THE HIDDEN SYSTEMS THAT OUR SOCIETY RELIES ON ARE STUPID.

TRAFFIC

WATER

POWER

We depend on infrastructure systems that are old and slow to adapt, but they're getting smarter. Historically, we have made decisions about how to direct the flow of our traffic, water and power using data that is collected on a scale of weeks, months or, most likely, years. Due to a recent push to upgrade these systems and the ubiquity of communications technology and low-power sensors, that scale will soon be measured in milliseconds.

HERE'S WHAT WE'RE CHANGING

BY EVAN DOUGHERTY & JENNIFER JUDGE HENSEL

300,000 SIGNALIZED INTERSECTIONS IN THE U.S. EQUALS ABOUT 1 TRAFFIC SIGNAL PER 1,000 CARS

That's a **lot of responsibility** for one traffic light. The smarter it is, the happier those 1,000 drivers become.

Source: Institute of Traffic Engineers

CRASHES

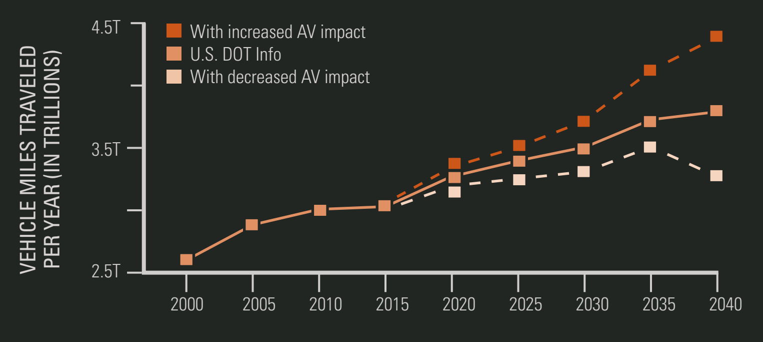
Accidents occur due to poor decisions by drivers. **A more intelligent system will greatly reduce the number of accidents,** causing fewer backups and, more importantly, fewer injuries and fatalities. Each year there are:

- 5.6 MILLION ACCIDENTS
- 2.3 MILLION INJURIES
- 33,000 DEATHS

Source: U.S. National Highway Traffic Safety Administration, 2012

AUTONOMOUS UNCERTAINTY

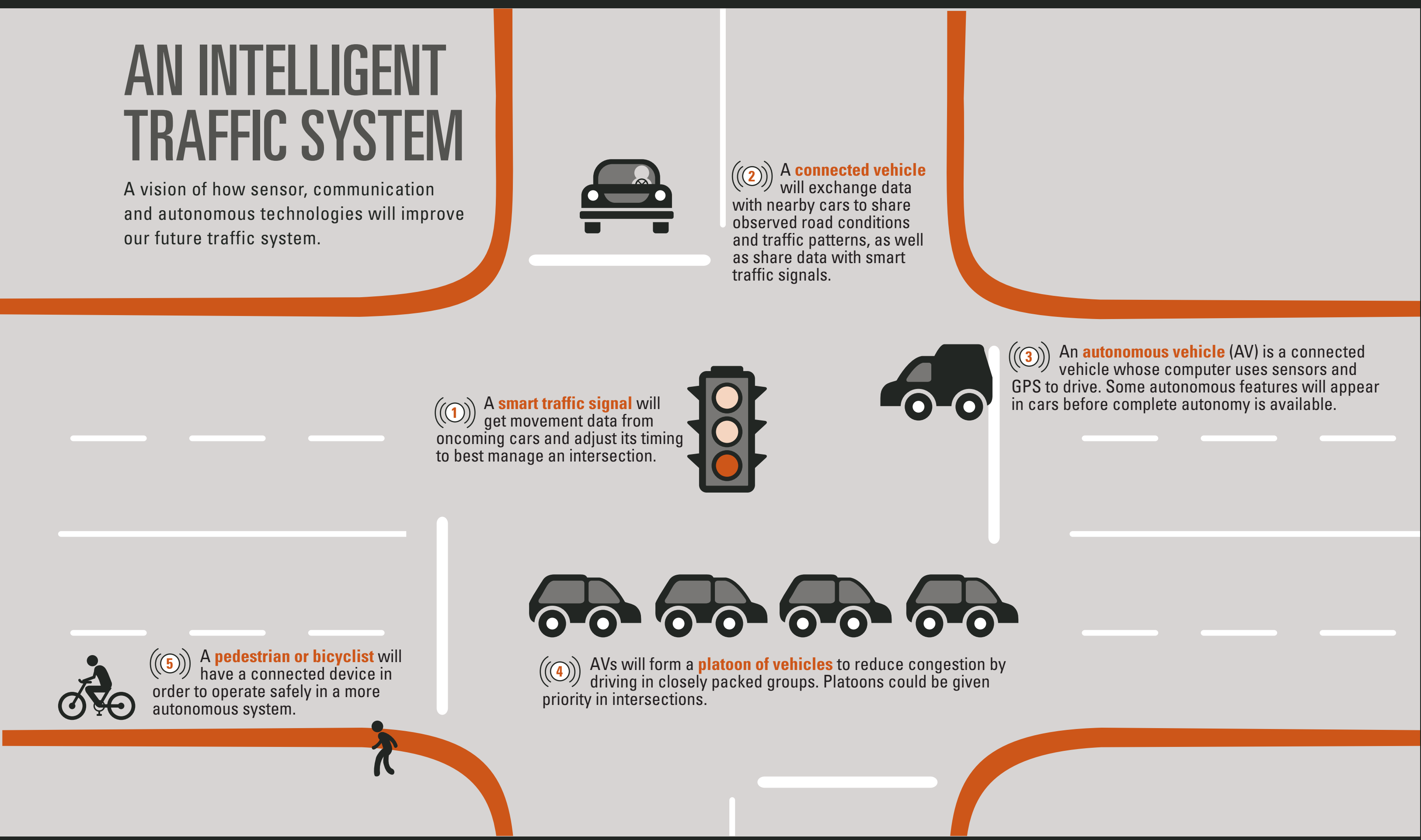
It is hard to predict how traffic will change in a smarter system. Congestion should decrease, but how will autonomous vehicles (AVs) affect travel by car? If AVs form pay-per-use and shared services, overall driving could decrease. We might be less likely to go on shorter trips if we have to pay each time. Longer commutes might also be cheaper if we share an AV with a neighbor. Overall driving could also increase, though. If AVs no longer require a driver's license, a new part of the population will have access to the road.



Source: Author's projections based on U.S. Department of Transportation Federal Highway Administration

AN INTELLIGENT TRAFFIC SYSTEM

A vision of how sensor, communication and autonomous technologies will improve our future traffic system.



TRAFFIC

In the decades following Detroit's installation of the world's first tri-color traffic light in 1920, researchers strove to develop and advance our understanding of traffic flow. But that period of progress greatly decelerated after almost 70 years. In 1988, U-M's Department of Civil and Environmental Engineering (CEE) dissolved its transportation research program when Professor Donald Cleveland, an educator of many great transportation scholars, retired. But the recent evolution of communications technology and low-power sensors has re-energized the field.“We've hit a new focal point,” said Henry Liu, a U-M professor in CEE who was hired to restart the department's transportation program after 26 years. “I tell my students, your field has hit the jackpot!”

On the horizon lies an intelligent transportation system. Not only are we using sensors to make our cars smarter and more autonomous, we are also making the entire system safer and more efficient by enabling communication between vehicles and infrastructure. These new components and systems will be rigorously tested through U-M's Mobility Transformation Center and its new intelligent proving grounds, M City.

When a system has more real-time information, it can make quicker and more informed decisions about its own operation. Our traffic lights will better time themselves to different types of oncoming cars, and vice-versa, with cars timing their own speed to hit an intersection at the ideal time. Previously, signals have been programmed to operate based on surveyed traffic patterns and by using vehicle detection sensors located at each intersection, without the consideration of any real-time vehicle-specific information.

