arpa·e energy innovation summit

# Going Places: Prospects for Transportation Alternatives

Moderator: Dr. Jonathan Burbaum, ARPA-E

Dr. Ilan Gur, Program Director, ARPA-E

Dr. Ping Liu, Program Director, ARPA-E

Dr. Liz Santori, ARPA-E

# The Panel

Moderator/Panelist:
Jonathan Burbaum
Program Director
[PETRO, OPEN 2012]

*PETRO vs. Petroleum: Opportunities for New Technologies*

Panelist:
Ping Liu
Program Director
[RANGE, OPEN 2012]

*One Battery for Everything*

Panelist:
Ilan Gur
Program Director
[AMPED, OPEN 2012]

*An Intelligent Electric Future*

Panelist:
Liz Santori
ARPA-E Fellow

*Grounding the Flying Car*

# ARPA-E ENERGY INNOVATION SUMMIT

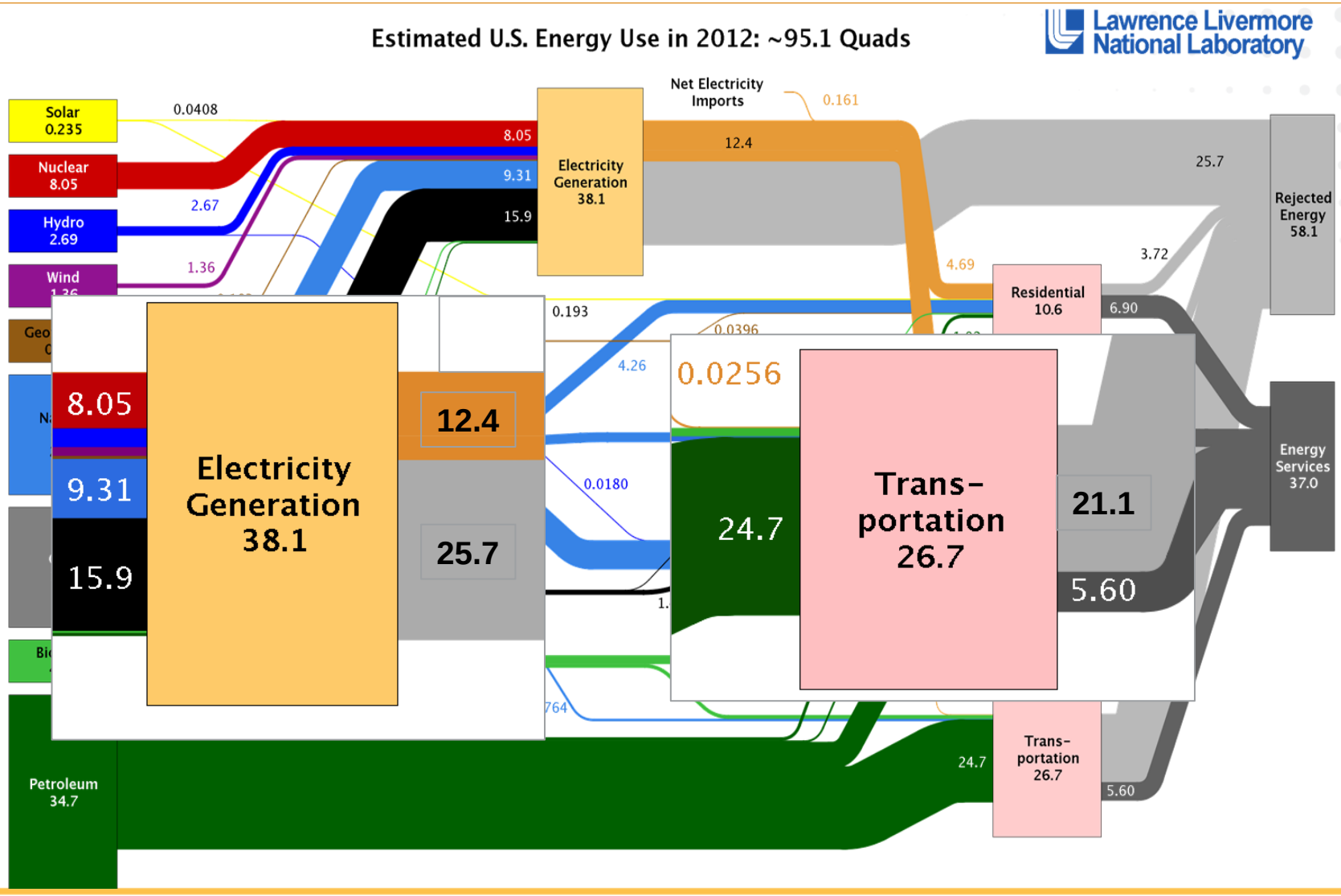
MARCH 1 - 3

GAYLORD CONVENTION CENTER

WASHINGTON DC

2010

# Rewiring the Sankey Diagram



CHANGING WHAT'S POSSIBLE

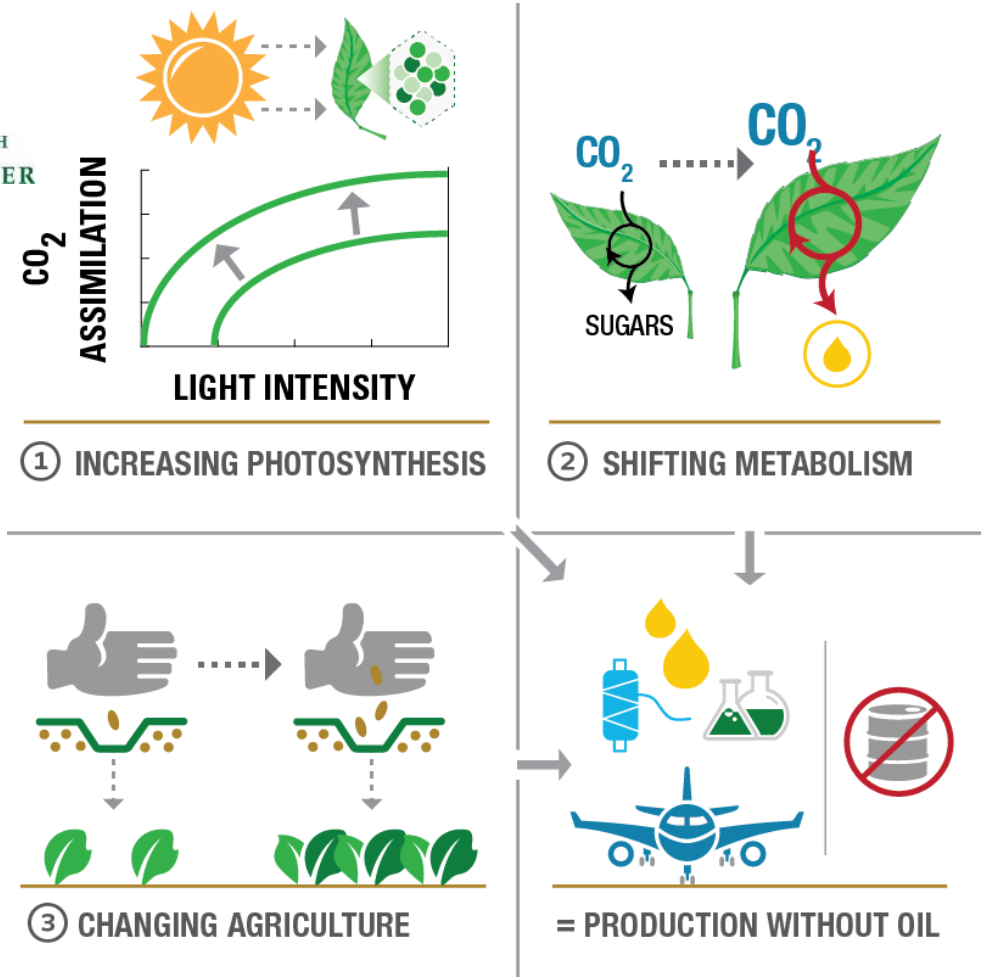
# PETRO *vs.* Petroleum: Opportunities for New Technologies

Jonathan J. Burbaum

Program Director, ARPA-E

February 24, 2014
ARPA-E Energy Innovation Summit
Washington, DC

# PETRO




DONALD DANFORTH PLANT SCIENCE CENTER

NC STATE UNIVERSITY

ILLINOIS

UMASS AMHERST

UCLA

Colorado State University

Allylix

Agrivida

BERKELEY LAB

UF UNIVERSITY of FLORIDA

Chromatin, Inc.

