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Smart Sensing for Coupled Food, Energy and Water Systems

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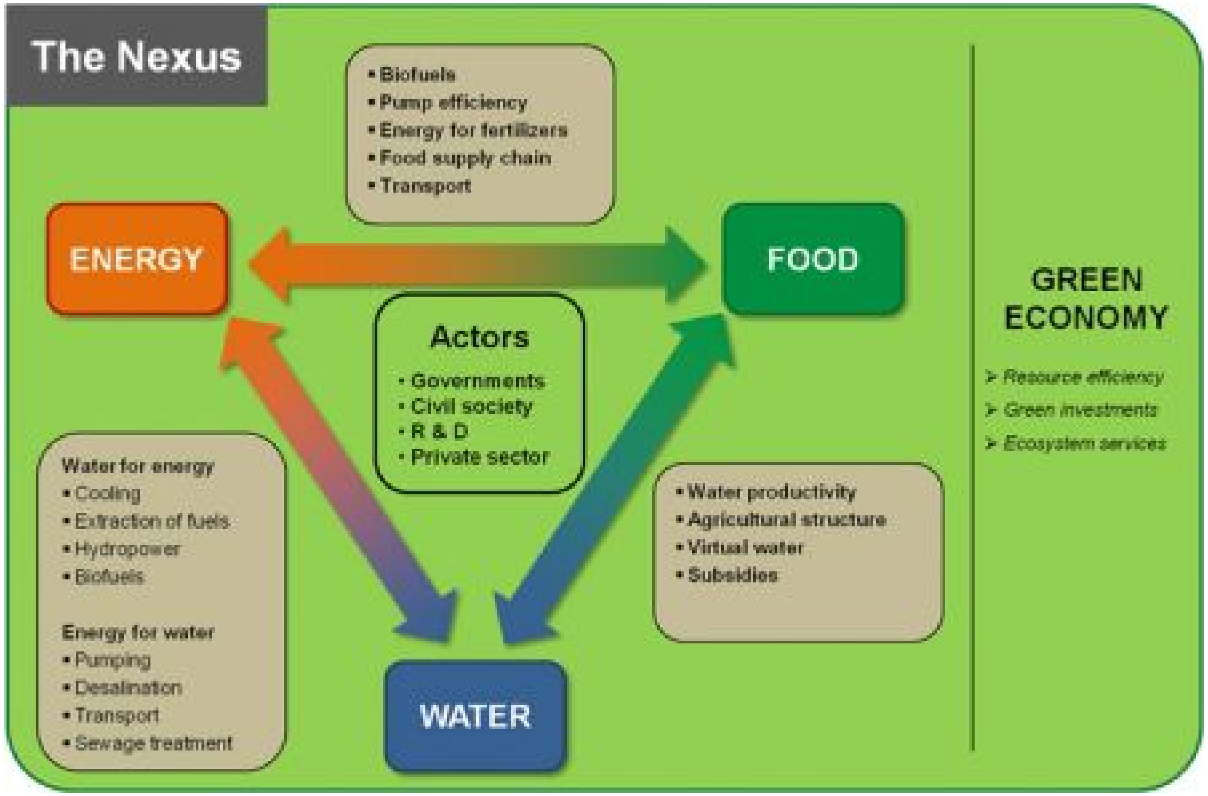
Smart Systems and Coupled Systems

- Smart farms, grids and water distribution combine sensors and distributed processing
- Progress continues on sensor autonomy, timing, smart system organization and security
- Smart cities require multiple (smart) services
- City management requires decision making running across service subsystems
- A smart city requires simultaneous control of multiple smart systems

Outline

- Interdependence of Food, Energy and Water (FEW) supply systems in cities
- Independent Smart Systems for Farms, Grids and Water Distribution - Data Collected
- The Run-off Problem
  - An Urban Water Supply System – Boulder, CO
- Quantifying Inter System Coupling
- Autonomous Sensor Packs and Water

A Nexus View of FEW



- A sudden change to one FEW subsystem causes a new evolution in all the subsystems