Beyond traffic signaling, congestion can result from selfish decisions made by drivers. We make our decisions based on how they benefit us – we don't immediately know or sometimes care how they affect the greater system. But we are starting to take advantage of new information with mobile apps like Google Maps, Waze, Uber and Moovit, and smarter vehicles and traffic signals are well into their development and experimentation. This new intelligence will promote greater cooperation within the system, with changes continuing as this renewed field of research matures.

“It is possible that in the future, there is no need for traffic lights,” said Liu, explaining that cars would simply schedule their place in the intersection. “But that will take some time!”

If each new car purchased were an

AUTONOMOUS VEHICLE, IT WOULD TAKE ABOUT 17 YEARS BEFORE ALL OF THE “DUMB” CARS WERE OFF THE ROAD.

That means even with **100% adoption**, autonomous vehicles would still have to **operate alongside human drivers** for almost two decades.

Source: Author's calculation based on US DOT FHWA data

We tend to think about water as being a major resource in two separate systems: the natural watershed, and our urban water networks. In reality, these two are tightly connected, and there are areas in both systems where our management is limited by our lack of available information.

In the western states, for example, up to 75 percent of the available freshwater is collected from snowmelt from the surrounding mountain ranges. In California, researchers combine data from about 30 snowpack measurement stations (SNOTELs), manual measurements and historic data to predict what the available runoff of the Sierra Nevada Mountains will be each spring. These predictions tend to have a high degree of error, primarily due to the limited resolution of available data - there just aren't enough diverse measurements being taken across the range. And once the snow melts into the surrounding reservoirs, residential, commercial and industrial sectors all claim rights to more water than is often present, causing massive shortages during years of drought.

This limited resolution of water data doesn't affect just California. Watersheds in every region present problems for our current management systems, especially with increasingly diverse weather patterns.

"The designs we put into place in the past can't cope with the dynamically changing environment," said Branko Kerkez, a U-M assistant professor in the Department of Civil and Environmental Engineering (CEE). "That's where all our sensors and actuators come in."

Kerkez is dedicated to creating what he jokingly calls the "internet of water." It would essentially be an intelligent water management system. Low-cost, networked sensors could be placed throughout and would be constantly measuring water levels, flow rates and quality. This data would be continually gathered and aggregated at a central location. A person or a computer would make decisions about how to control the water and whether there are problems that need to be addressed.

Because our pipe network is so old, sensors could be instrumental in identifying leaking pipes or water quality degradation between the treatment plant and the consumer. But unlike the already revitalized area of transportation research, the integration of water and data will be hard to implement. Utilities and municipalities will be slow to change, especially with the obstacle of combining disciplines.

"If we want to build smart water grids, who's going to do it?" said Kerkez. "Is it going to be people in computer science or in civil engineering? Is it going to be a collaboration, or just people on the fringe who try to have an understanding of both things?"

That's a big question for the use of big data across all fields. As a member of CEE's Intelligent Systems Group, Kerkez sends his civil engineering students to also take classes in computer science. This new generation of multidisciplinary engineers will be instrumental in demonstrating the benefit that real-time information brings to these systems.

"It's just intuitive," said Kerkez. "Combining data with water cannot be a bad thing. It cannot be a bad thing to know more about your system. And right now we don't know much."

WATER

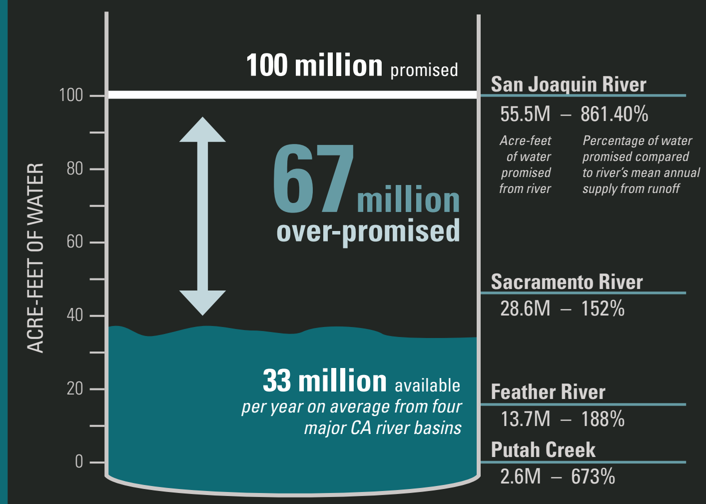
1.46 TRILLION GALLONS OF WATER ARE LOST EACH YEAR, WITH **75%** DUE TO **leaky pipes, theft or other correctible items**.

