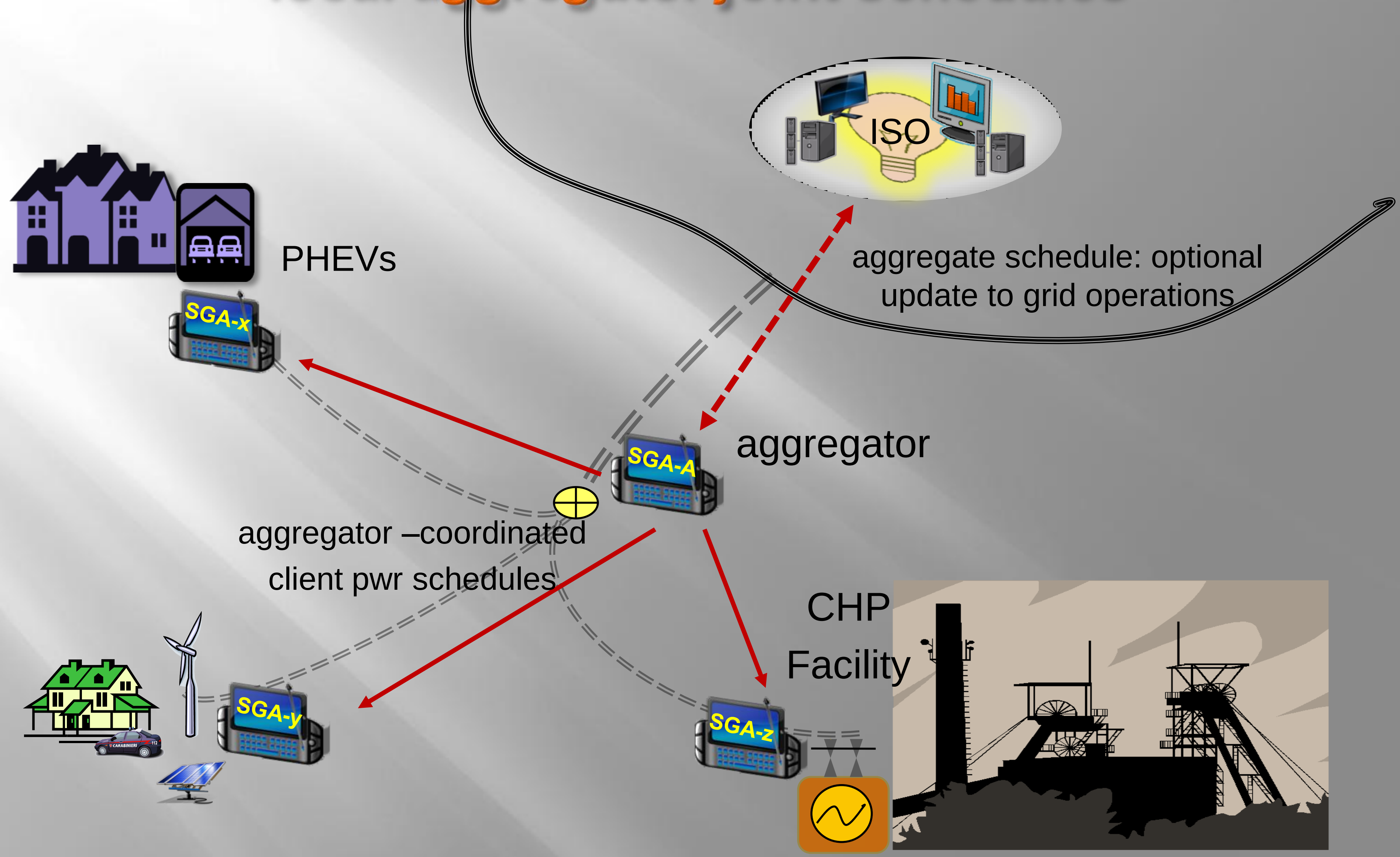
Multi-agent coordination *supports*

- ❖ Collaboration amongst members of ‘power cooperatives’ in the interest of maximizing members collective reward
  - o Cooperation increases need for and *boosts the impact of* ‘trivial’ Smart Home power scheduling
- ❖ Increased power reliability for cooperative members *and* the regional grid
  - o “Islanding” concept (DOE)
  - o More effective leveling or time-shifting of demand peaks than a single client can achieve
  - o Coordinated implementation of ‘adaptive load management’ and price-responsive demand