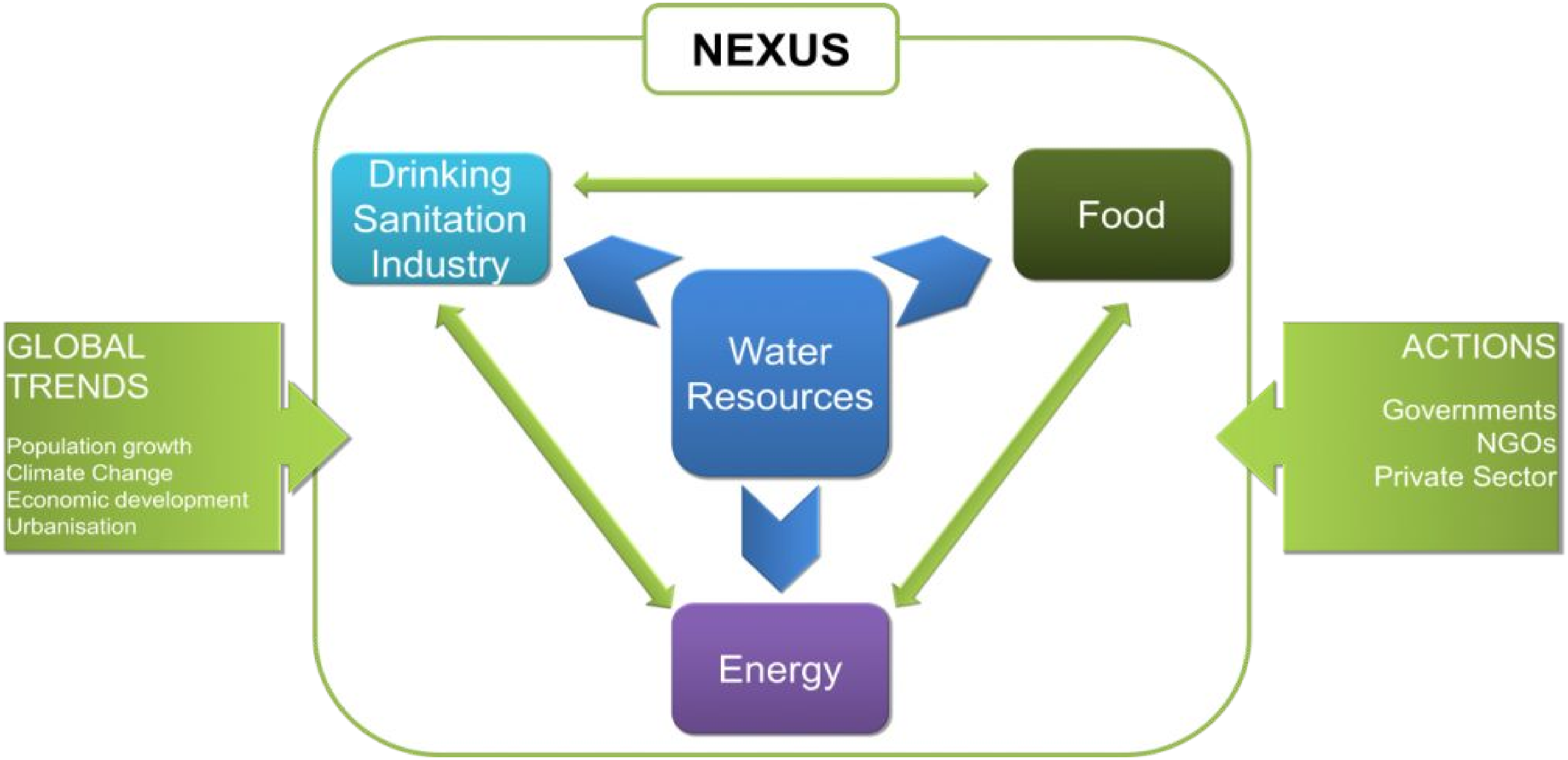
Characteristics of a Smart City

- Economy of scale offers advantages in efficiency
- Operation requires on-demand supplies of food, energy and water throughout the city
- Smart food, smart grids and smart water distribution systems given sufficient supplies of raw materials (feed, fuel) and water
- System stressors couple the individual subsystems
- Understanding system coupling is important

Coupling in FEW Systems

- Agricultural consumes water for irrigation and requires supply of seed, feed and fertilizer
- Moving water and materials requires energy
- Energy production also requires water for fuel production and equipment cooling
- Water must be distributed from central storage for industrial (grey water) and human (potable) use and black water needs to be reprocessed
- Water is central to the nexus