Source: Environmental Protection Agency; number of gallons includes all non-revenue water types

SUPPLY & DEMAND

In California, access to the natural water supply is granted to individuals and groups by the State Water Resources Control Board. With rights going back to 1914, the state has apportioned access to major river basins that can add up to more than 800% of the average annual supply from runoff.

According to the Associated Press, **the board has admitted it doesn't actually know how much water some of its major users are taking**, such as for corporate or agricultural use. In a wet season, it's not much of a problem, but in a drought, like we've seen in recent years, the lack of immediate data about water availability and usage makes rationing difficult.



Amount of water over-promised for four California Rivers

Source: University of California

240,000 WATER MAINS BREAK PER YEAR

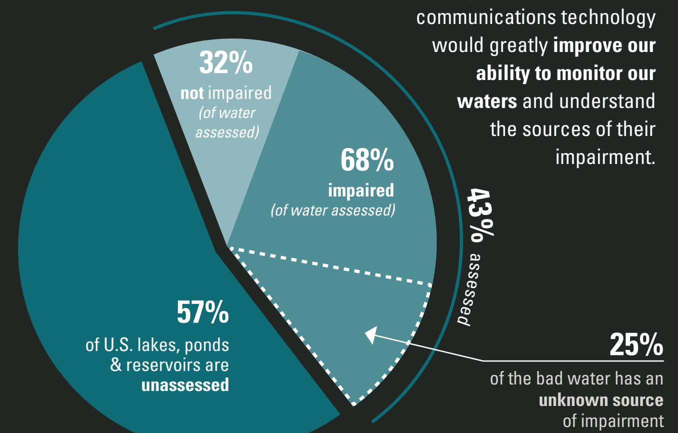
IN THE U.S., SOME OF WHICH ARE MORE THAN **100 YEARS OLD.**

And in some places, there are still **pipes made of wood**.