TEXAS A&M UNIVERSITY

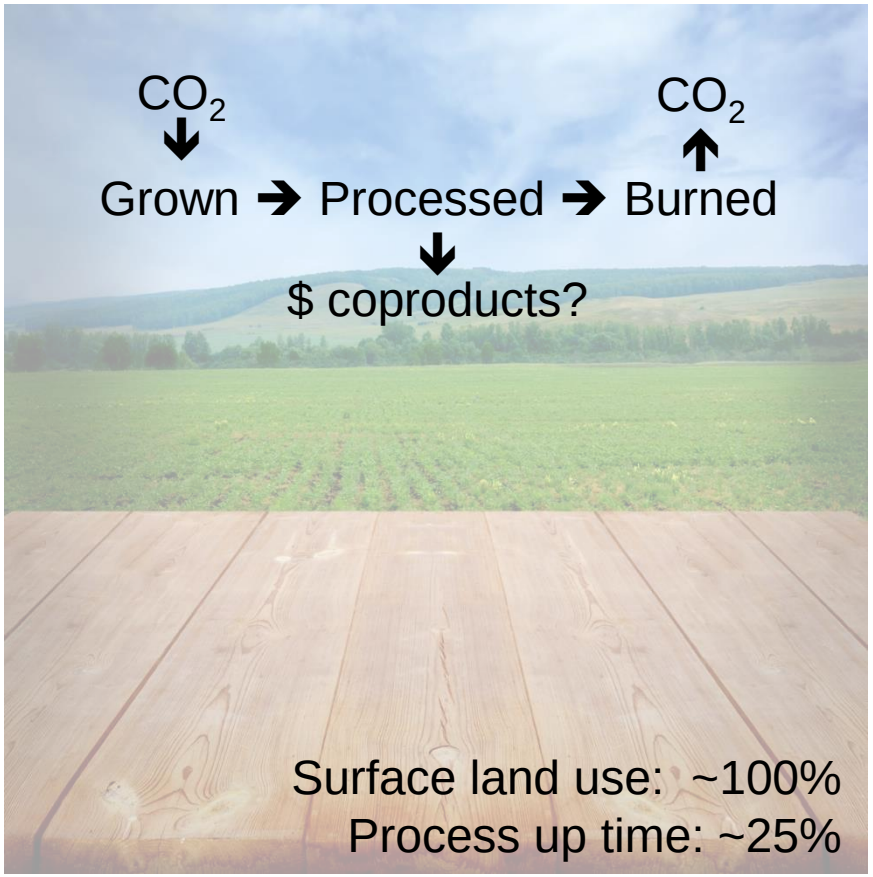
Plant Sensory Systems

THE UNIVERSITY of TENNESSEE KNOXVILLE

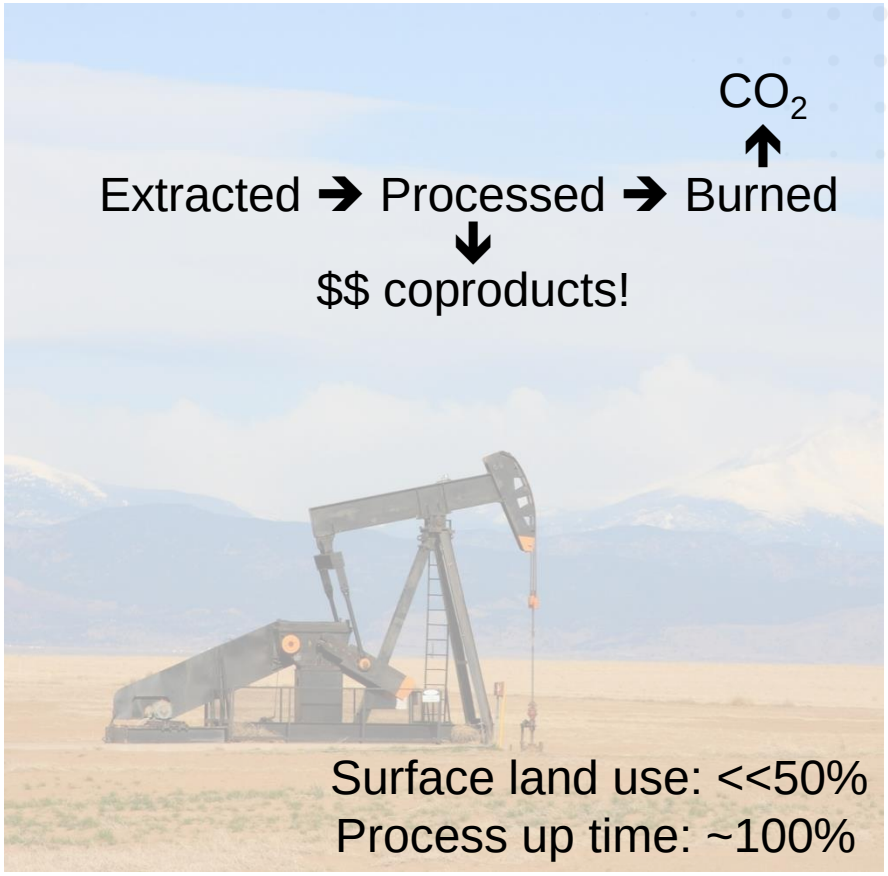
arpa·e CHANGING WHAT'S POSSIBLE

# Biofuel *vs.* Petroleum

## Biofuel




## Petroleum



# FOOD OR FUEL?

Nearly a billion people will go hungry tonight, yet this year the U.S. will turn nearly 5 billion bushels of corn into ethanol. That's enough food to feed 412 million people for an entire year.

**8** BUSHELS OF CORN = **21.6** GALLONS OF ETHANOL FUEL OR ENOUGH FOOD TO FEED A PERSON FOR A WHOLE YEAR

### DOING THE MATH...

5 billion bushels / 8 bushels of corn (enough calories to feed a person for a year) = sufficient calories to support 625 million people, minus one-third to account for distiller's grain (DDG) = 412 million

8 bushels of corn (feeds a person for a year) X 2.7 gallons of ethanol per bushel = 21.6 gallons of ethanol per bushel

### SOURCES

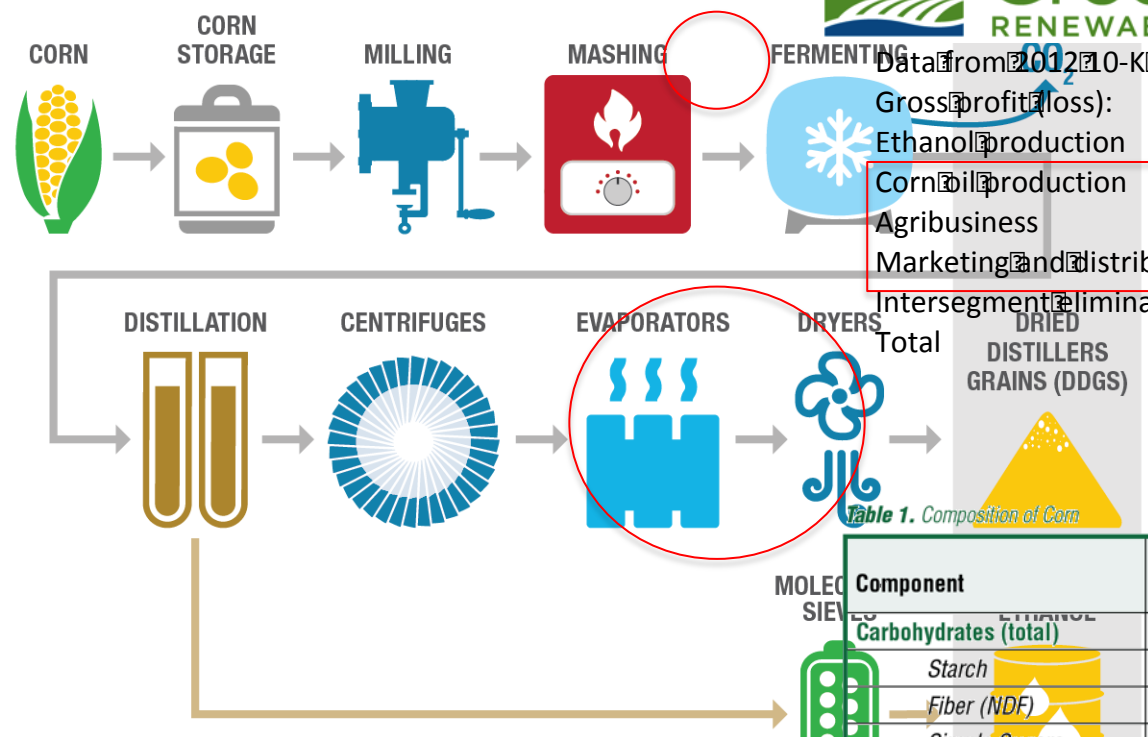
450 pounds of corn supplies enough calories for one person for a year (http://www.foreignaffairs.com/articles/62609/c-ford-runge-and-benjamin-senauer/how-biofuels-could-starve-the-poor)

About 5 billion bushels of U.S. corn production is slated for ethanol production (http://www.usda.gov/oce/commodity/wasde/latest.pdf)

One bushel of corn produces 2.7 gallons of ethanol (*Purdue Extension, "How Fuel Ethanol is Made From Corn," http://www.extension.purdue.edu/extmedia/ID/ID-328.pdf*)

resourcemedia

# What *really* happens: Food AND Fuel!




Green Plains RENEWABLE ENERGY, INC.

Data from 2012 10-K (in thousands)

| | |
|---|---|
| Gross profit (loss): | |
| Ethanol production | $ (4,895) |
| Corn oil production | $ 32,388 |
| Agribusiness | $ 35,973 |
| Marketing and distribution | $ 32,362 |
| Intersegment eliminations | $ 943 |
| Total | $ 96,771 |

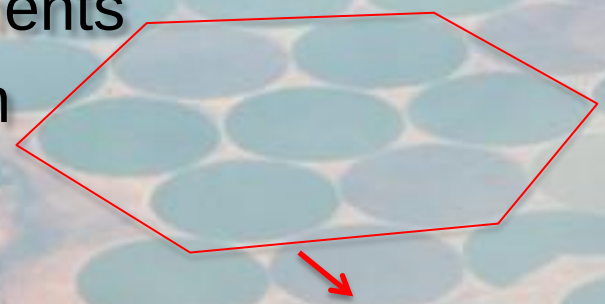
*Table 1. Composition of Corn*

| Component | Percent (average) Dry Matter |
|---|---|
| Carbohydrates (total) | 84.1% |
| *Starch* | *72.0%* |
| *Fiber (NDF)* | *9.5%* |
| *Simple Sugars* | *2.6%* |
| Protein | 9.5% |
| Oil | 4.3% |
| Minerals | 1.4% |
| Other | 0.7% |

(from *Corn: Chemistry and Technology*, 1987)

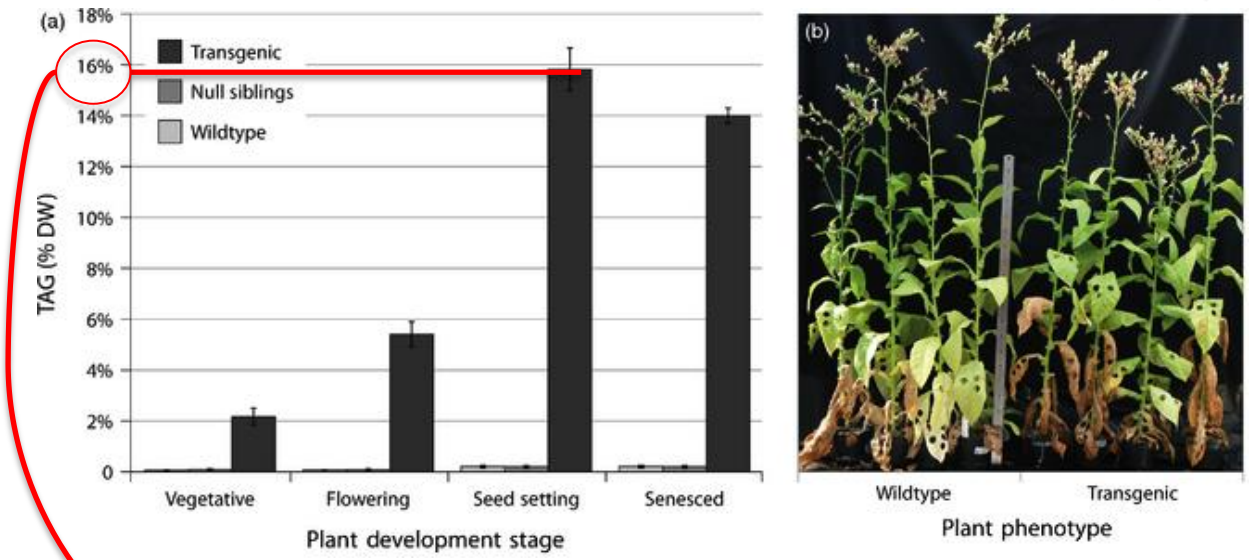
# What's next after PETRO?