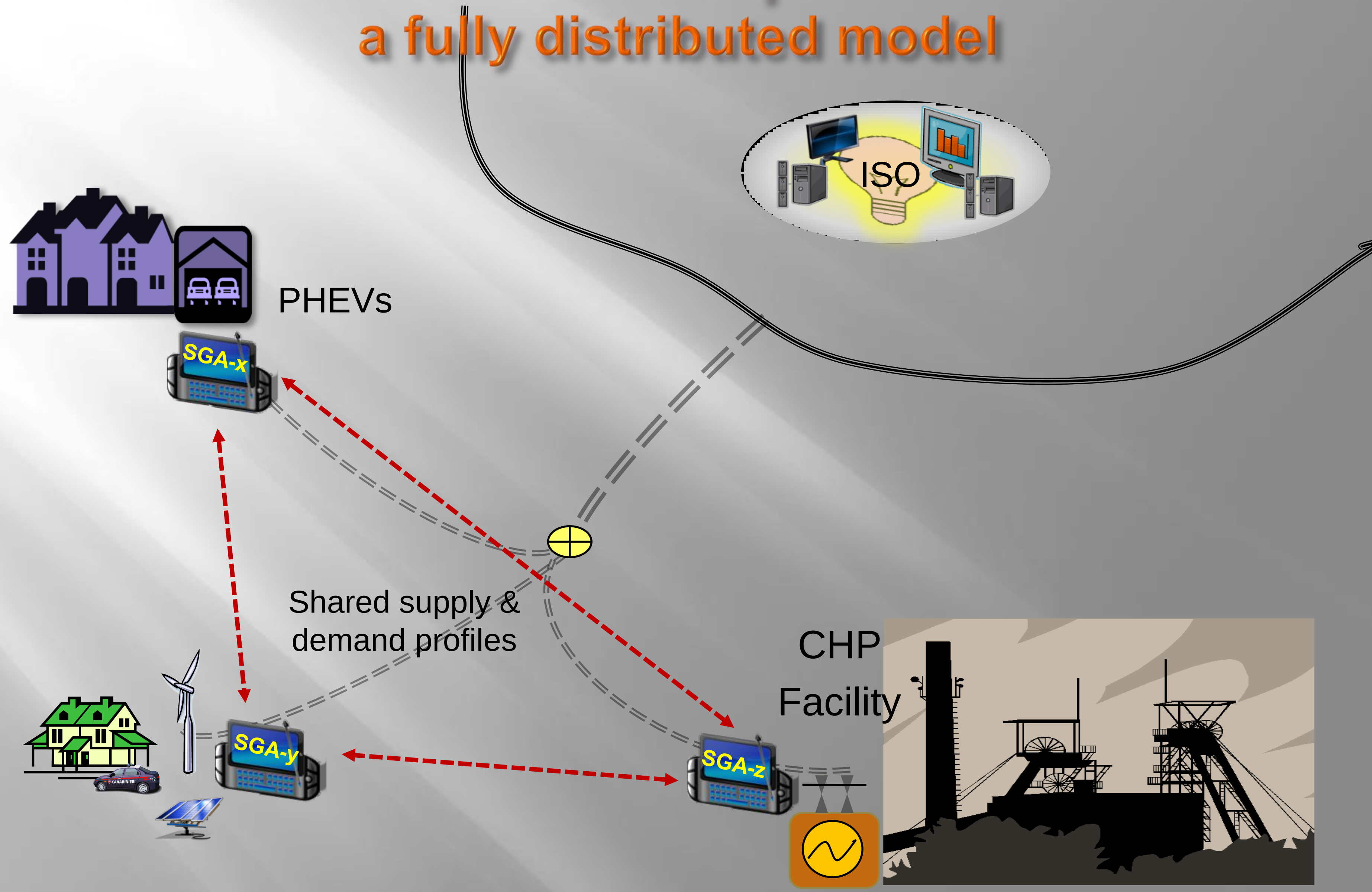
SGAs in Cooperation
A local aggregator model