Source: Environmental Protection Agency, NYTimes

QUALITY

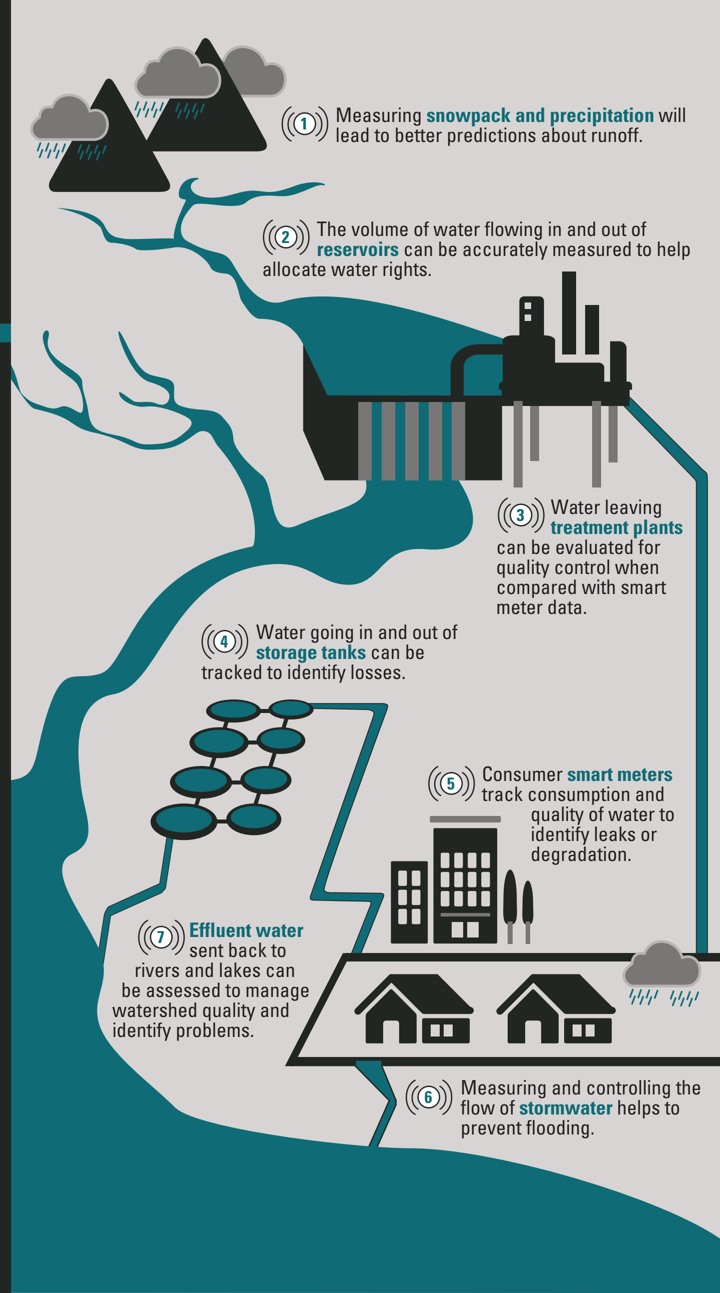
The EPA requires states to submit water quality data every two years, but some states lag, with available reports ranging from 2006 to 2014. States also report data differently. From current water data, **far less than 50% of waters are even assessed**. Some states choose which waters to study based on importance and differ on which waters to study each cycle. (The Great Lakes are an exception, with more than 80% assessed.) A massive integration of sensors and communications technology would greatly **improve our ability to monitor our waters** and understand the sources of their impairment.



Source: Environmental Protection Agency

THE INTERNET OF WATER

The addition of sensors to various points along our water systems will help capture real-time data about water quality and availability, leading to better allocation and retention.