- PETRO
  - Improving Energy & Carbon Flow *via* engineering biology
  - Sole metrics: Cost /Energy in fuel product, ~~coproducts~~
- Other Approaches:
  - IT-enabled "Precision" Agriculture
  - Component Improvements
  - Rethinking the System



10% improvement of land use based on geometry alone!

# Can tobacco be an energy crop?




16% DW TAG
× 9 tons per acre = **48 GJ•ha$^{-1}$•y$^{-1}$**
…vs. soybean = 17 GJ•ha$^{-1}$•y$^{-1}$
…vs. corn = 80 GJ•ha$^{-1}$•y$^{-1}$

**Plant Biotechnology Journal**
24 OCT 2013 DOI: 10.1111/pbi.12131

CHANGING WHAT'S POSSIBLE

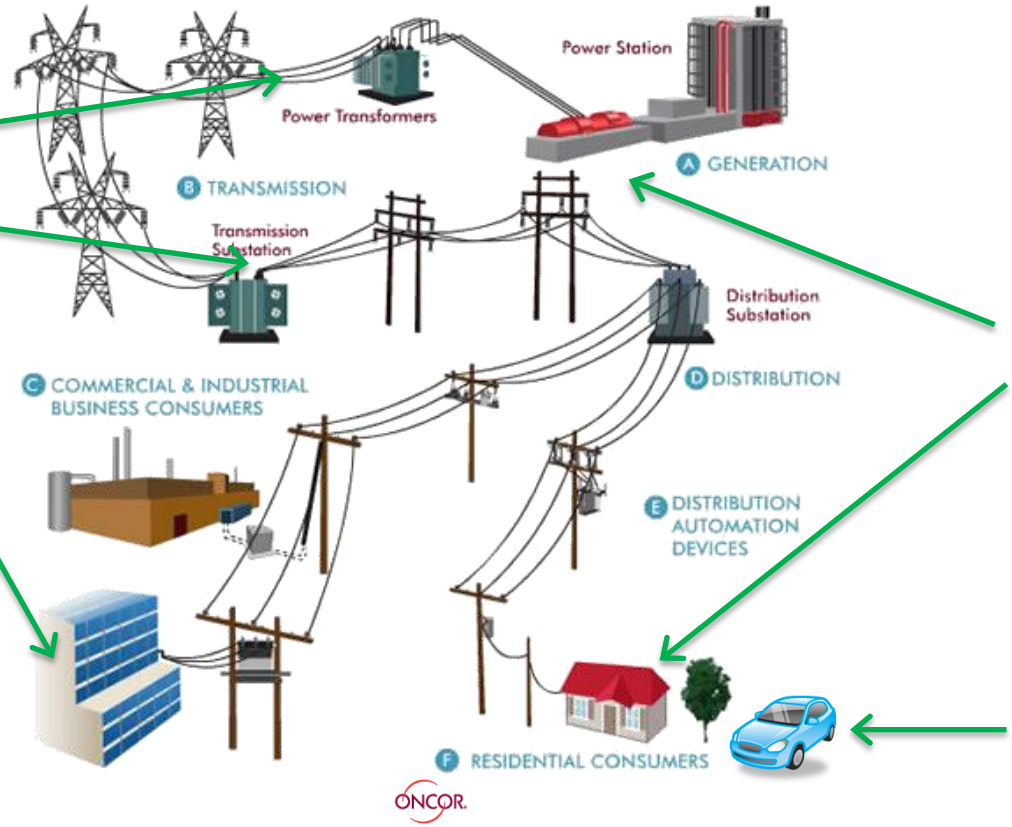
# One Battery For Everything

Dr. Ping Liu
Program Director

February 24, 2014

# Storage: Cornerstone of Grid and Vehicle

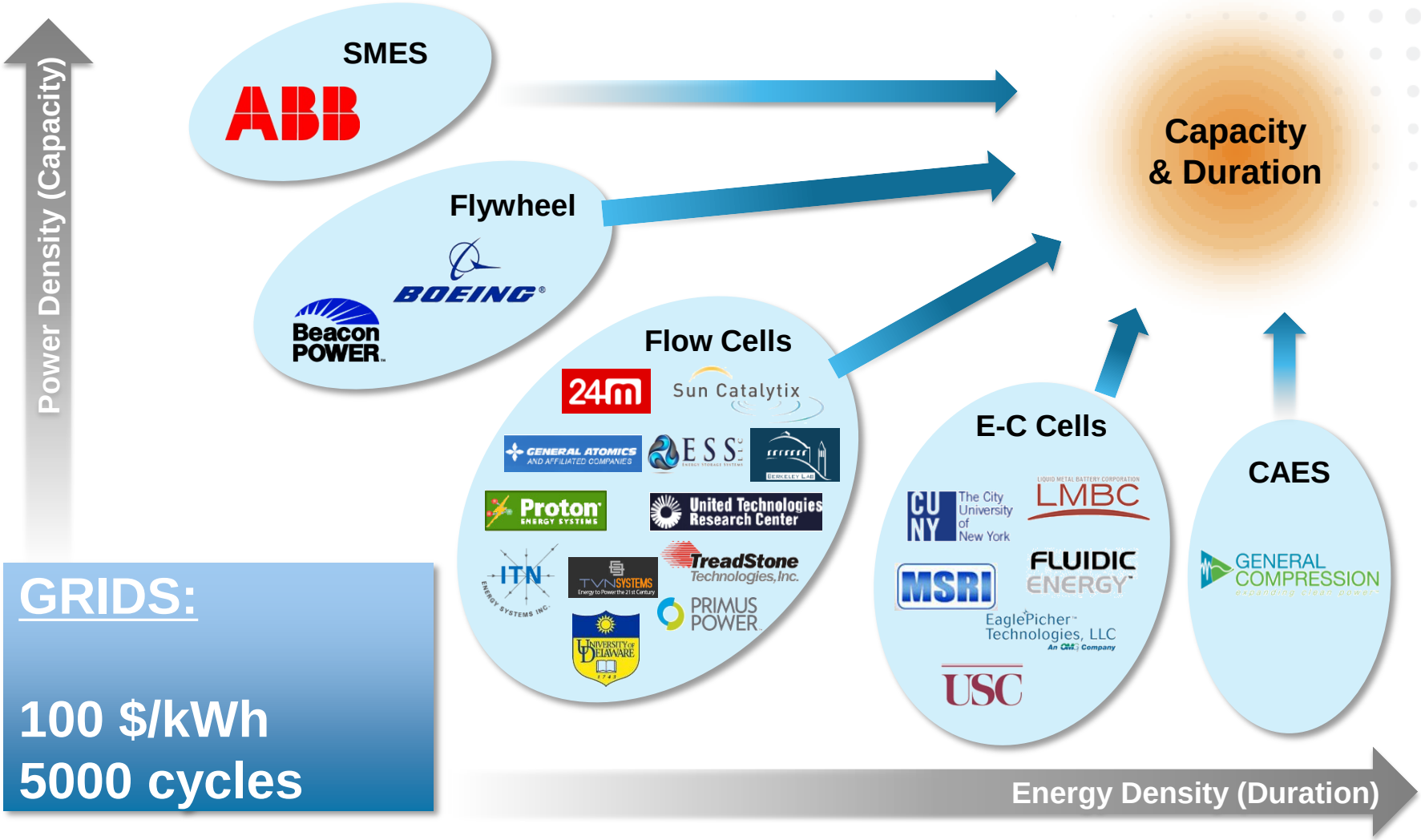
Grid Storage: GRIDS




Distributed Generation

Vehicle Storage: BEEST RANGE

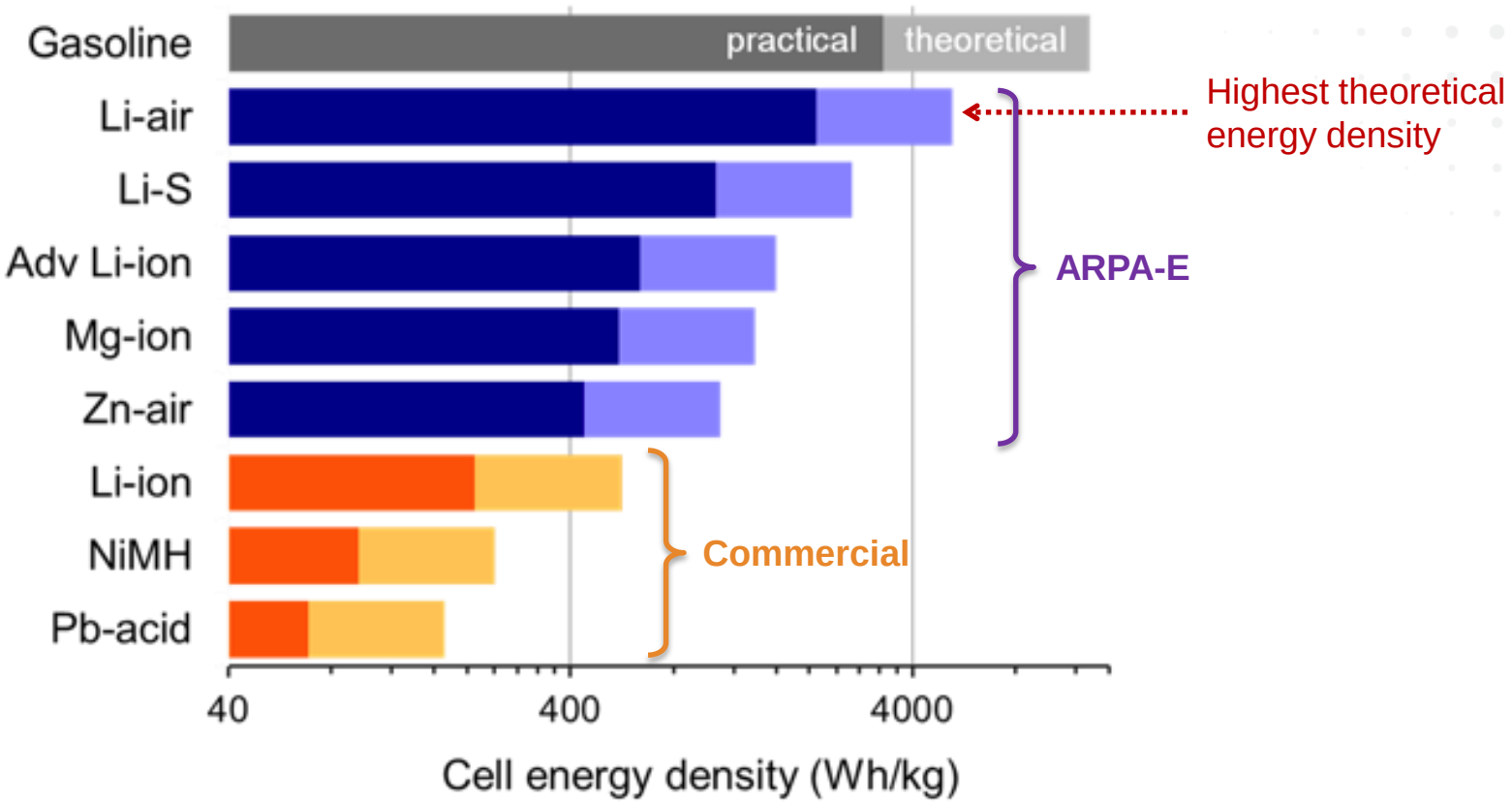
# ARPA-E's Grid Storage Portfolio




**GRIDS:**

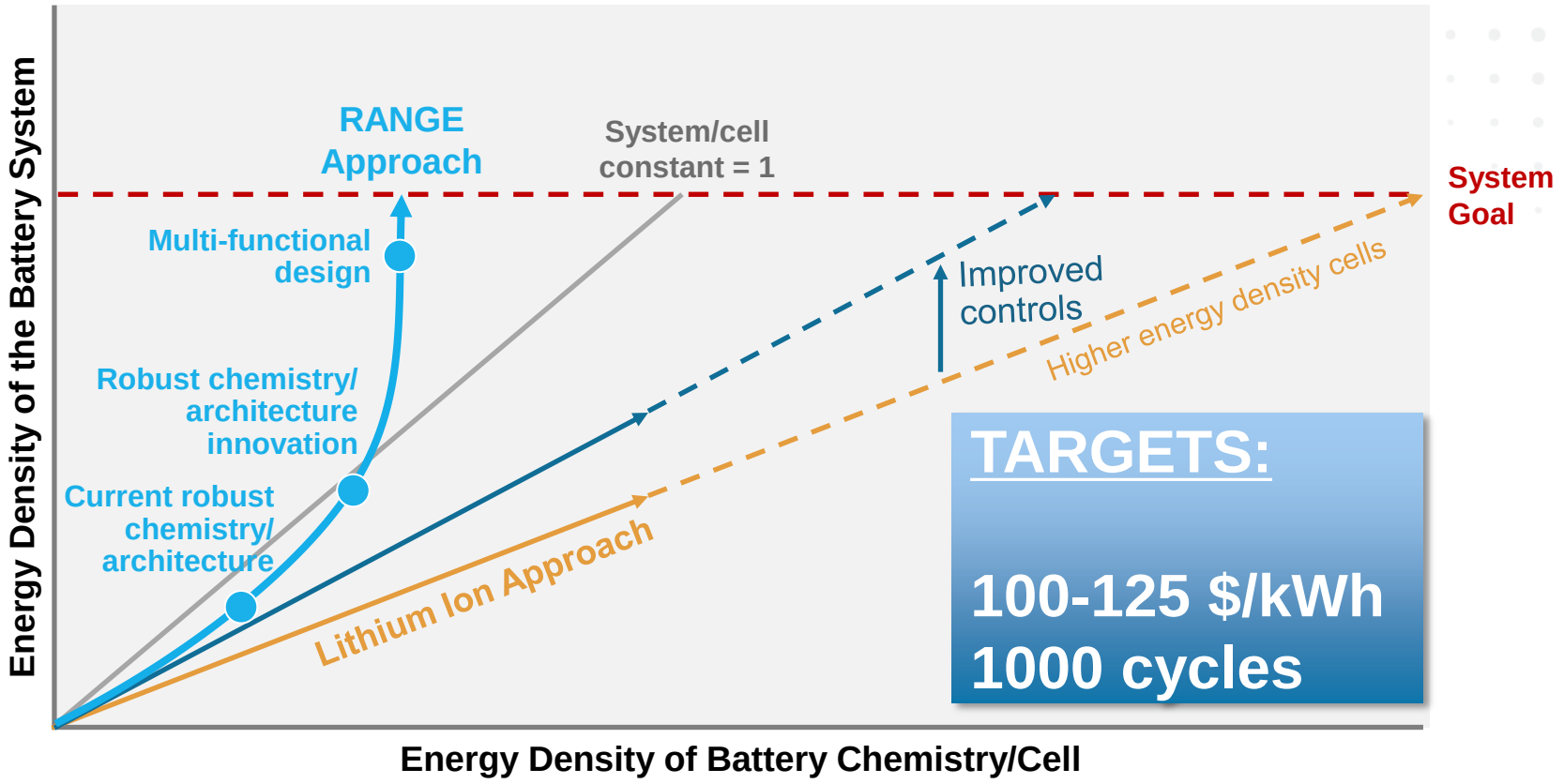