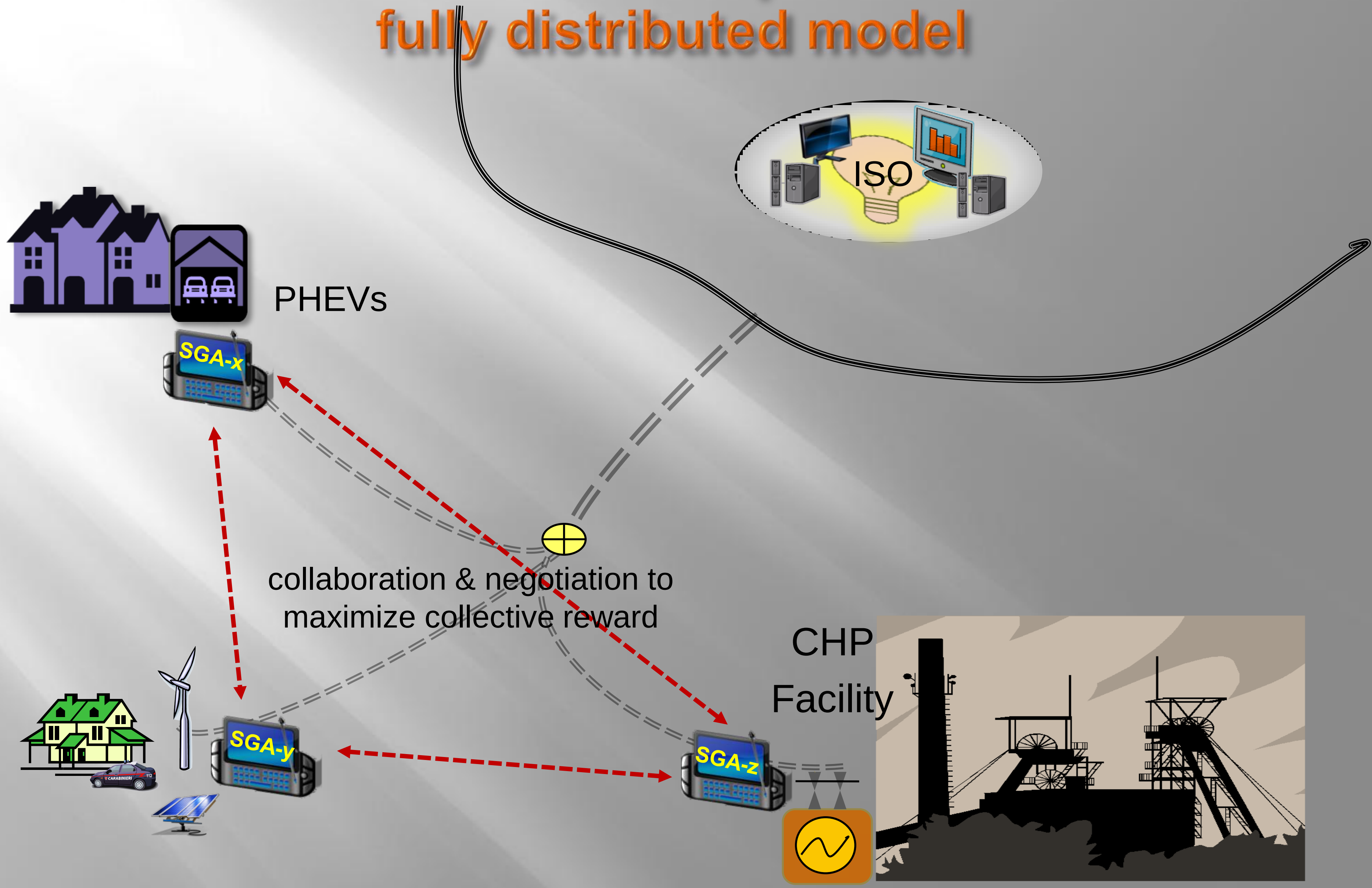
SGAs in Cooperation
local aggregator joint schedules



