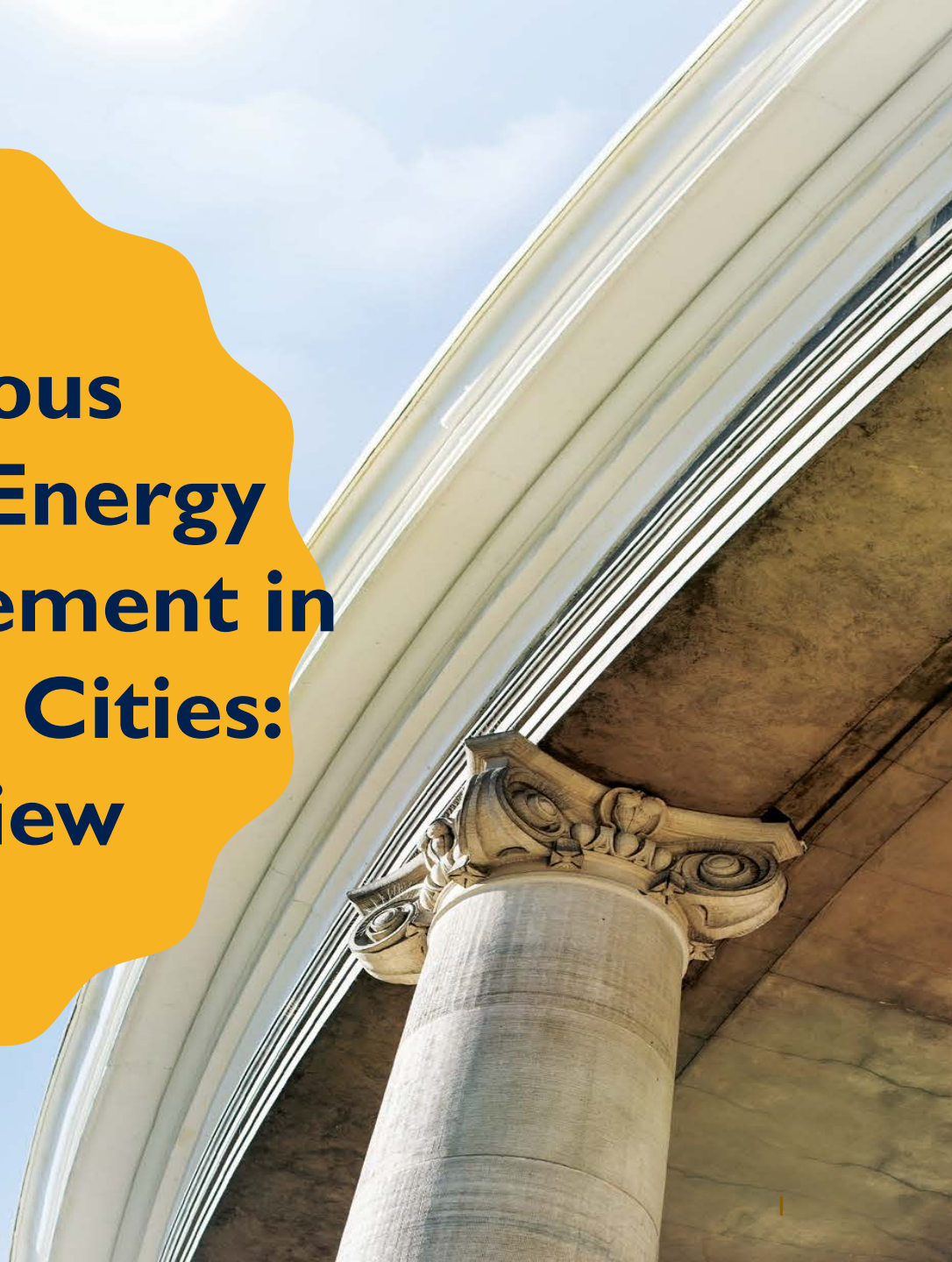
UNIVERSITY OF TORONTO

# Autonomous Mobility and Energy Service Management in Future Smart Cities: An Overview



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# Outline

- **Urban Mobility and Energy Future**
  - issues in current cities
  - need for change: disruptive transformations
  - a three-layered view
- **Autonomous Service Management**
  - AMoD: autonomous mobility-on-demand
  - AFoD: autonomous flexibility-on-demand
  - challenges of coordination between AMoD and AFoD
- **Conclusions**