**100 $/kWh**
**5000 cycles**

# ARPA-E's Vehicle Storage Portfolio-BEEST




**BEEST pushed the boundaries of energy storage**

# ARPA-E's Vehicle Storage Approach-RANGE




**Focus on system optimization led to novel EV storage approaches**

# RANGE Program Portfolio

## *Aqueous*

## *Robust Non-aqueous*

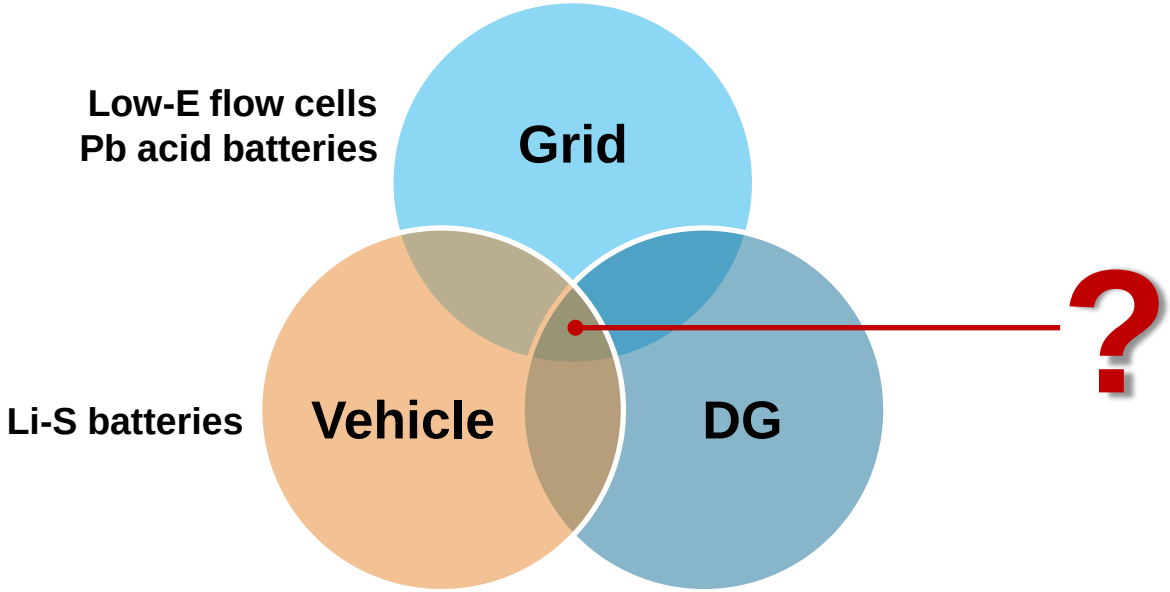
## *Solid State*

## *Multifunctional*

cloteam, LLC

# Requirements for "One Battery For Everything"

| | Cost ($/kWh) | Life (cycles) | Specific energy (Wh/kg) |
|---|---|---|---|
| **Grid** | 100 | 5000 | - |
| **Electric Vehicles (EVs)** | 100-150 | 1000 | 100+ |
| **Distributed Generation** | ? | 5000? | - |

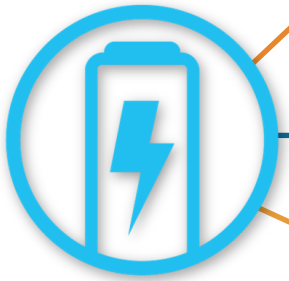



**A > 100 Wh/kg, >> 10000 cycle solution is the key**

# Benefits of “One Battery For Everything”

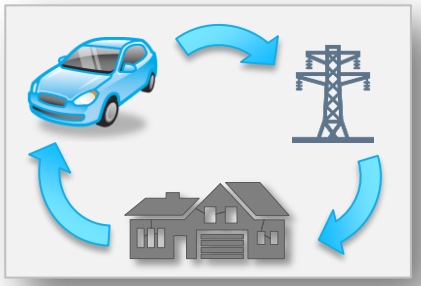
| | Cost ($/kWh) | Life (cycles) | Specific energy (Wh/kg) |
|---|---|---|---|
| **Grid** | 100 | 5000 | - |
| **EVs** | 100-150 | 1000 | 100+ |
| **Distributed Generation** | ? | 5000? | - |
| **One Battery for Everything** | **< 200?** | **>> 10000** | 100+ |