Water Resources and Nexus

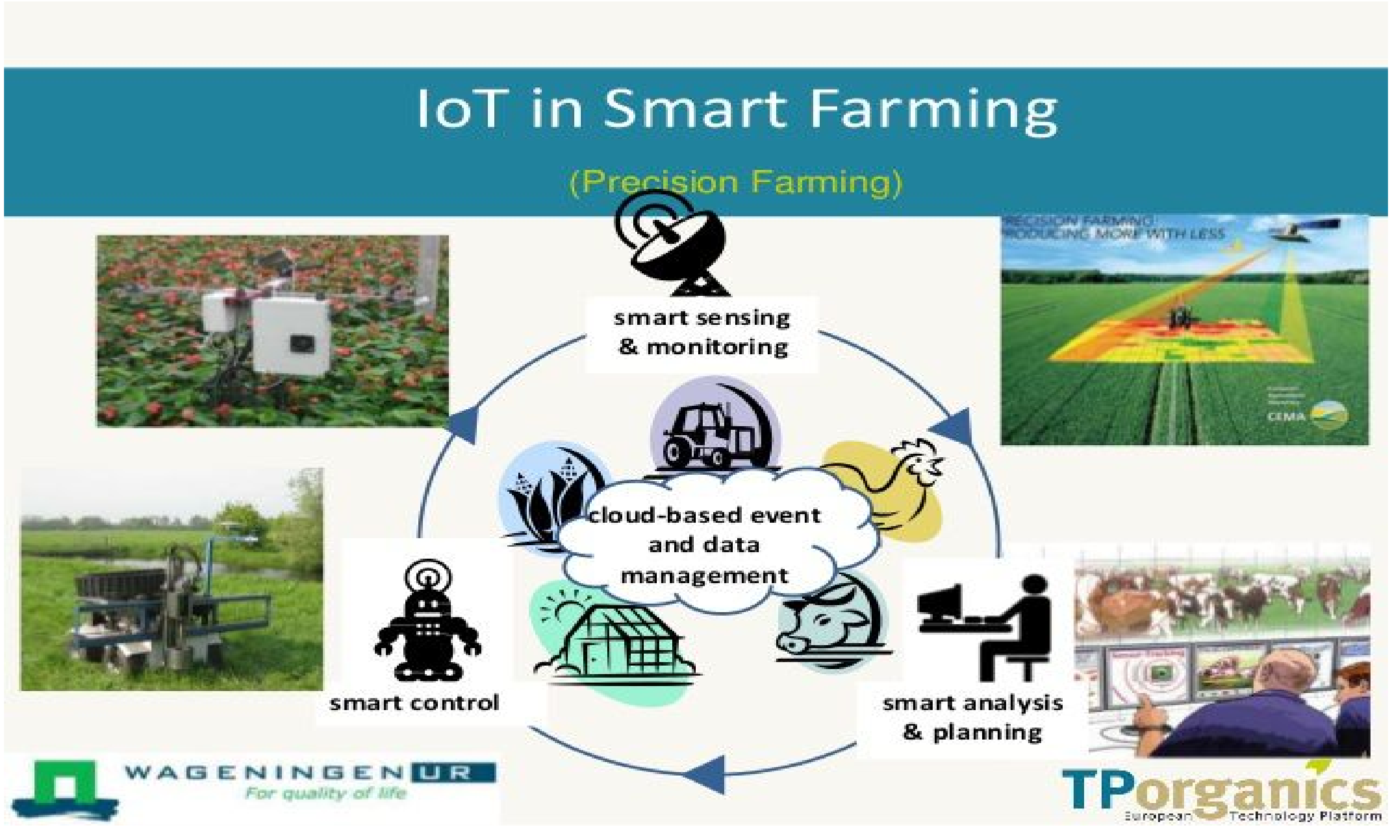


- **Water resources are central to nexus smart city control**

Present Day Smart Systems

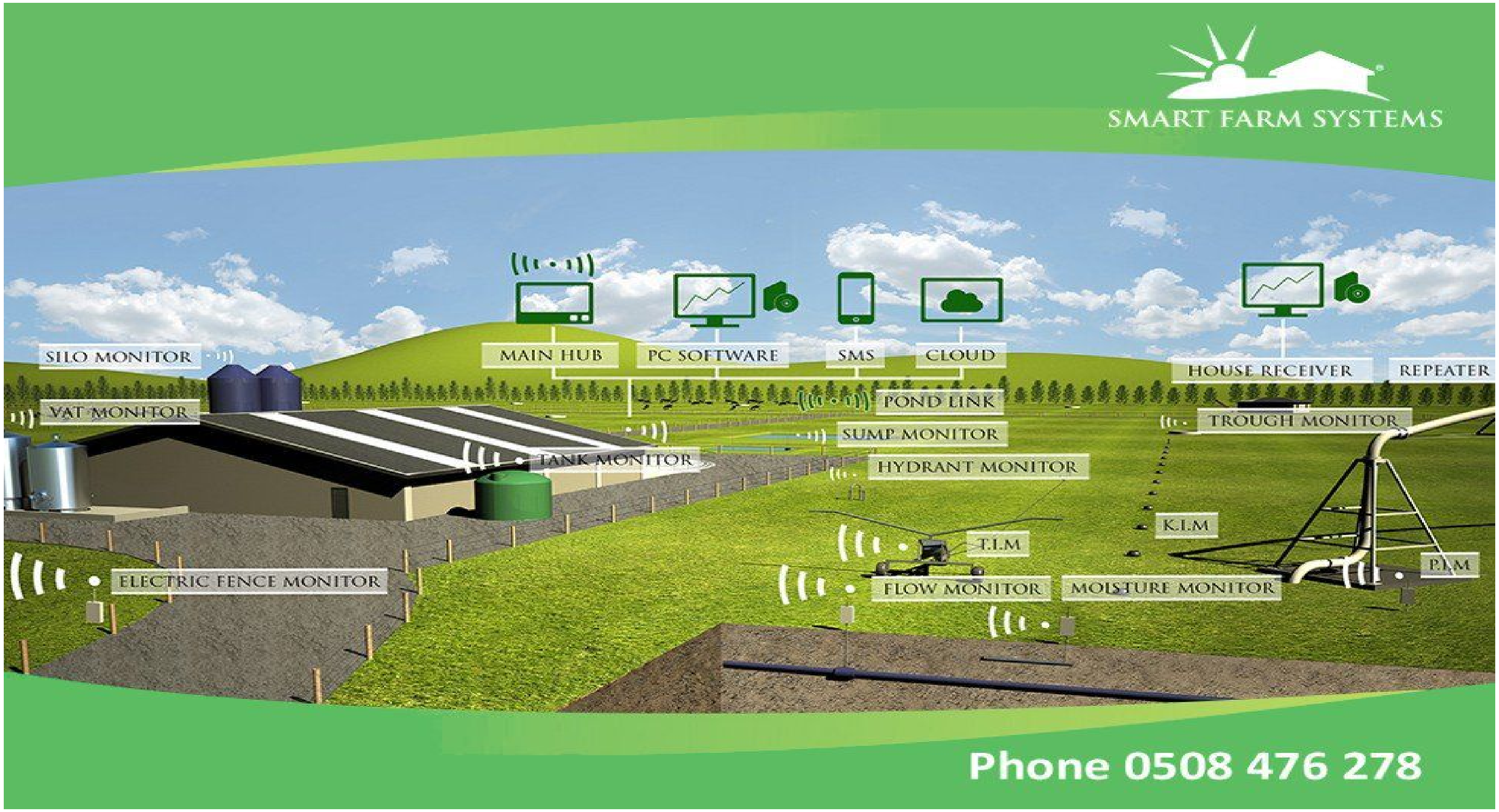
- Smart Farming by GIS and Ground Sensor
- Smart Grids
- Smart Water Distribution
- Investigation of the smart systems indicate that much of the information concerning coupling of the systems to each other is already gathered by individual smart systems