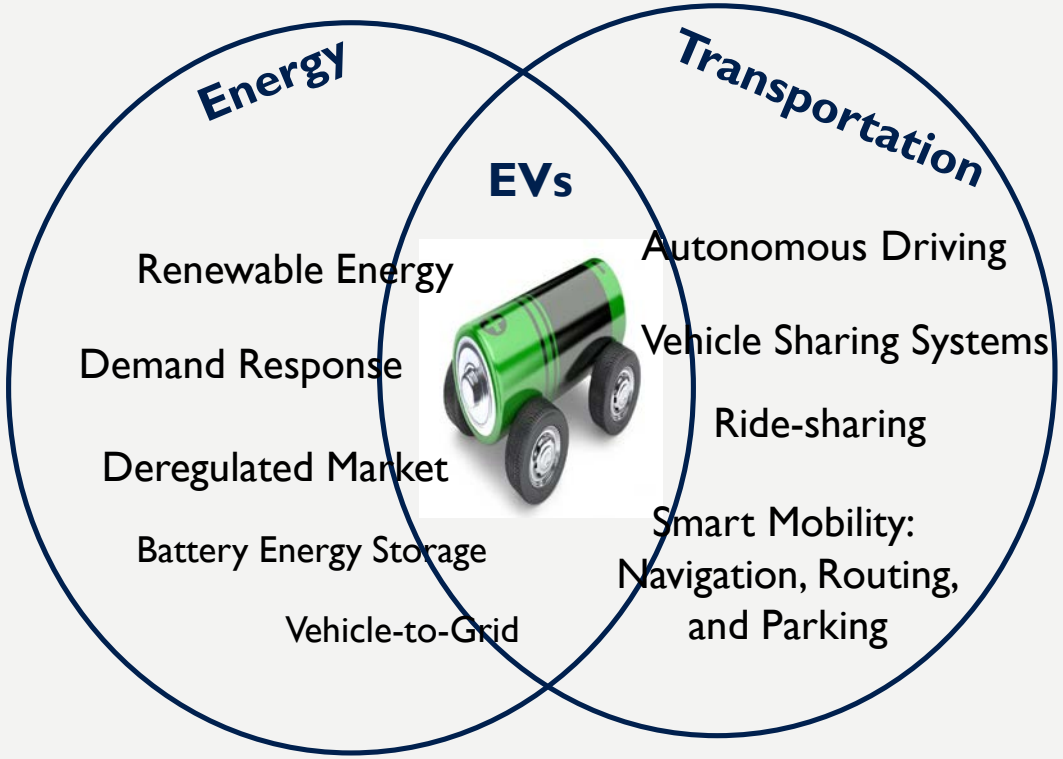
# Issues in Current Cities

- **Urbanization**
  - over 50% of current population is living in cities, will rise to 70% by 2050.
- **Energy Sector**
  - not smart and clean enough.
- **Environment Sector**
  - climate change.
  - air pollution.
- **Transportation Sector**
  - traffic congestion.
  - limited parking space.
- **Infrastructure**
  - road networks, housing, etc.

# Disruptive Transformations

- **Automobile**
  - electric vehicles
  - autonomous driving
- **Energy**
  - distributed energy resources
  - demand-side management
  - electricity market deregulation
  - battery energy storage

  } **vision of smart grid**
- **Transportation**
  - advancement in sensing, monitoring, control technologies
  - innovative business models: user-centric, app-based, and on-demand access to ride-sharing, bike-sharing, etc.