*Favorable economics*

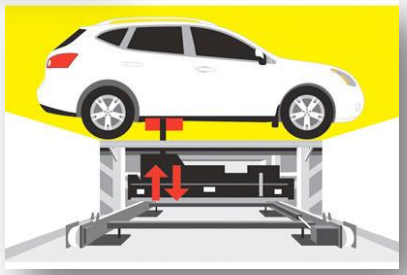


**“One For All” Solution**

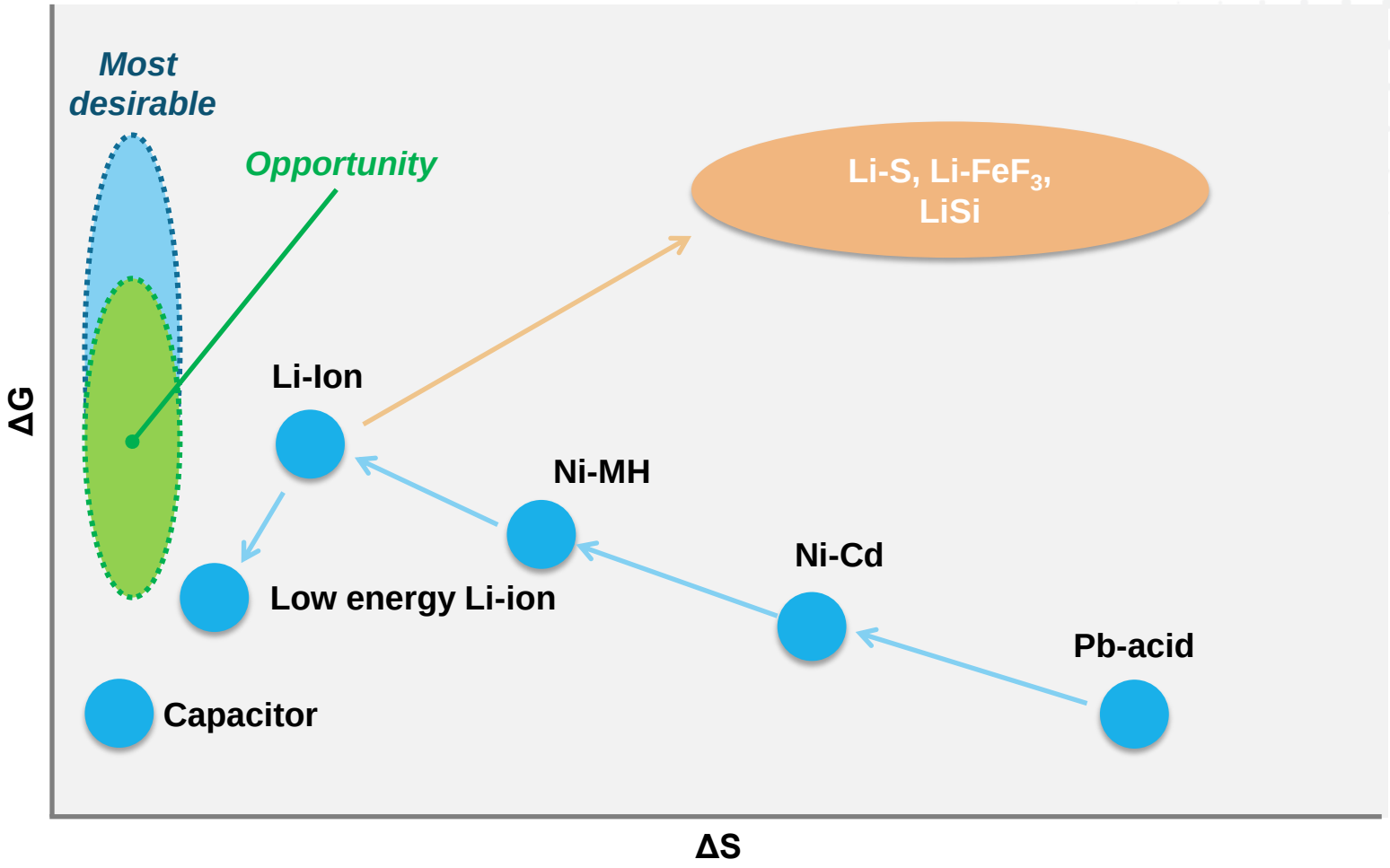
**Viable V2G**



**Rapid charging**



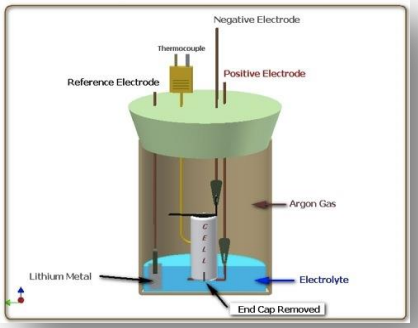
# Searching For The Ultimate Energy Storage

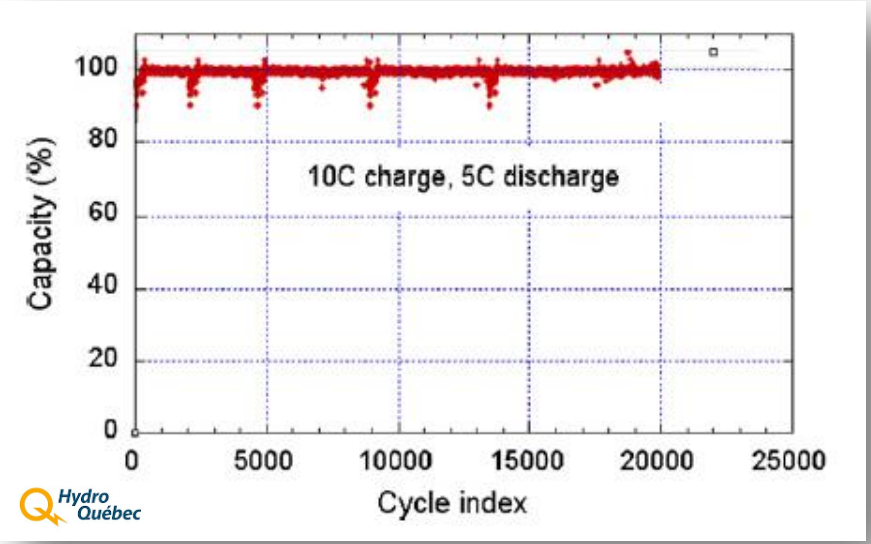


# Batteries That Live "Forever"

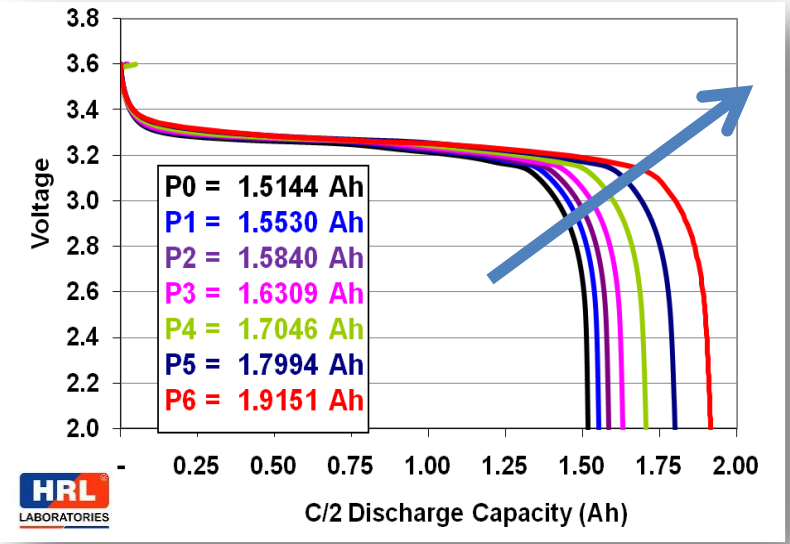
**The ultra long life $LiFePO_4$-$Li_4Ti_5O_{12}$ Battery**