GIS for Smart Farming



- GIS systems together with satellite imagery are used to monitor/control fields

IOT for Smart Farming

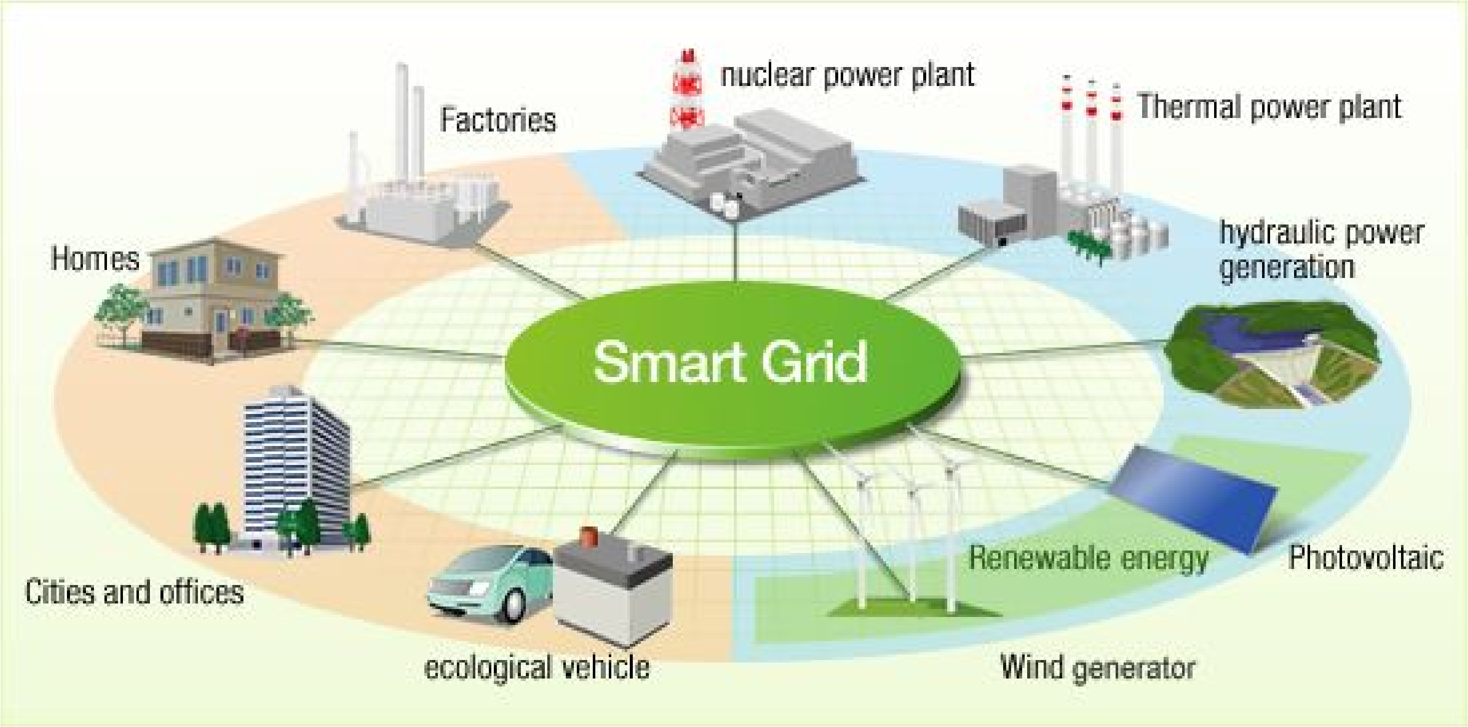


- **A more holistic view of farming includes imagery as well as flow with control**