**Proliferation of (autonomous) EVs can potentially create a converged urban mobility and energy systems**



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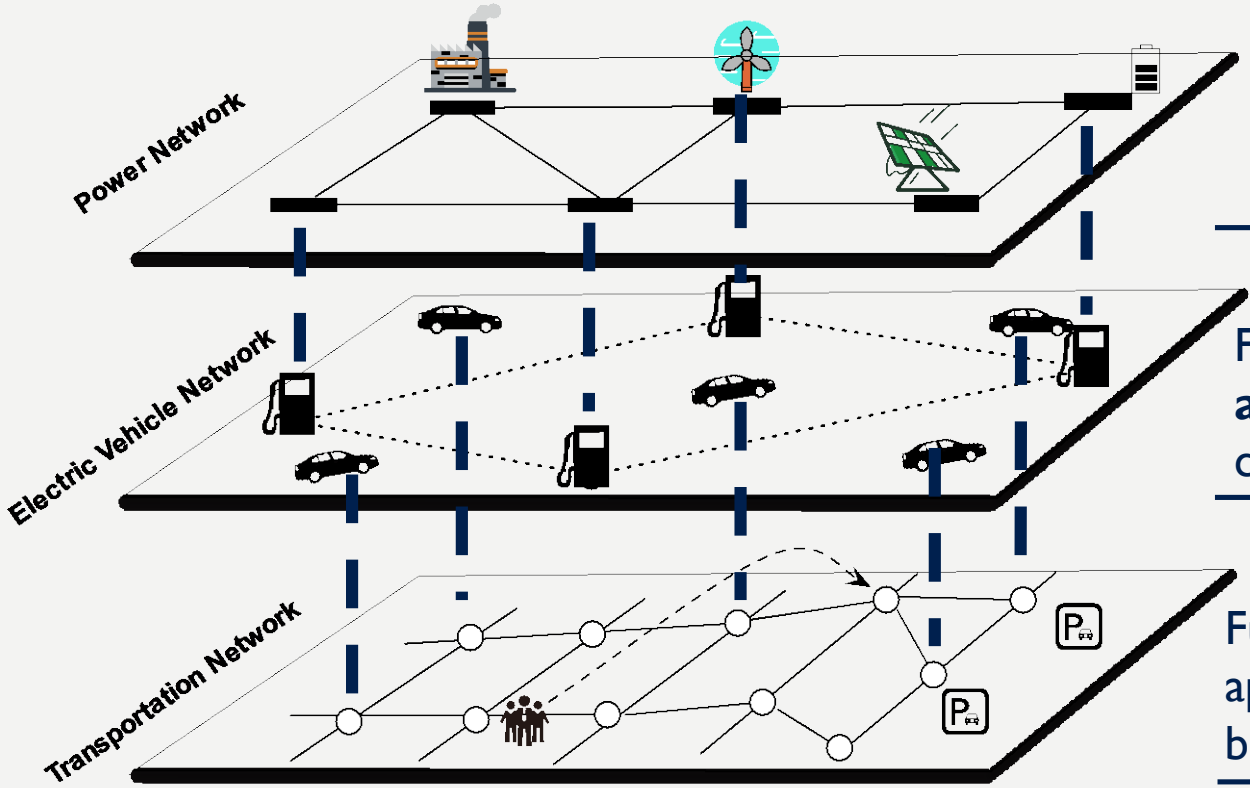
# A Three-Layered View