20%

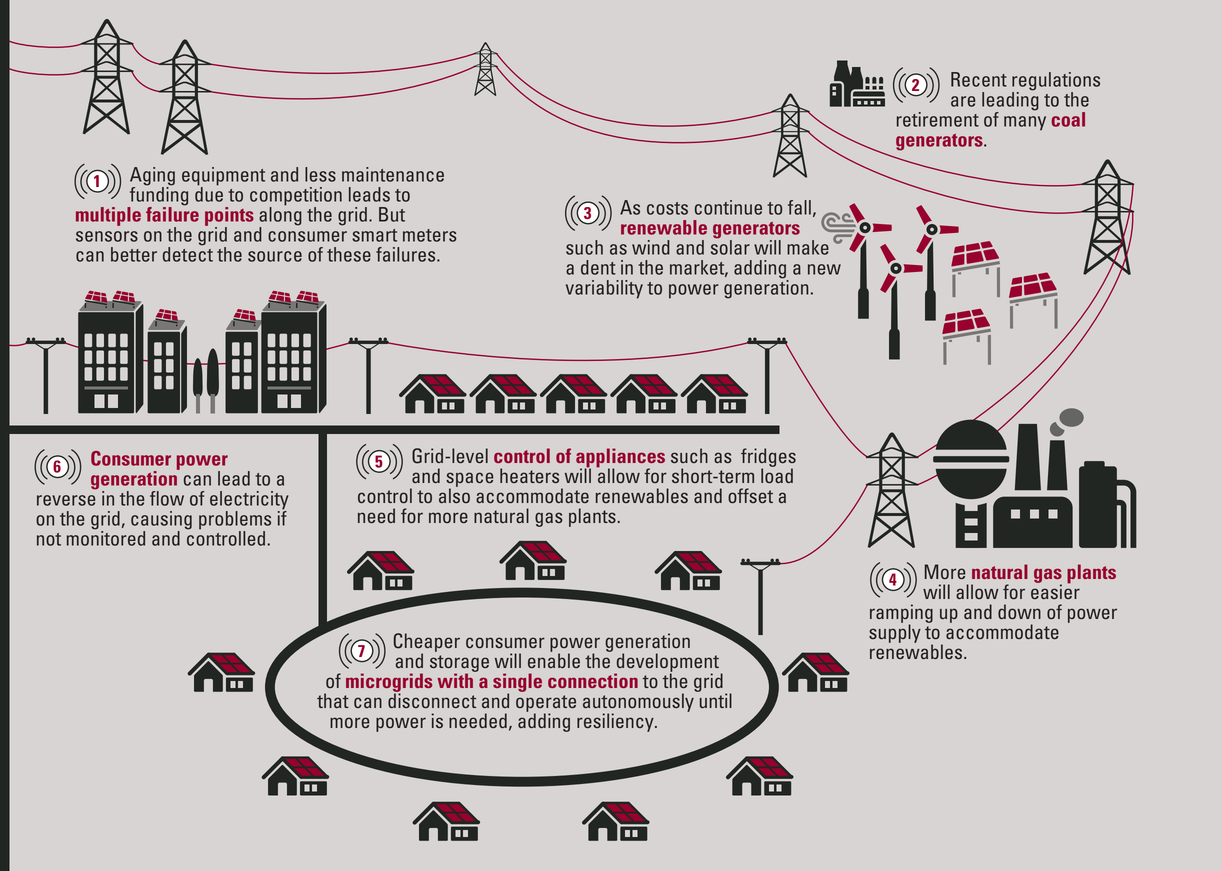
OF U.S. COAL CAPACITY FROM 2012 WILL BE RETIRED BY 2020

which means we will rely much more on **natural gas and renewables**.

Source: US Energy Information Administration

A VARIABLE GRID

We are bringing major changes to our grid as its physical infrastructure continues to age and our supply of power becomes less predictable.



POWER

IN THE LAST FIVE YEARS, THE U.S. HAS INSTALLED

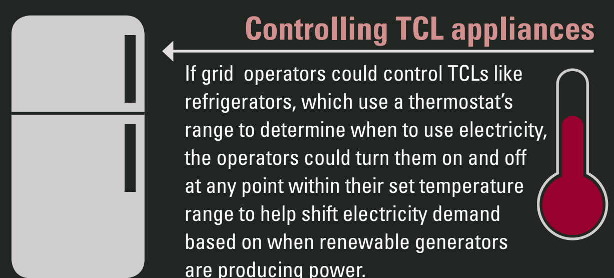
16.9M SMART METERS

& SPENT **$1.8 BILLION ON INSTALLATION** OF AUTOMATED DEVICES & SYSTEMS

with funds from the Smart Grid Investment Grant in the 2009 Recovery Act.

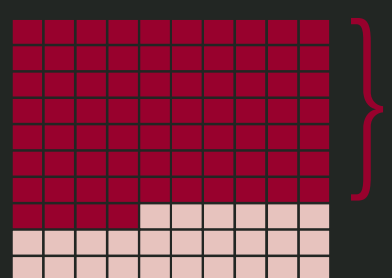
SHIFTING DEMAND

One way we could accommodate the variability of renewable generation is to broadly manage the electricity our appliances use, especially those referred to as thermostatically controlled loads (TCLs).



Controlling TCL appliances

If grid operators could control TCLs like refrigerators, which use a thermostat's range to determine when to use electricity, the operators could turn them on and off at any point within their set temperature range to help shift electricity demand based on when renewable generators are producing power.



74%

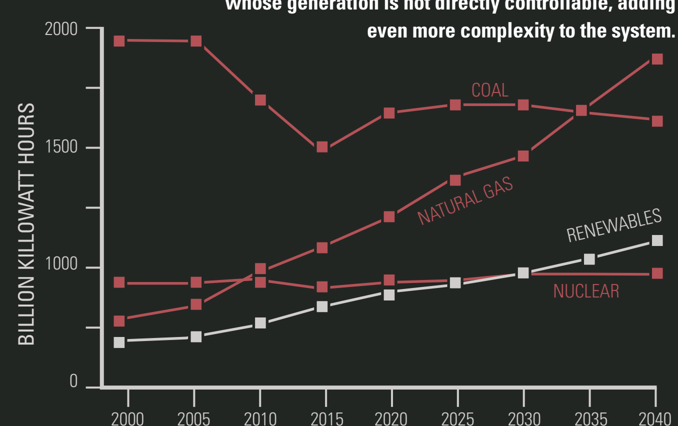
of residential electricity usage powers TCLs, so the impact on the grid can really add up.