Coupling Data from Smart Farming

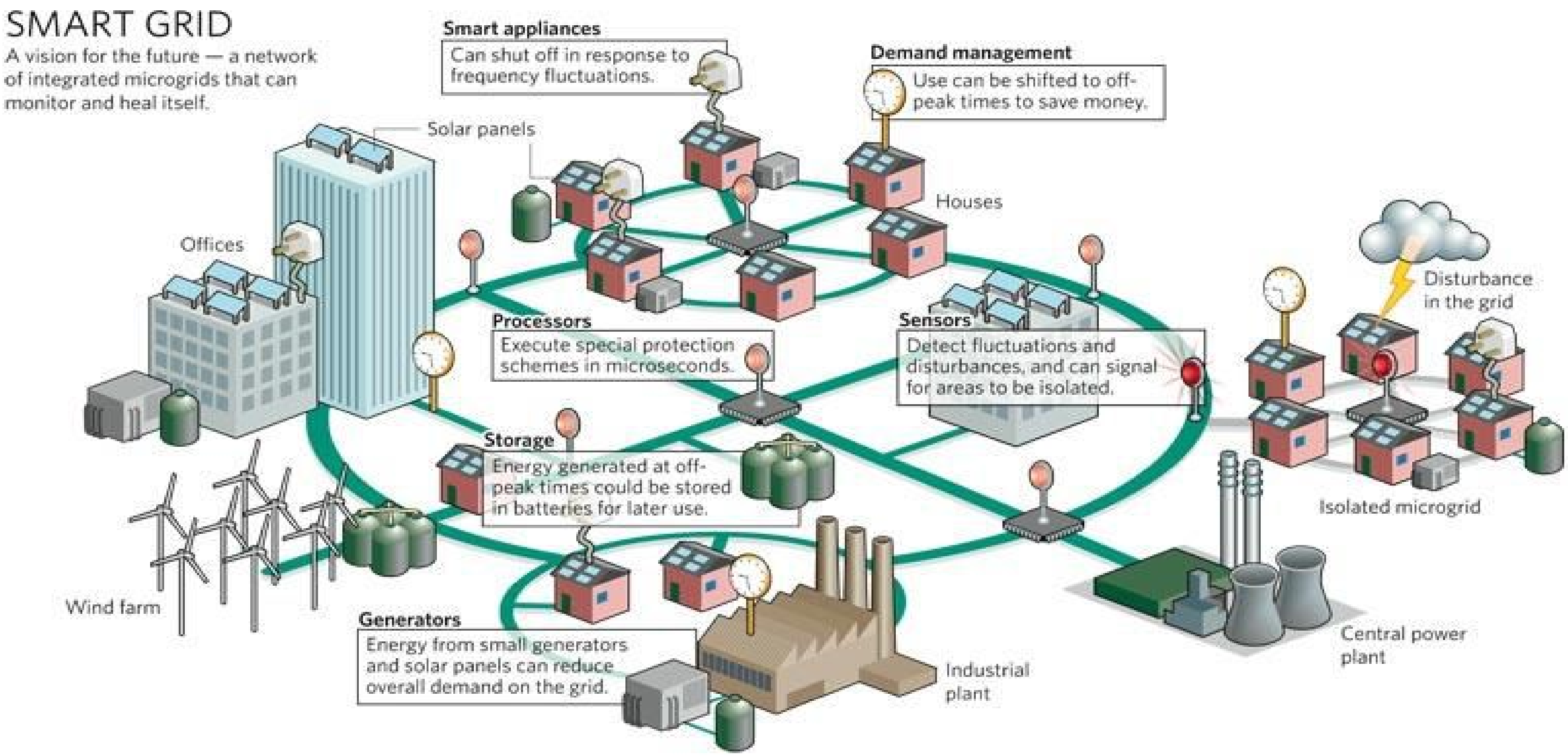
- Water used for irrigation is monitored
- Energy used by system is monitored
- Energy used in transporting raw materials to end use can be monitored
- Energy used in transporting water for irrigation can be monitored by smart grid
- What is not monitored is **run-off** (and run-off contents) that enter feeders to water supply

A Smart Grid



- A smart grid is used to control power inputs (nuclear, thermal, hydro, PV and wind) and outputs (chargers, offices, homes and factories)

A Smart Grid of Micro-Grids



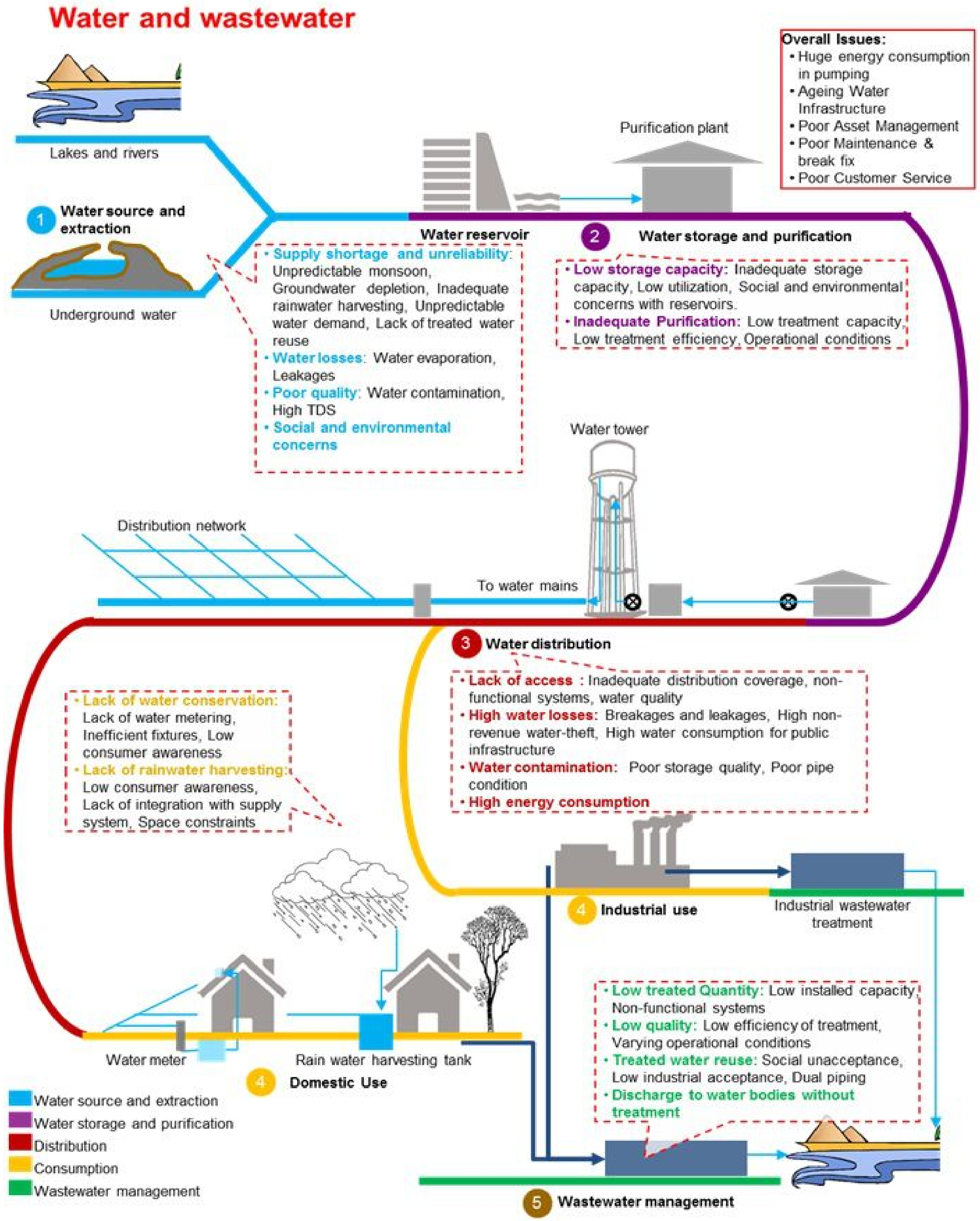
- One view of smart grid is as a linking of multiple semi-autonomous micro grids