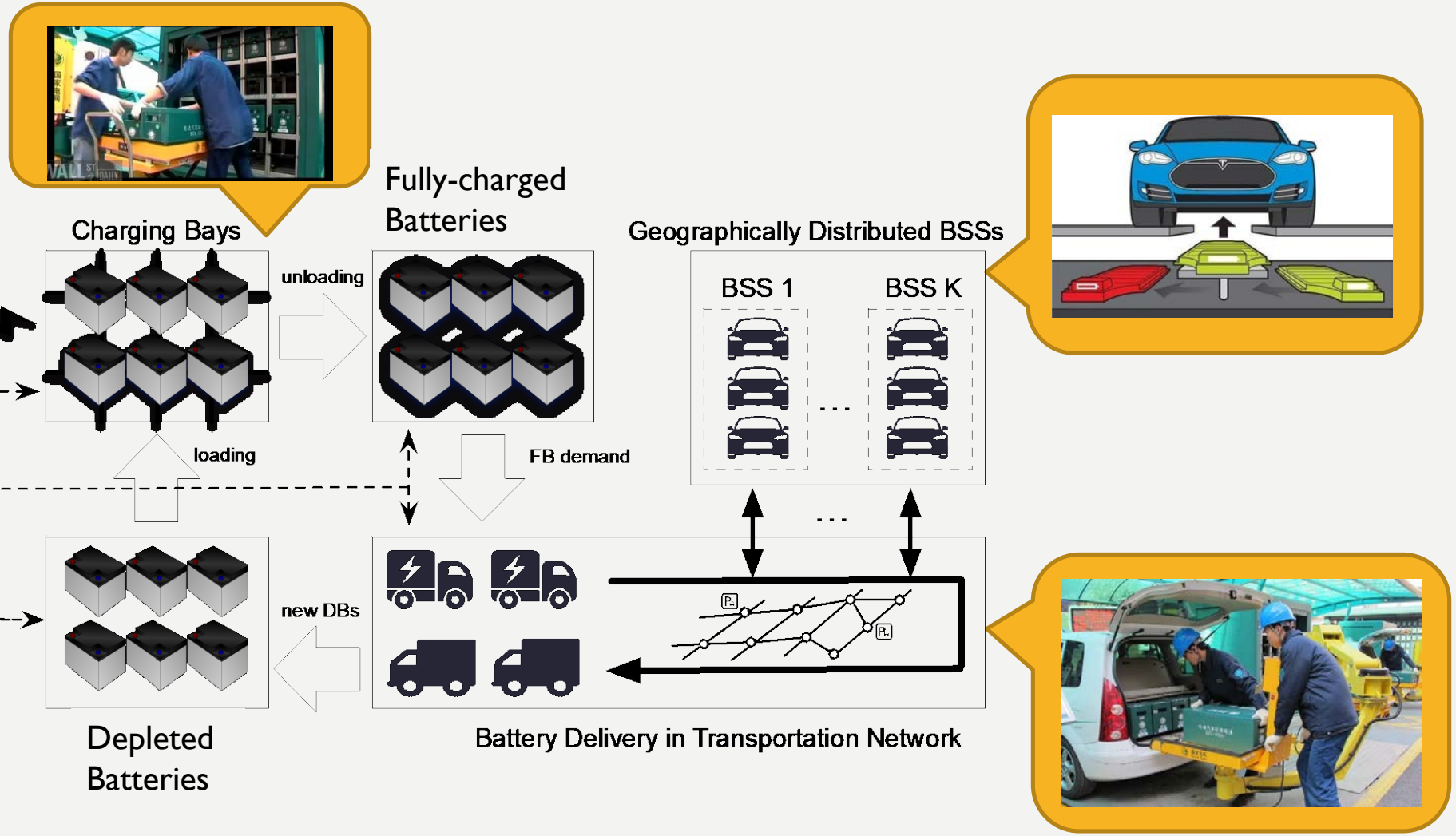



Future power grid will have high penetration of **distributed energy resources**, supported by advanced **demand-side management** techniques.

Future vehicles will be **electrified** and **autonomous**, supported by a network of plug-in charging stations and/or battery swapping stations.

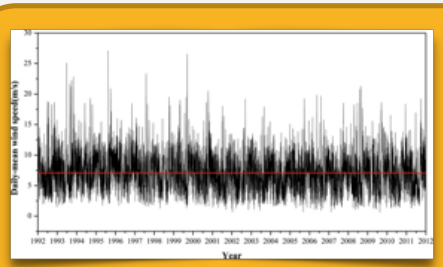
Future urban mobility systems will be **user-centric**, app-based on-demand access, with **shared mobility** being ubiquitous.

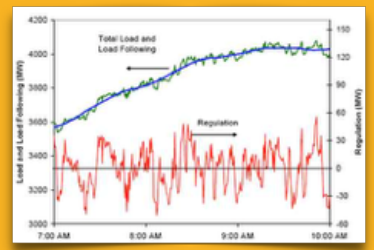
# A Three-Layered View: An Example*




* X. Tan, et al, " Optimal Scheduling of Battery Charging Stations Serving Electric Vehicles Based on Battery Swapping," *IEEE Transactions on Smart Grid, in press.*