Source: U.S. Energy Information Administration

ENERGY GENERATION

The way we generate and deliver power is heavily influenced by the laws of physics. **Because electricity flows nearly instantaneously, we need to generate the same amount of power as that which is being used at any given moment.** To do this, we have different types of power plants: large base load generators, like coal and nuclear, that are always running, peaking generators that turn on during high demand periods, and load-following generators, like natural gas, that can quickly adjust their output based on demand.

And now we are throwing renewables into the mix, whose generation is not directly controllable, adding even more complexity to the system.



Source: U.S. Energy Information Administration

Our power grid is a complicated behemoth. It is an ever-growing labyrinth of distribution and transmission lines that often can be traced back to large, centralized power plants. It's a bloodstream. In order for our society to function, we need a strong and reliable supply of power.

Overall, the grid has worked very well. The widespread addition of sensors and controllers would certainly help the system run more smoothly, but it hasn't been necessary, until recently.

"We are trying to upgrade the grid because we are seeing more big, catastrophic power outages," said Johanna Mathieu, an assistant professor in the Department of Electrical Engineering and Computer Science at U-M. "It's old. It wasn't ever designed. It's like we built a small grid and we kept adding on and connecting grids and nothing was ever optimized. It was just sort of put together. And when you start putting bigger and bigger pieces together, sometimes you get interactions that you didn't expect."

Another problem is the integration of renewable generation, particularly wind and solar, because we cannot control how much electricity a wind farm or a solar field generates at any given time.

Before, demand was the biggest variable. But if we needed more power, we would just ramp up the output of some of our plants to match the load. Now generation is also becoming a variable, so those load-following plants will have to work harder to even out both our demand and our supply. This continuous ramping up and down of a generator's output will mostly fall on the shoulders of natural gas plants - because of the flexibility of gas turbines - and could end up offsetting some of the environmental benefits that the integration of renewables is meant to offer.

But Mathieu sees a solution – one that wouldn't be possible without a widespread communications and sensing infrastructure - and it's referred to as load control. The idea is simple: take advantage of the great resource offered by our power-hungry appliances, specifically those that store thermal energy, such as refrigerators, furnaces, hot-water heaters and air conditioners. If we control en masse when these devices turn on and off within the ranges of their thermostats, we can better respond to short-term fluctuations in the available electricity from renewable generators. Mathieu predicts that in California, a state with 60 gigawatts of peak consumption throughout the year, load control could offer 10-40 gigawatts of a potential resource to accommodate short-term demand and supply fluctuations. That's a huge, untapped resource.

But like Kerkez, Mathieu has some convincing to do – especially to the American consumer who doesn't want the utility controlling how his or her fridge operates. It would always be kept within its normal internal temperature range, but there is a concern that turning the compressor on and off more frequently could shorten its lifespan.

"One idea is that people could lease their fridges from third party companies who control them within customer-set temperature bands," said Mathieu, "and then they do whatever they want to it and if it breaks it's their problem."

Still, many of these upgrades to our various infrastructure systems demand a lot of buy-in from us as consumers in ways we might find strange or challenging.

DEALING WITH OUR DATA

As we integrate more and more sensors and communications technology into our physical infrastructure systems, we rapidly increase the flow of data they will soon rely on. The integration of tens, hundreds, or even thousands of sensors and data-driven components to a small section of our infrastructure represents a cost-effective, non-destructive way to upgrade its effectiveness compared to the money and obtrusions required to widen a highway or operate a high-capacity coal plant. And the advantages start to add up fast. But for all this data to be useful, it needs to be intelligently managed.