Smart Grids and Energy Use

- Energy drawn into grid from all sources is monitored and can be recorded
- Energy used by individual branches is monitored and can be recorded
- Sub-grid exchange can be monitored and recorded
- What is hard to record is run-off of pollutants and heat

Controlling (Monitoring) Water Input

- Smart water systems monitor input from diverse sources



Controlling (Monitoring) Distribution

- Water used where is monitored
- Energy used in transport can be monitored
- Quality can be monitored

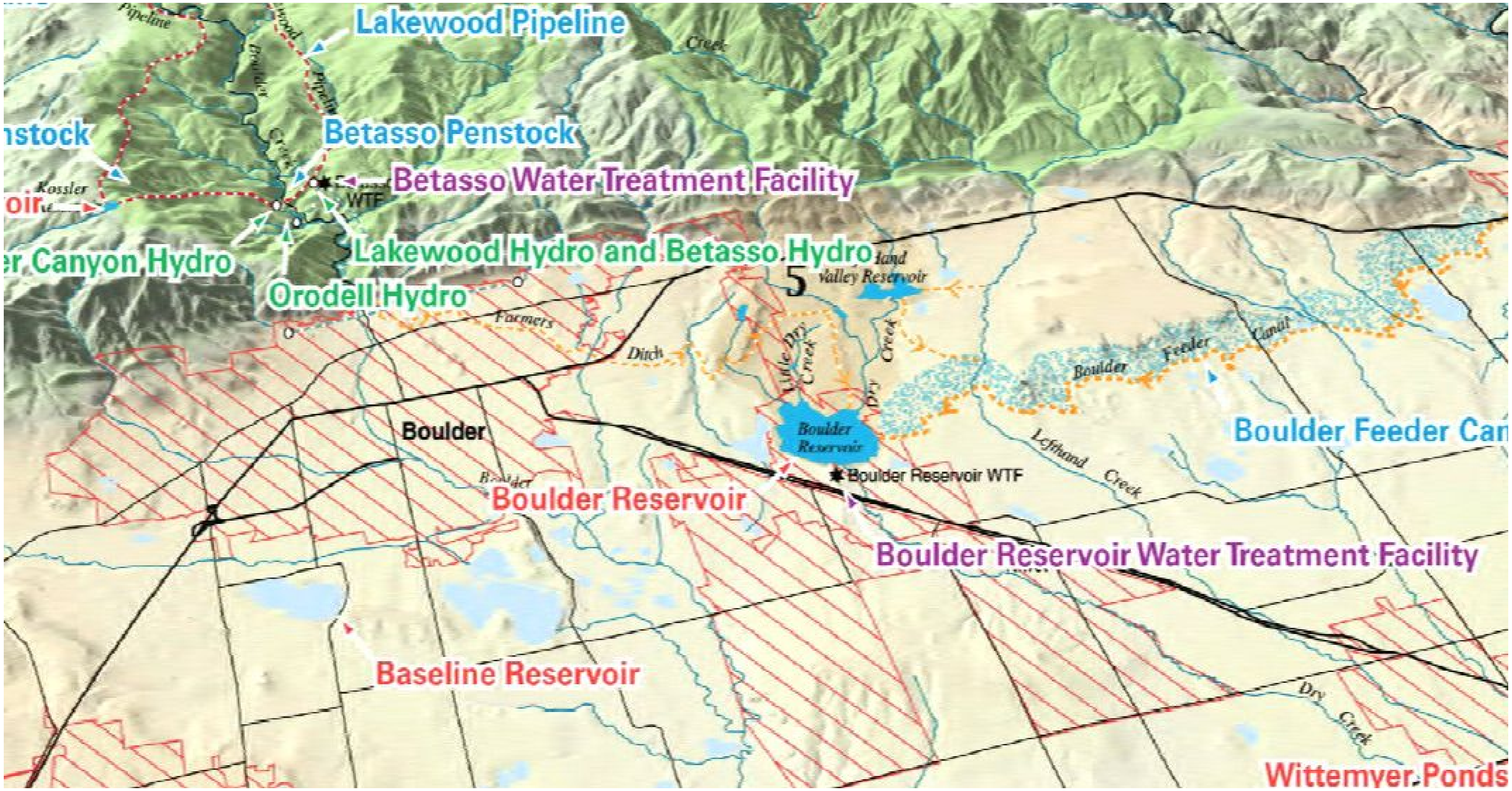
(Unmonitored) Coupling in FEW Systems

- Agricultural affects water quality by nitrate and phosphate pollution (fertilizer) as well as organic pollution from livestock