# Autonomous Service Management





smoothing volatile
renewable energy

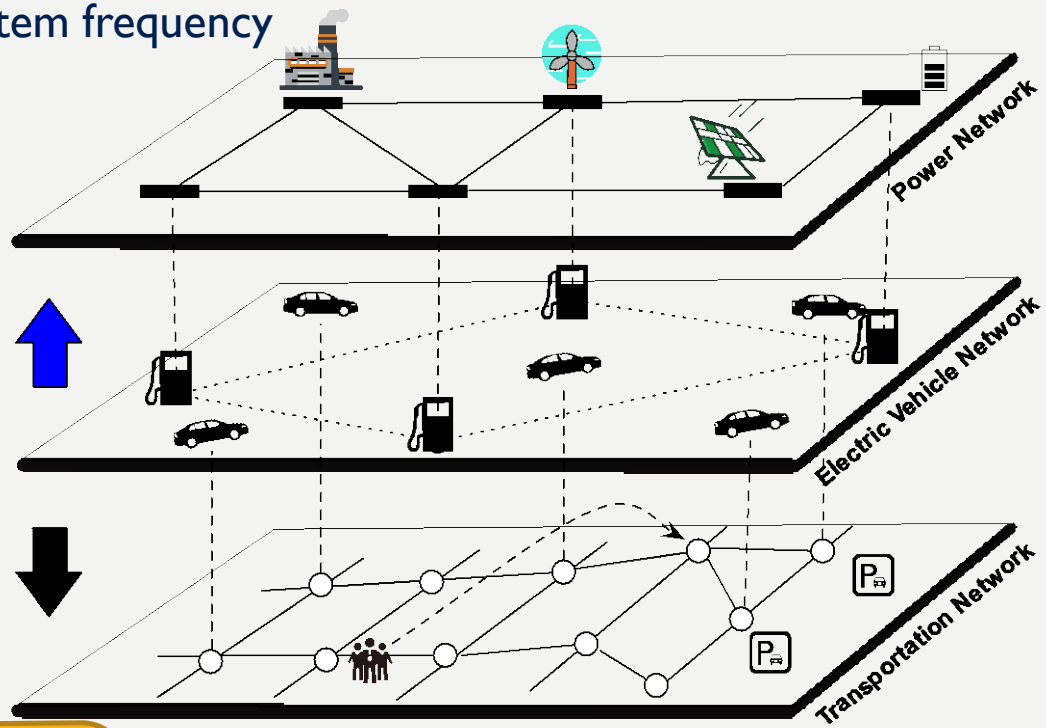
stabilizing/regulating
the system frequency

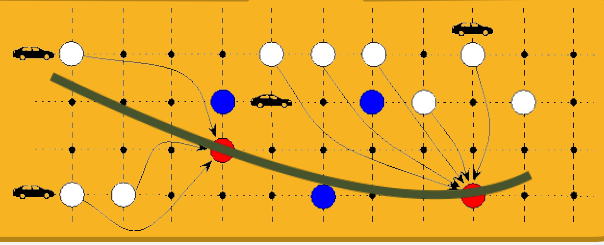
**AFoD Service**

**(Energy Service)**
Autonomous
Flexibility-on-Demand

**AMoD Service**

**(Mobility Service)**
Autonomous
Mobility-on-Demand



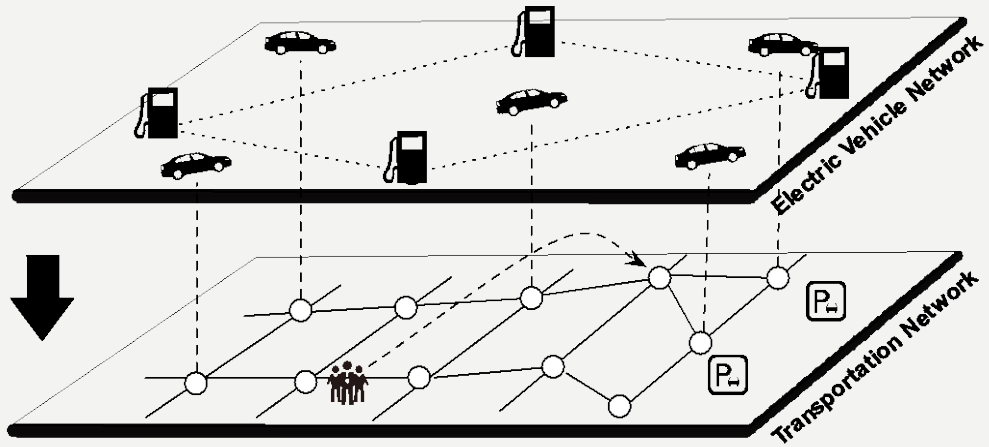



freight transportation

ride-sharing, car-rental, etc.

# AMoD: Benefits and Opportunities

- **Reduction in Number of Vehicles**
  - from current vehicle ownership model to mobility-on-demand in future.
- **Reduction in Parking Spaces**
  - less parking space is needed
  - less parking demand is needed
- **Autonomous Balancing**
  - reduction in extra manpower cost
  - reduction in extra traffic
- **Autonomous Charging**




- promising to achieve **anytime**, **anywhere**, and **coordinated** charging control of EVs in massive scale.
- a perfect source of **demand flexibility** in smart grid.