**Anode for Li replenishment**



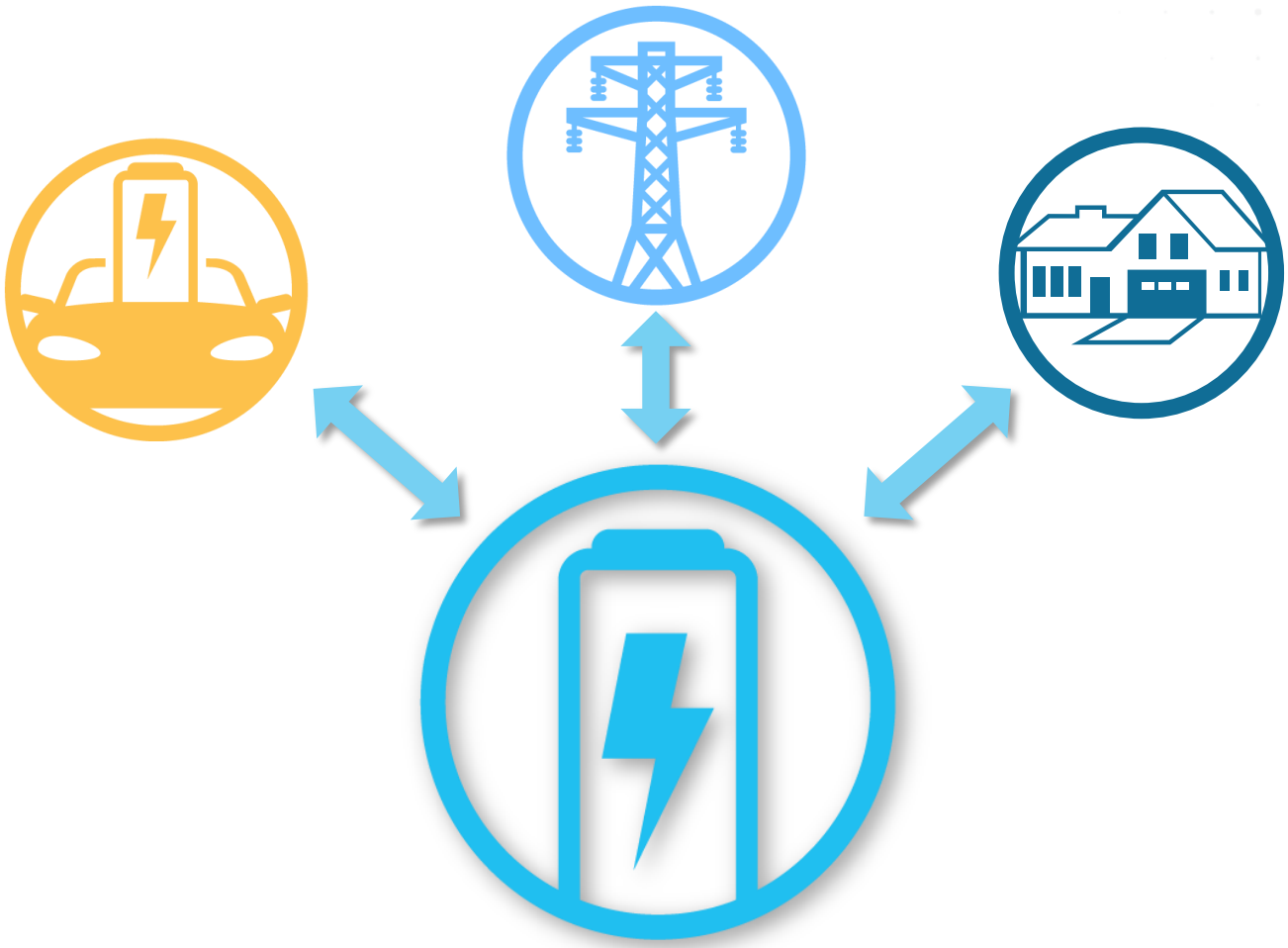




Zaghib, et al, J. Power Sources, 196, 3949




Wang, et al, J. Power Sources, 196, 5966

# A Unified Generation/Storage Future

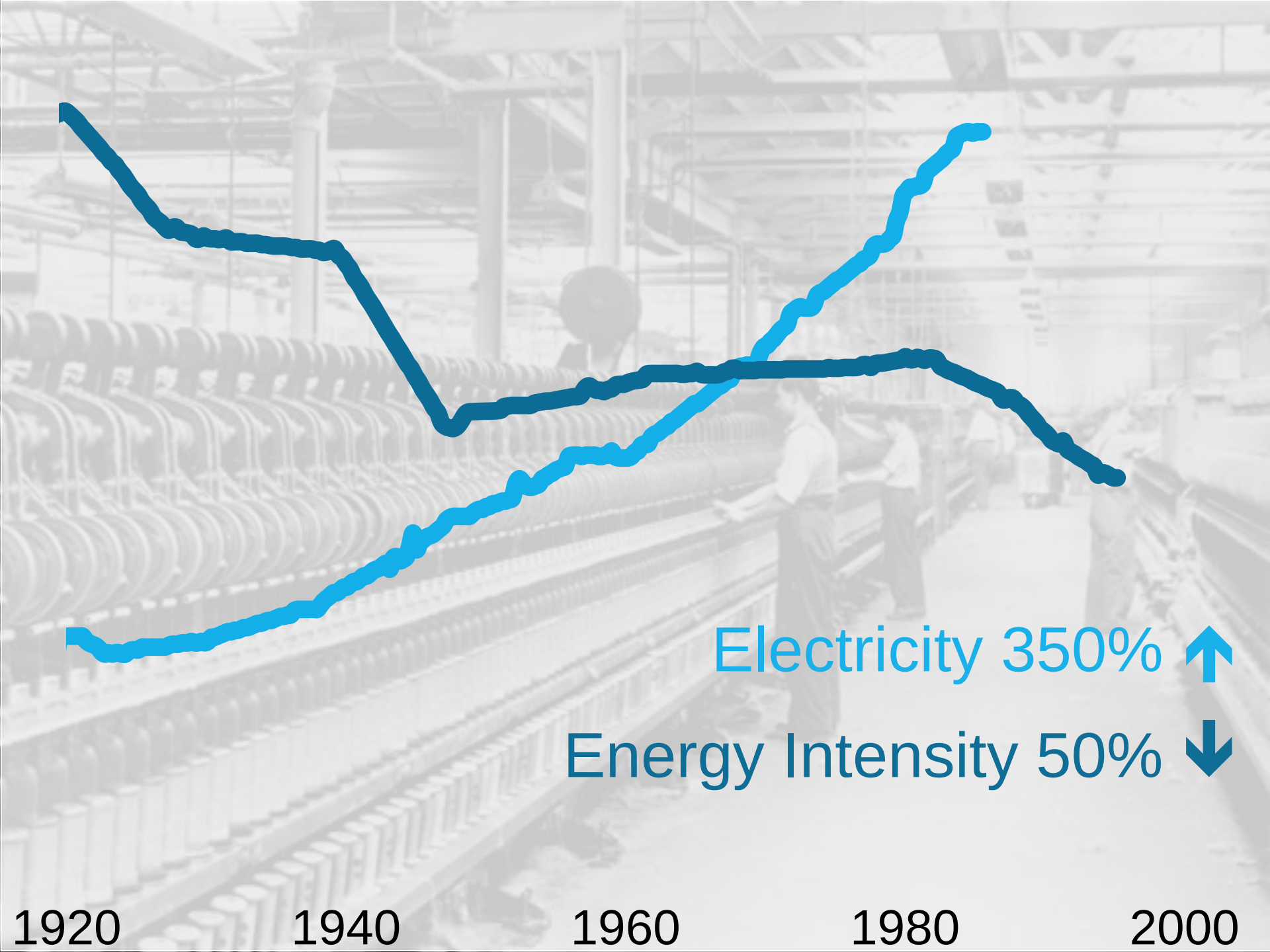


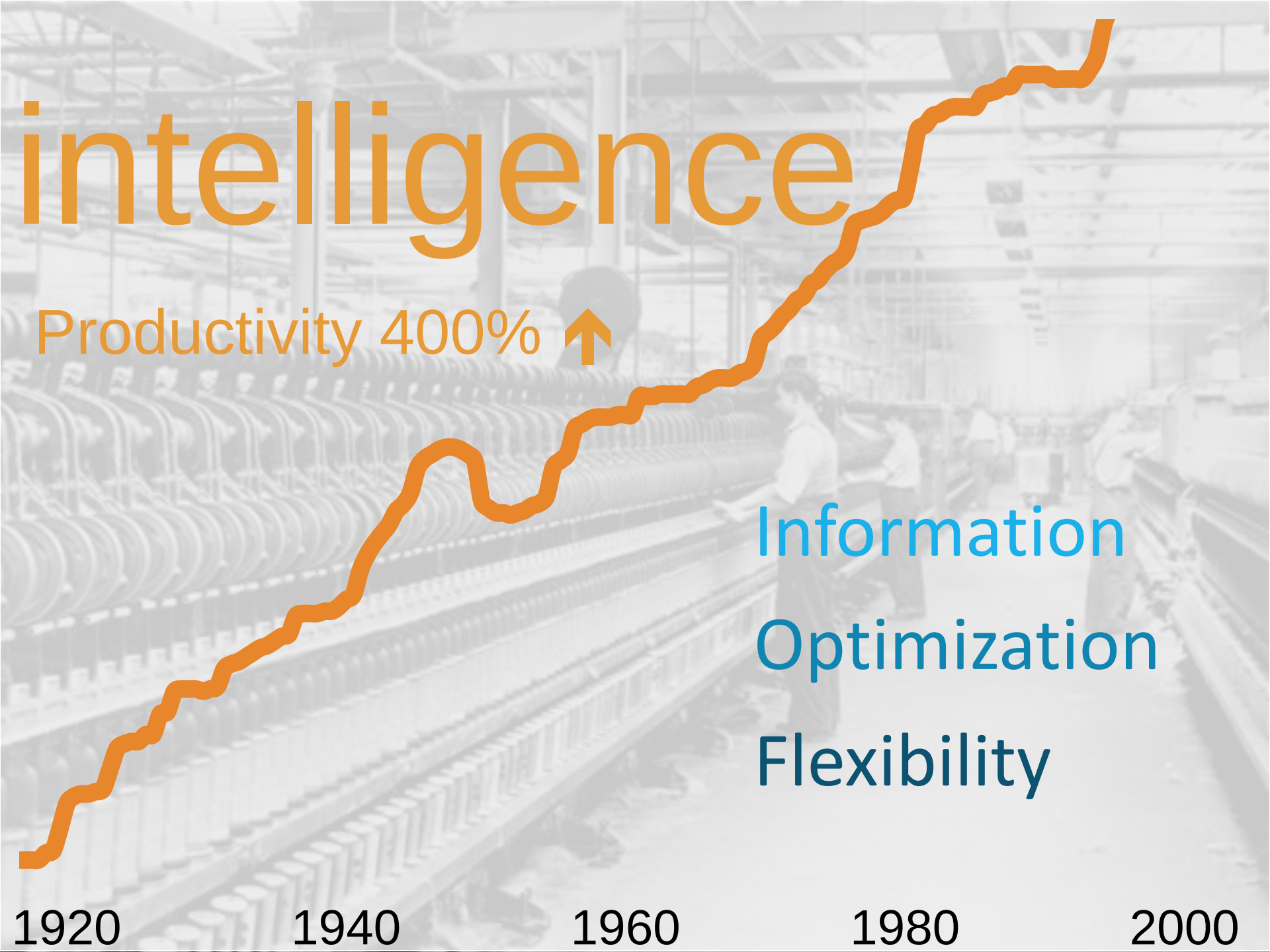
CHANGING WHAT'S POSSIBLE

# An Intelligent Electric Future

Dr. Ilan Gur
Program Director

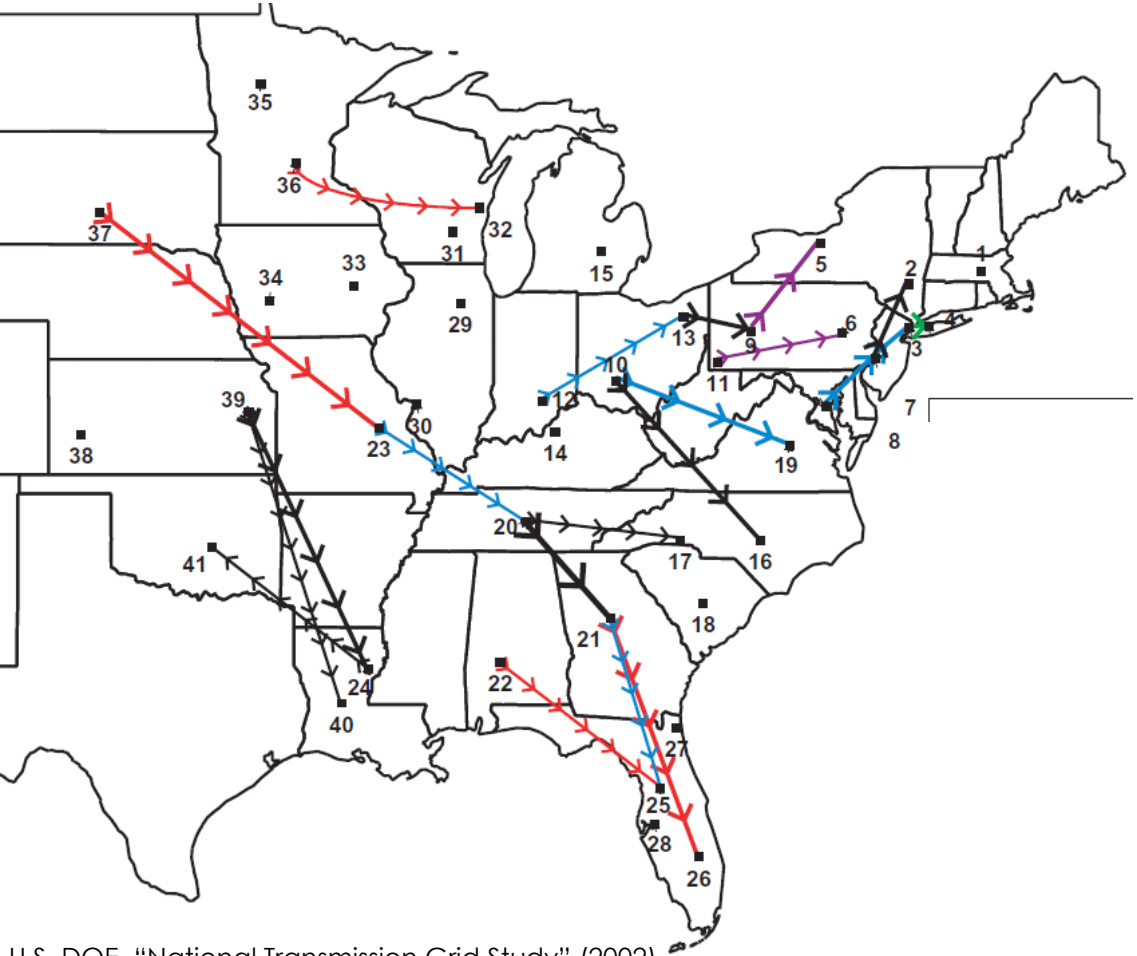
February 24, 2014


Electricity 350% ↑
Energy Intensity 50% ↓
1920
1940
1960
1980
2000


intelligence
Productivity 400%
Information
Optimization
Flexibility
1920
1940
1960
1980
2000

intelligence

# Grid Intelligence: GENI




U.S. DOE, "National Transmission Grid Study" (2002)

**Information**

Synchrophasor
Load disaggregation
AMI
Condition mon.
Digital subs.