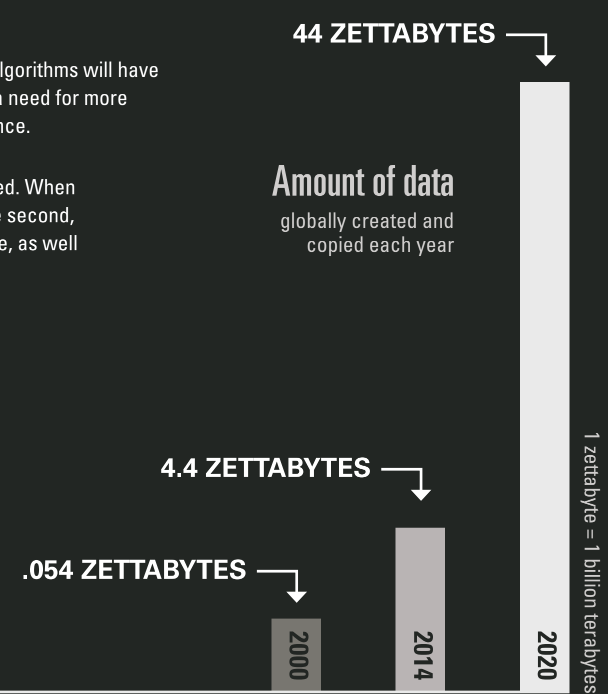
4Vs OF DATA

VOLUME The sheer amount of data that our data algorithms will have to ingest and sort through is ever growing, creating a need for more integration between engineering and computer science.

VELOCITY But it's not just the quantity, it's the speed. When you have gigabytes of water data streaming in by the second, you have to parse through some of it in near real-time, as well as store it in archives to be analyzed later.

VARIETY And we will have an increasing variety of data, from clean spreadsheets of GPS and speed measurements to hardly organizable tweets and Facebook posts.

VERACITY In the end, our algorithms that handle data must be reliable. Robust and skeptical programs should be able to accommodate an incorrect or incomplete dataset due to a malfunctioning synchrophasor along our grid, and should also identify the bad sensor so it can be fixed or replaced.



Source: International Data Corporation

GROWING CONCERNS

Beyond the technical challenges of sorting through and understanding this new data, there are concerns that our integration of data is growing much faster than our ability to keep it private and secure, and to know who owns and controls the information.

PRIVACY

Data gathered for an intelligent system that interacts with people will inherently contain personal information. In our new traffic system, for example, data will be collected that reflects a driver's travel patterns. This information is crucial to the system, yet to almost everyone else, it wouldn't be very exciting, nor accessible. But there is always the possibility of it falling into the wrong hands, so how do we ensure our privacy is maintained? Data can be anonymized in a variety of ways - by excluding personal details, or, say, eliminating the first and last 5 minutes of a driver's trip - but with so much personal information available on the Internet, those steps might not be that preventative. A more data-driven society might require a sacrifice of privacy if protection protocols can't be effective.

SECURITY

One way to minimize the risk of privacy violations is to protect gathered data and prevent unauthorized access, which is why cybersecurity is garnering a lot of attention from both private and public research efforts. And cybersecurity isn't just focused on privacy. If anyone from a prankster to a criminally-minded hacker achieved access to a data-heavy system, they could, for example, take control of your vehicle or inject false power data into the grid in an attempt to cause a blackout. Cybersecurity is an ongoing challenge. Computer systems are ever-changing and criminals are always looking for new ways to exploit them. That's why universities like U-M will play a key role in evolving our understanding of how to fortify our increasingly complex systems.

OWNERSHIP

As we develop a broad range of sensors and systems that gather data, we must ask ourselves important questions about who owns the data and what can be done with it. If a power utility company gathers data about a customer's electricity usage, does the company own that data? Can they then sell that data? Or if a researcher gathers a bunch of traffic data and provides it to a colleague who goes on to develop a profitable system component based on that data, who should be profiting? How does intellectual property come into play? We will need to work out a lot of legal distinctions as data-heavy systems and research continue to grow.

110 MILLION PEOPLE IN THE U.S. HAVE HAD INFORMATION HACKED

in data security breaches between May of 2013 and May of 2014.

Source: CNN & Ponemon Institute