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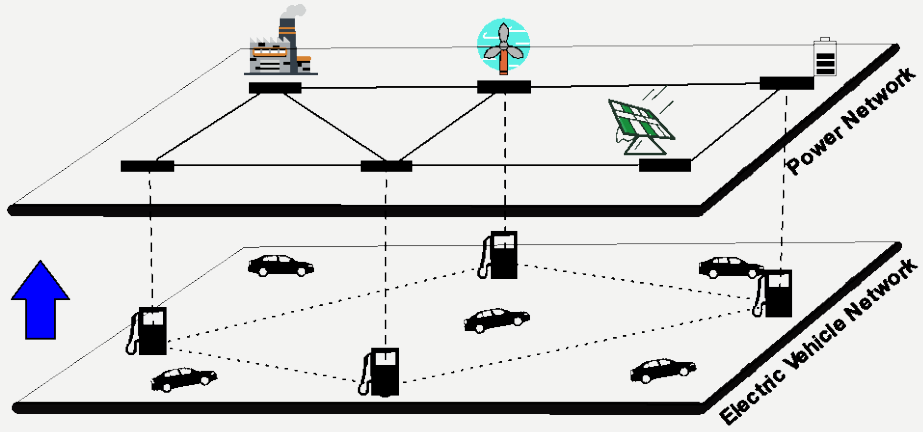
# AFoD: An EV-based DSM Program

- **Flexibility-as-a-Service in Smart Grid**
  - change load from dump followers to proactive participants.
  - cost and carbon-emission reduction in electricity generation.
  - create win-win solutions between utilities and customers.

**Demand-Side Management (DSM) In Smart Grid#**

- **An EV-based DSM Program in Smart Grid**
  - a perfect candidate of DSM program.
    - massive in scale (potentially).
    - charging flexibility in multiple dimensions:
      - power domain: charging rates.
      - energy domain: charging demand.
      - temporal domain: charging periods.
      - spatial domain: charging locations.
  - possible to be coordinated in both modes.
    - plug-in charging mode: vehicles + batteries.
    - battery swapping mode: standalone batteries.




**EV-based DSM programs can be even more significant when autonomous driving is realized**

# A. Mohsenian-Rad, V. W. S. Wong, J. Jatskevich, R. Schober and A. Leon-Garcia, "Autonomous Demand-Side Management Based on Game-Theoretic Energy Consumption Scheduling for the Future Smart Grid," in *IEEE Transactions on Smart Grid*, vol. 1, no. 3, pp. 320-331, Dec. 2010.



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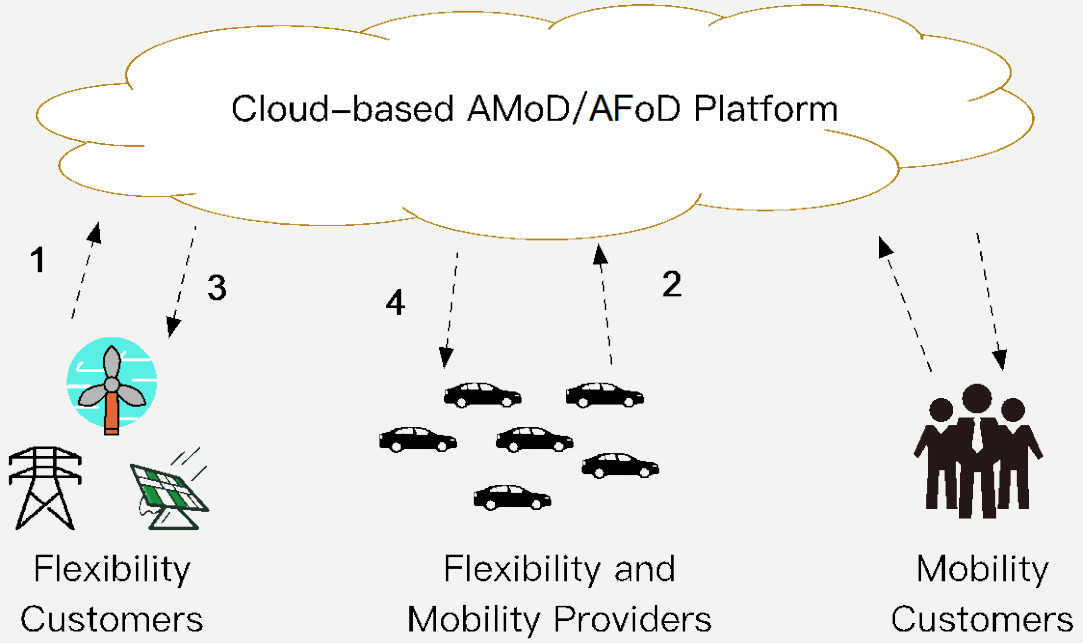
# Cloud-based AMoD/AFoD Platform