- Energy production also affects water quality thru
  - Organic and inorganic wastes from fuel production
  - Organic and inorganic waste from the burning of fuel
  - Waste heat from energy conversion
- Run-off in not easily monitored in smart system
- Water quality is sufficiently sensitive to the state of food and energy production to be a predictor

Run-Off into Water Supplies

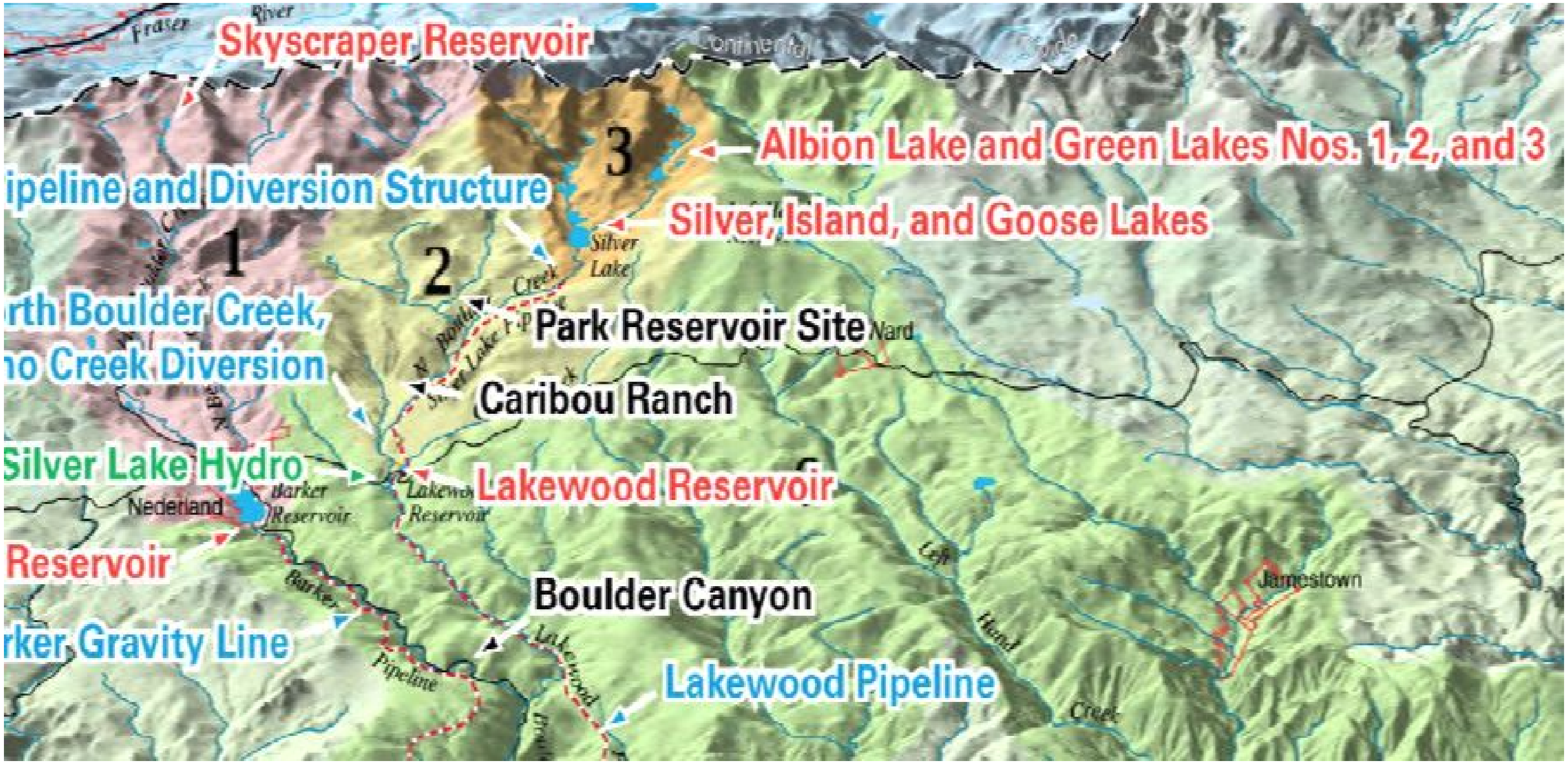
- Water supplies can come from rivers, be piped in from distant resources (high flow areas, glaciers) or be stored (reservoirs) for seasonal use
- Pipes are easy to monitor
- Open groundwater channels are much harder to monitor for flow and the composition of the flow