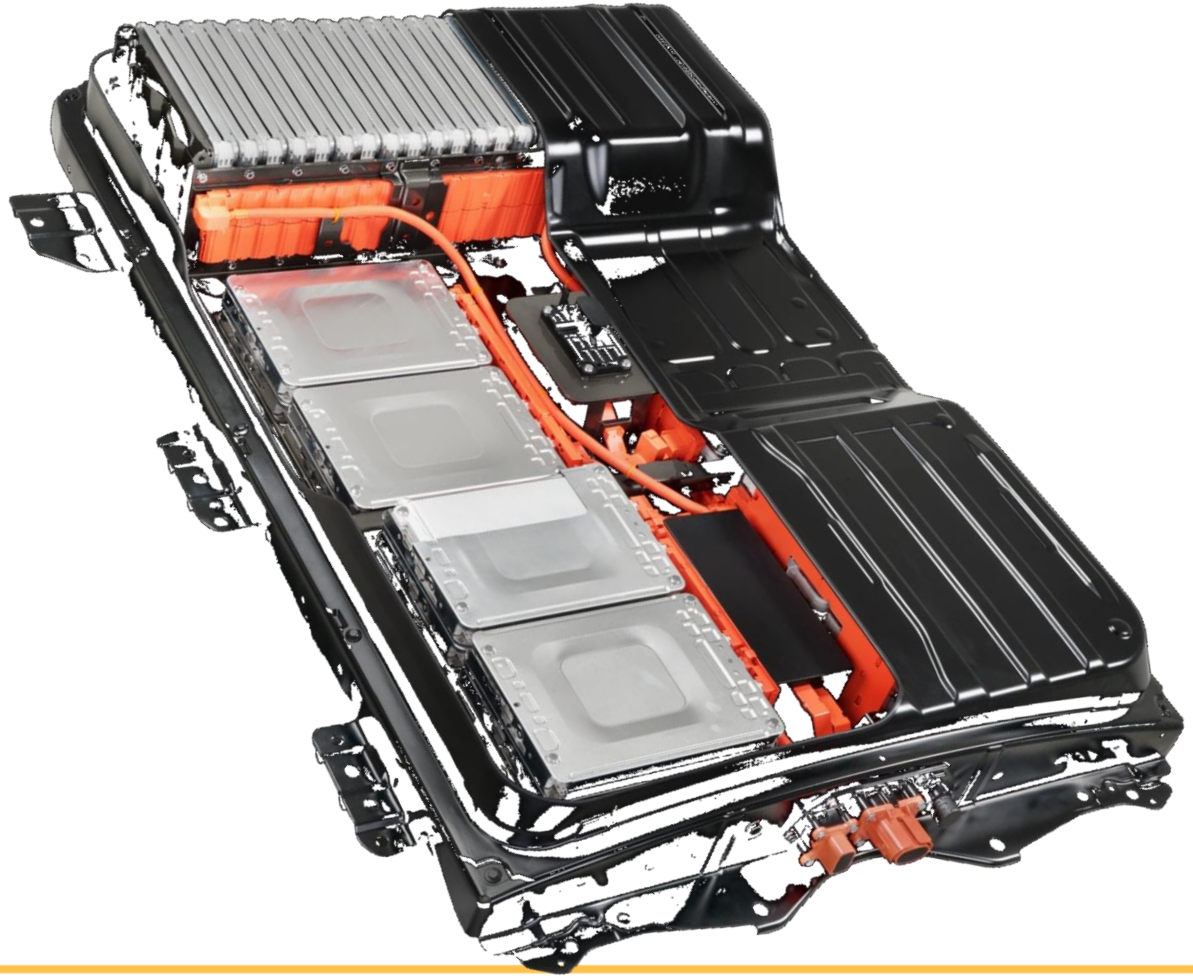
**Optimization**

Topology control
Demand opt.
Reactive P cont.
Stochastic opt.

**Flexibility**

HVDC
FACTS
Breakers
DSR
Storage

# Battery Intelligence: AMPED



**Information**

Internal Temp
Strain
Potential
Chemistry

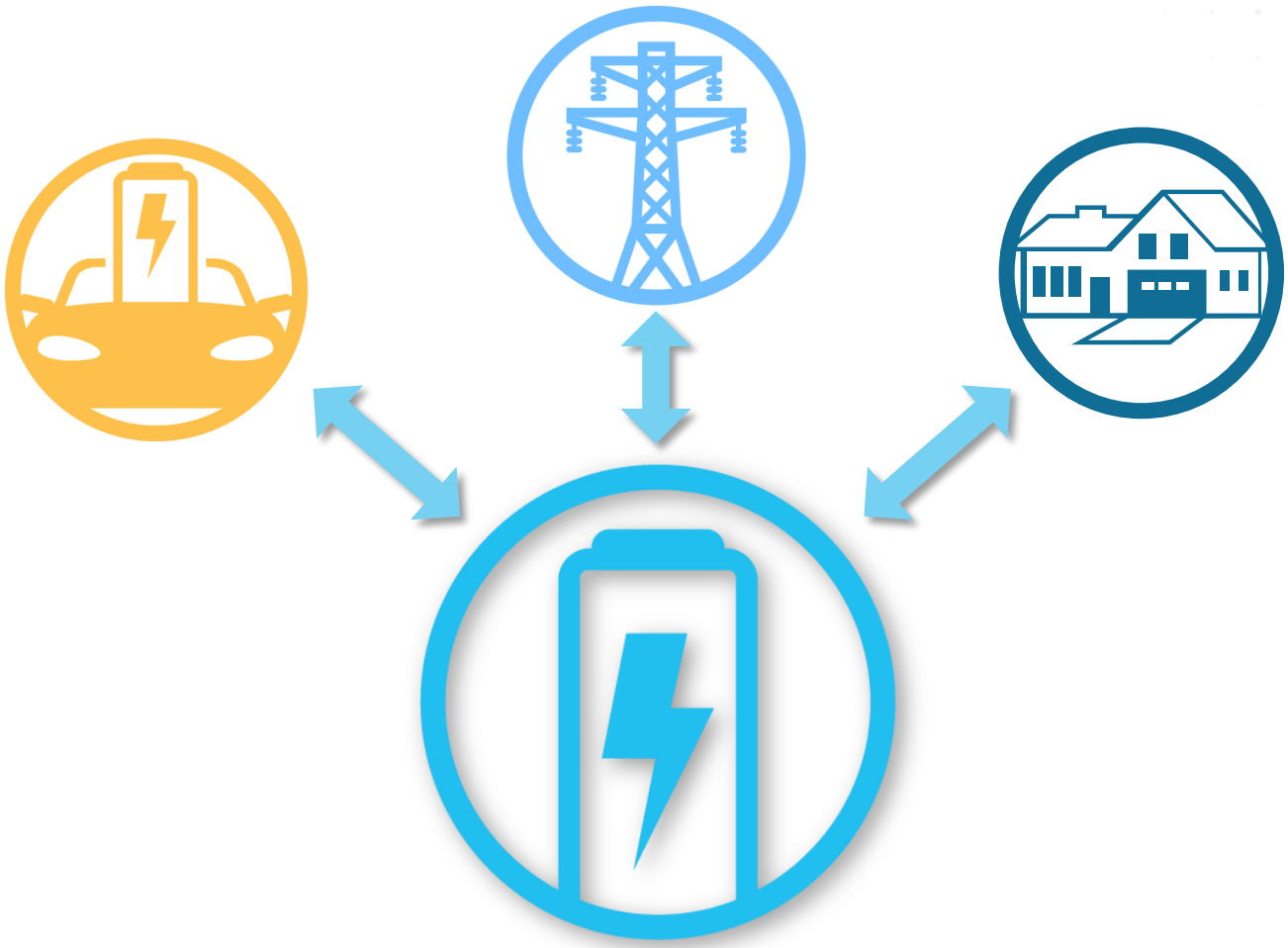
**Optimization**

Physics models
Degradation models
Dynamic controls
Load prediction
Order red.

**Flexibility**

Reconfigurable
Cell power mgmt
Cell thermal mgmt
Wireless bms

# One Battery for Everything



# One Intelligent Battery for Everything

- Integrated sensors
- Power conversion
- Computation, control, and diagnostics
- Wireless readout

# One Intelligent Battery for Everything

CHANGING WHAT'S POSSIBLE

# Grounding the Flying Car

Dr. Liz Santori
ARPA-E Fellow

March 4, 2014

# Air travel for short-duration trips

## Shorten travel times

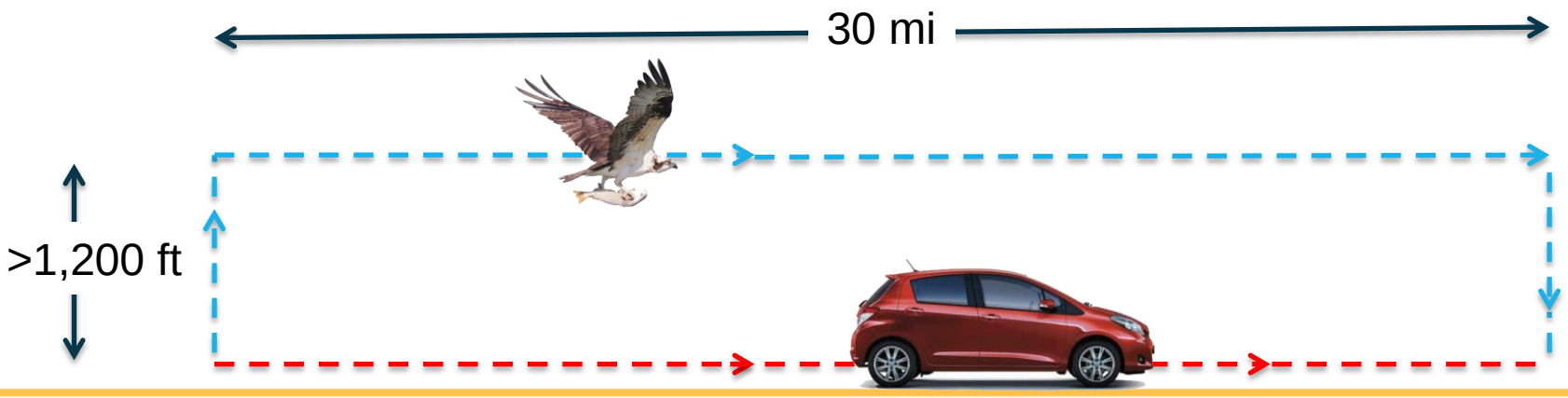
- Average speed: **>100 mph** vs. average city speed ~**30 mph**

## Reduce idling and braking

## Direct routes

## Potential for safer travel

- In a collision of 1,500 lb car vs. 15,000 lb truck, who wins?