1. Flexibility customer (e.g., renewable generators) send requests to the cloud.

2. (Autonomous) EVs report their availability and interests.
   - under appropriate market and incentive design.

3. Cloud sends the scheduling results (e.g., when and how many EVs, payment) to flexibility customers.

4. Cloud sends the scheduling results (e.g., when and where to charge, payment) to EVs.




**Coordination between AMoD and AFoD is the key issue.**



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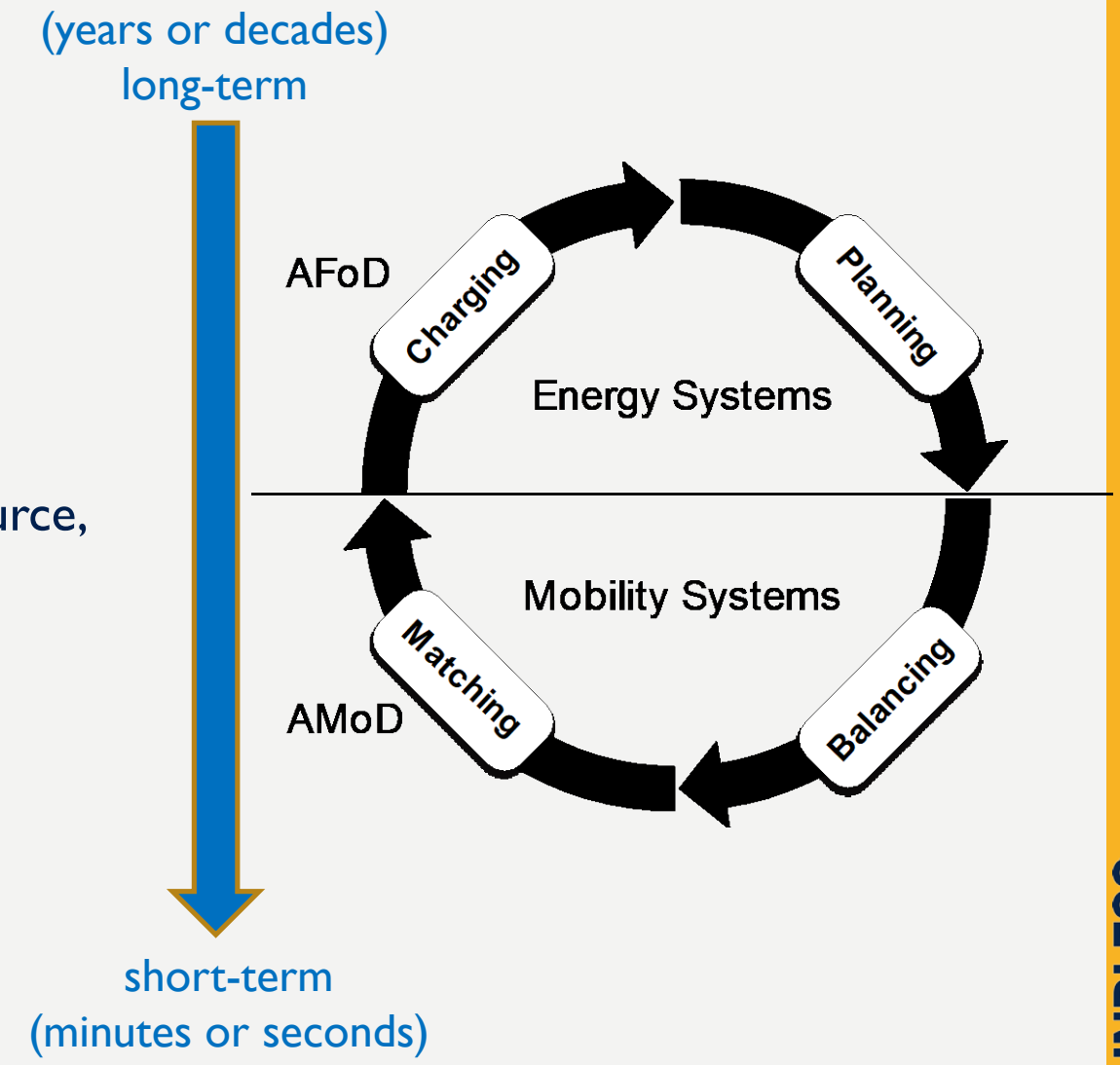
# Coordination between AMoD and AFoD