An Urban Water Supply System



- Boulder, Colorado
  - Glacier fed system by a distant (25 mile) glacier with multiple holding lakes and pipes down the mountain

The System from the Glacier



- **The conduit down the mountain is closed, however, the lakes and channels are open**

Water Quality Monitoring

- Spatial and temporal monitoring of open groundwater channels can be used to locate inputs and composition of input water
- A smart water quality monitoring system can determine the hard to determine couplings
- Requires sufficiently high spatial and temporal resolution
- A solution is autonomous sensors

Autonomous Sensing

- State of the Art from USGS
- More important than present water quality is future water quality as determined by FEW
- The simplest FEW package would involve temperature, dissolved oxygen and nitrogen
- Expanding to turbidity, Ph and phosporus as well would straightforward

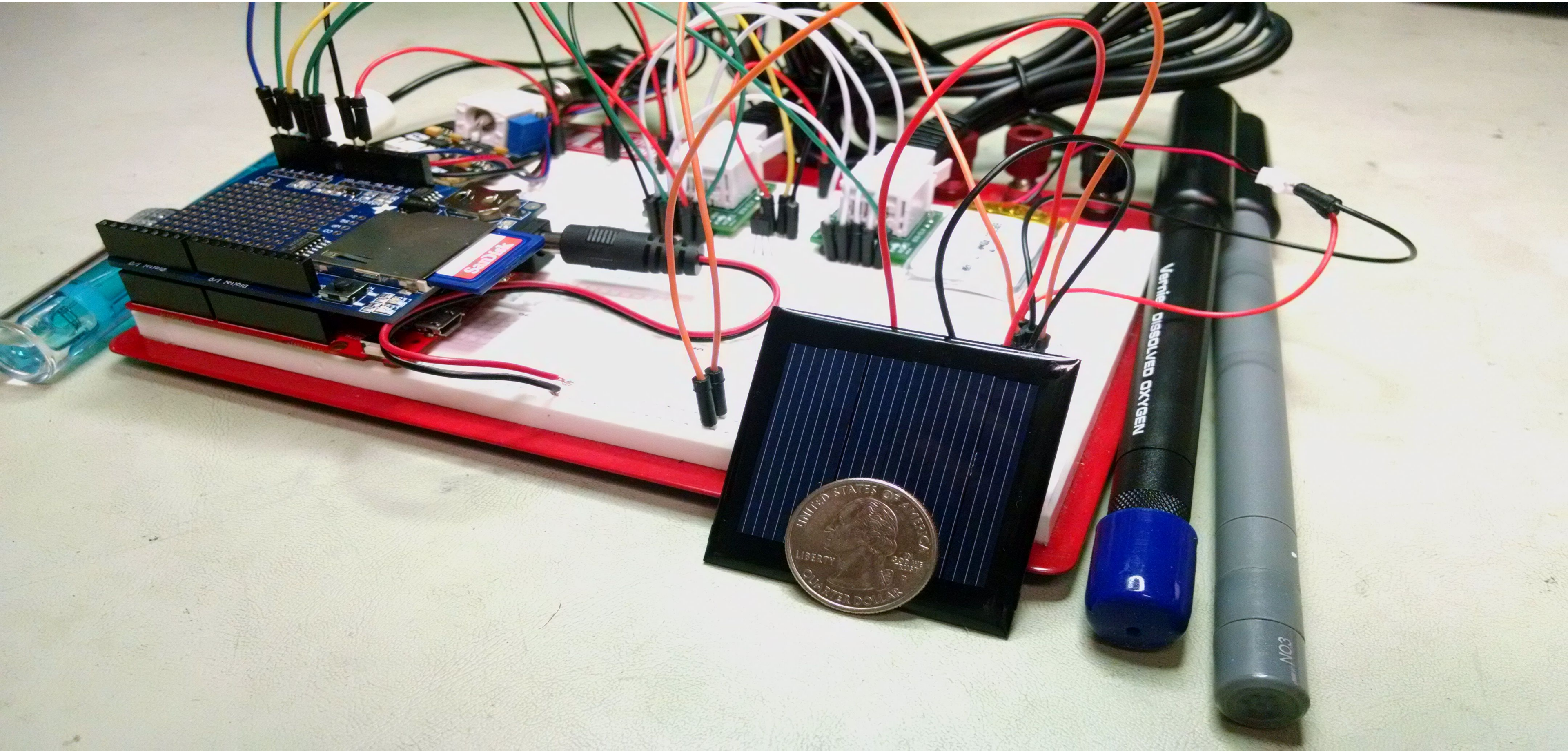
Lake Muttamuskeet NC

- **Almost autonomous but fixed location**

A Sensor Pack for a FEW System

1. Turbidity senses the quantity of foreign substances in water
2. Dissolved oxygen is sensitive to algal blooms
3. Nitrate acts as a predictor of future water quality
4. Temperature is sensitive to waste heat from energy conversion

All the Components on a Board



- **Components are light, compact and self-contained (solar powered)**

Conclusions

- **Smart city management requires knowledge of the state of each FEW subsystem as well as the coupling between the subsystems**
- **An urban water supply is shared by all the FEW subsystems and is sensitive to coupling**
- **Autonomous water quality sensing can be the basis of a smart water quality system**
- **Microprocessor based sensors can be small, autonomous and cost effective**