# Move toward automation

Collision avoidance

↓

Vehicle-to-vehicle communication

↓

*Autonomous vehicles*

**Sensing**

**Communication**

**Intelligent Controls**

Fly-by-Wire

↓

Semi-autonomous unmanned aerial vehicle

↓

*Fully autonomous aircraft*

# ‘Flying cars’ are cool…
# Would they consume much more energy?

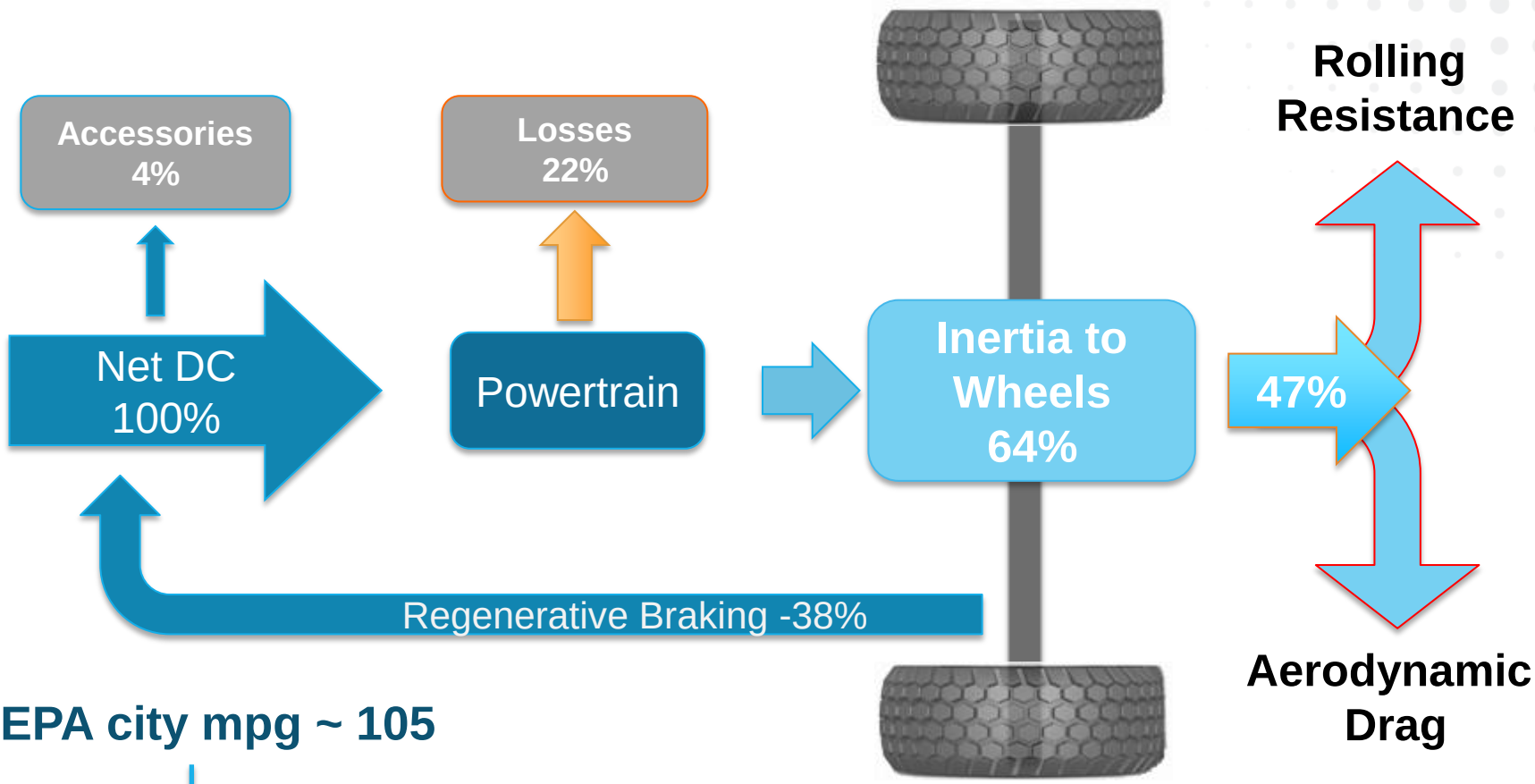
Moller M400

Terrafugia Transition

Terrafugia TF-X

Joby Aviation Monarch

# Breakdown of electric vehicle losses




**EPA city mpg ~ 105**

**65 mpg in heavy summer traffic**

*Nissan Leaf*. Argonne National Laboratory

# Current light aircraft

Sikorsky

**Sikorsky S-333™**

- **MPG ~ 5**
- 2,460 lbs
- 4 person

Cirrus Aircraft

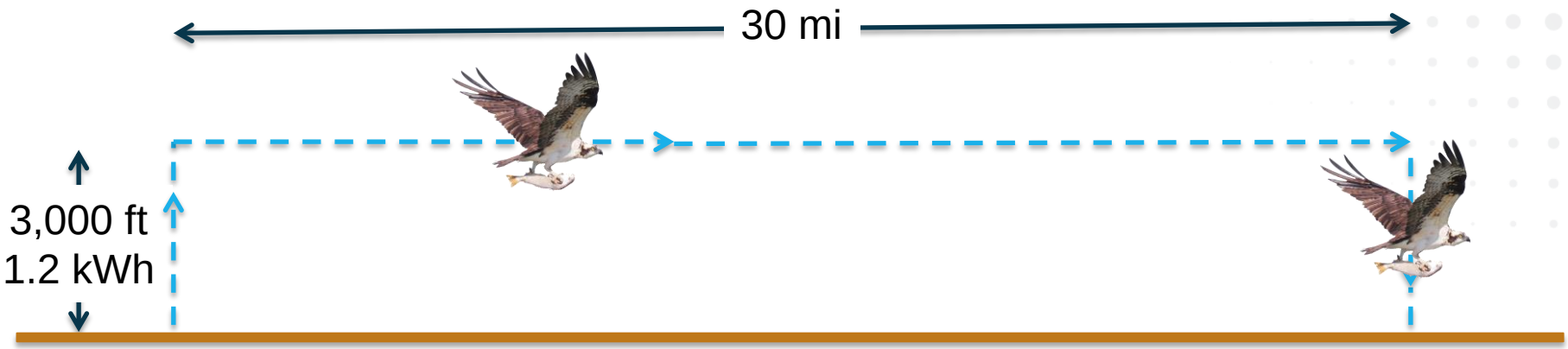
**Cirrus SR22**

- **MPG ~ 16**
- 3,600 lbs
- 4 person

**Camcopter® S-100 (UAV)**

- **MPG ~ 8**
- 441 lbs

# Estimation of MPG for VTOL




$$C_D = C_d + \frac{C_L^2}{p \times AR \times e_s}$$

$$F_D = \frac{1}{2} r S C_D v^2$$

*Losses from drag in cruise*

$$E = mgh$$

*Potential energy of aircraft*

***Key assumptions:***

1100 lb aircraft

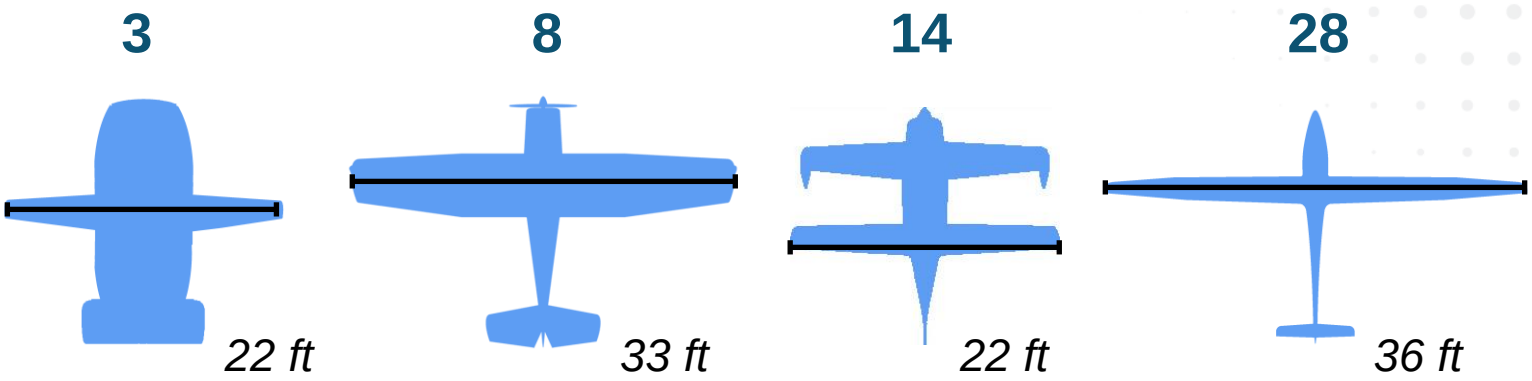
$\eta_{EM}$ = 92%

$\eta_{battery}$ = 97%

$\eta_{prop}$ = 80%

# Estimation of MPG

## Cruise Lift over Drag (L/D)




| | | | | |
|---|---|---|---|---|
| Cruise power | 80 kW | 45 kW | 28 kW | 16 kW |
| % mgh | 5% | 13% | 20% | 35% |
| % weight battery | 94% | 38% | 24% | 15% |
| **MPG** | **30** | **80** | **120** | **200** |

# Thank You

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