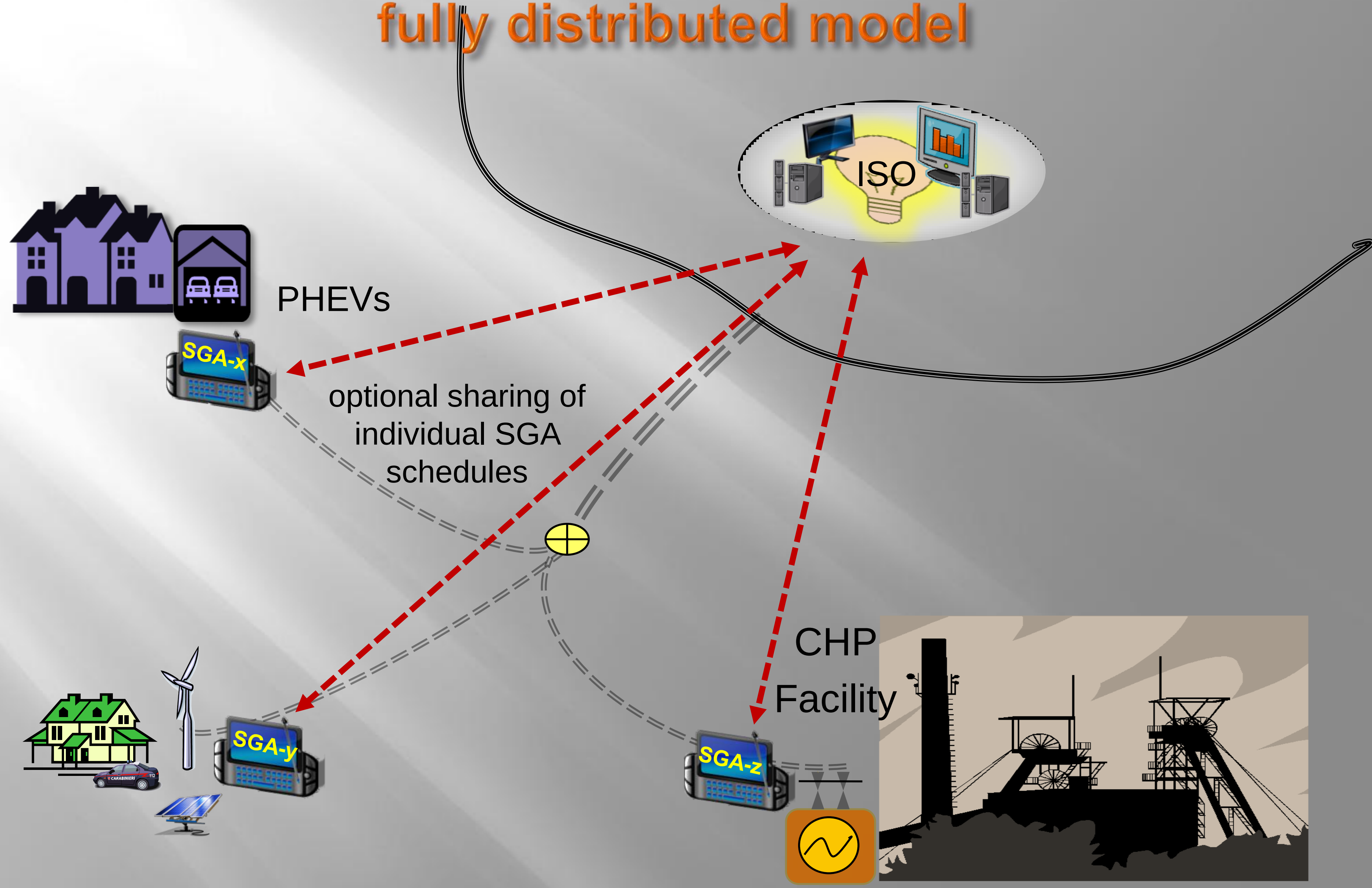
SGAs in Cooperation
a fully distributed model



SGAs in Cooperation
fully distributed model



SGAs in Cooperation
fully distributed model



Research Issues:

- Scheduling to maximize economic return
  - Incorporating price profile constraints
  - Effective response to price changes
  - Adjustable autonomy – according to client interest
  - Configurable models of client system dynamics (e.g., smart home templates)
- Protocols for integrating supply and demand of collaborating SGAs
  - Alternative auction mechanisms
  - Regulatory constraints
  - Dynamic versus structured hierarchical organization

In Summary: The Smart Grid Agent Advantage

- A flexible approach, adaptable across a range of clients: *smart homes - aggregators - CHP facility - micro-grid*
- Energy conservation / Cost Minimization on the client side *with minimal client involvement*
- Leveling or time-shifting of demand peaks (particularly for collaborating SGAs)
- Support for grid operations *while* respecting privacy
  - Less intrusive alternative to '*Non-Intrusive Load Monitoring' (NILM)*
  - Client control over what is shared and when
- Infrastructure and opportunity for more stable distributed power management (as DER and storage capabilities expand)
- Close relationship to *JIT, JIP, JIC* concepts

Relevant ICLL Pubs

Barbulescu, L., Smith,S.F., Rubinstein, Z., Zimmerman, T. "Distributed Coordination of Mobile Agent Teams: The Advantage of Planning Ahead", *To Appear* in Proceedings of AAMAS 2010, May 2010.

Smith,S.F. Gallagher, A., Zimmerman, T., Barbulescu, L., and Rubinstein, Z. "Distributed management of flexible times schedules," In Proceedings of AAMAS 2007, May 2007.

Hiatt, L., Zimmerman, T., Smith, S.F., and Simmons, R. "Strengthening schedules through uncertainty analysis," In Proceedings of IJCAI-09, 2009.

Gallagher, A., Zimmerman, T., and Smith, S.F. "Incremental scheduling to maximize quality in a dynamic environment". In Proceedings of the International Conference on Automated Planning and Scheduling, 2006.

Wang, X., and Smith, S. 2005. "Retaining flexibility to maximize quality: When the scheduler has the right to decide durations." Proceedings of the 15Th International Conference on Automated Planning & Scheduling.

Policella, N.; Wang, X.; Smith, S.; and Oddi, A. 2005. "Exploiting temporal flexibility to obtain high quality schedules". In Proceedings of AAAI-05