- **Planning** of Energy Supply Infrastructures
- **Balancing** of (Autonomous) Electric Vehicles
  - unbalanced spatial-temporal distribution of mobility requests.
  - also influenced by locations of energy supply infrastructures.
- **Matching** between (Vehicle, Customer ) and (Source, Destination)
  - vehicle-to-customer dispatching.
  - source-to-destination routing.
- **Charging** of Electric Vehicles
  - plug-in charging coordination of vehicles.
  - charging coordination of aggregated batteries.

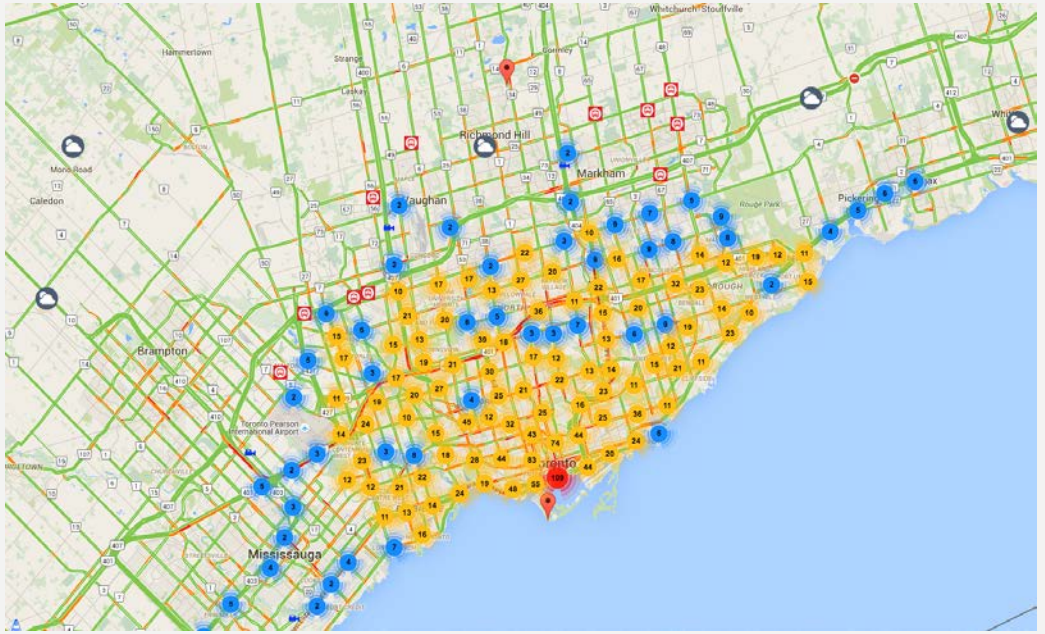


# Challenges

- **Large-scale and High-dimension.**
  - large-scale and complex system
  - high-dimensional system uncertainties
  - real-time acquisition and processing of data

- **Complexity of Key Operational Algorithms for Real-time Implementation.**
  - smart balancing of vehicles temporally and geographically
  - vehicle-to-customer dispatching
  - source-to-destination routing
  - coordinated charging of vehicles in massive scale
  - all require an efficient real-time implementation

- **Market Design for Incentivizing Collaboration.**
  - multiple stakeholders.
  - different interests (e.g., mobility and energy services).




http://portal.cvst.ca/



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# Conclusions

- **Convergence of Energy and Mobility Future.**
  - Smart Grid
  - Electric Vehicles
  - Mobility-on-Demand
- **Autonomous Service Management.**
  - AMoD.
  - AFoD.
- **Challenges in Coordination between AMoD and AFoD**.