arpa·e energy innovation summit

Generation for the Next Generation

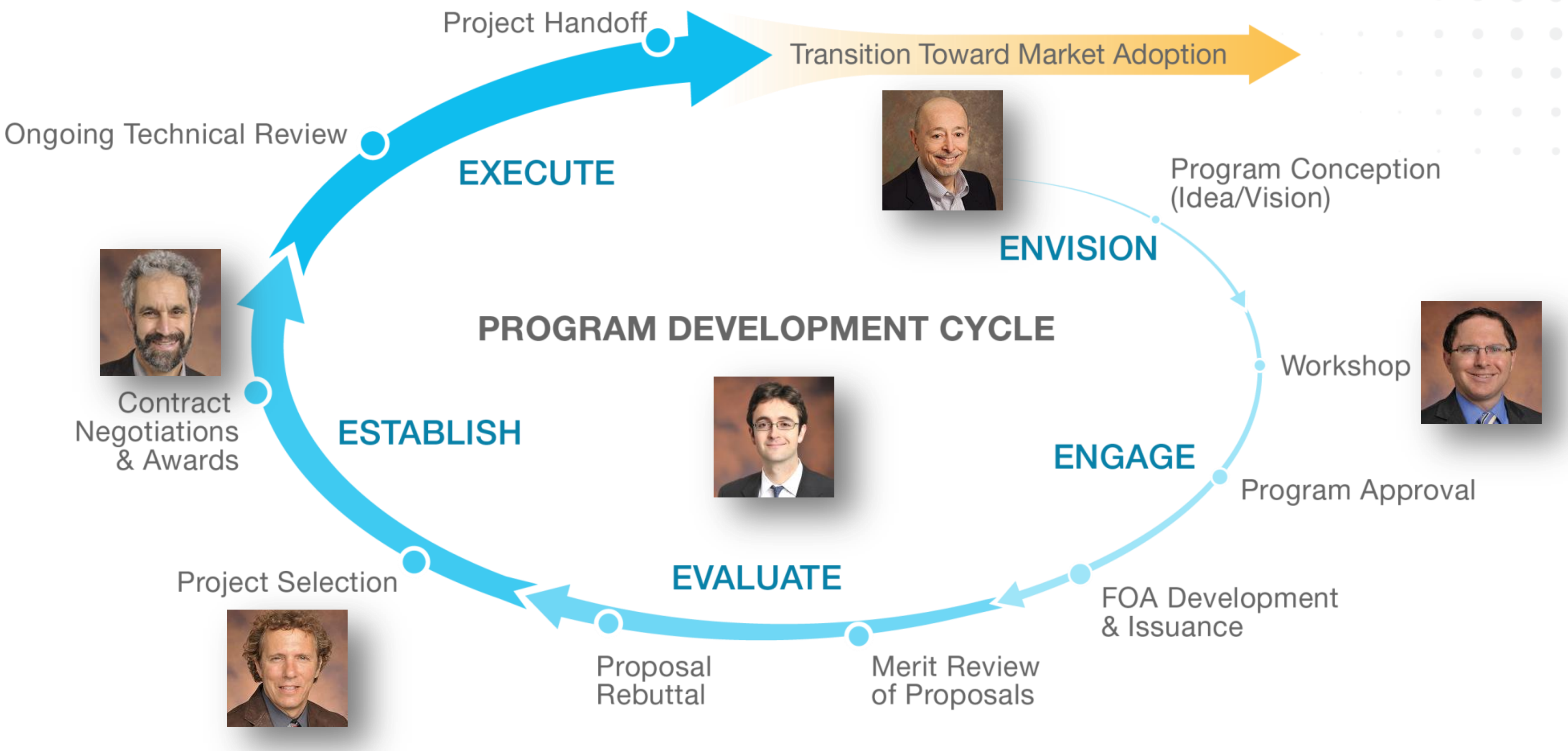
Moderator: Dr. John Lemmon, ARPA-E

Dr. Howard Branz, ARPA-E

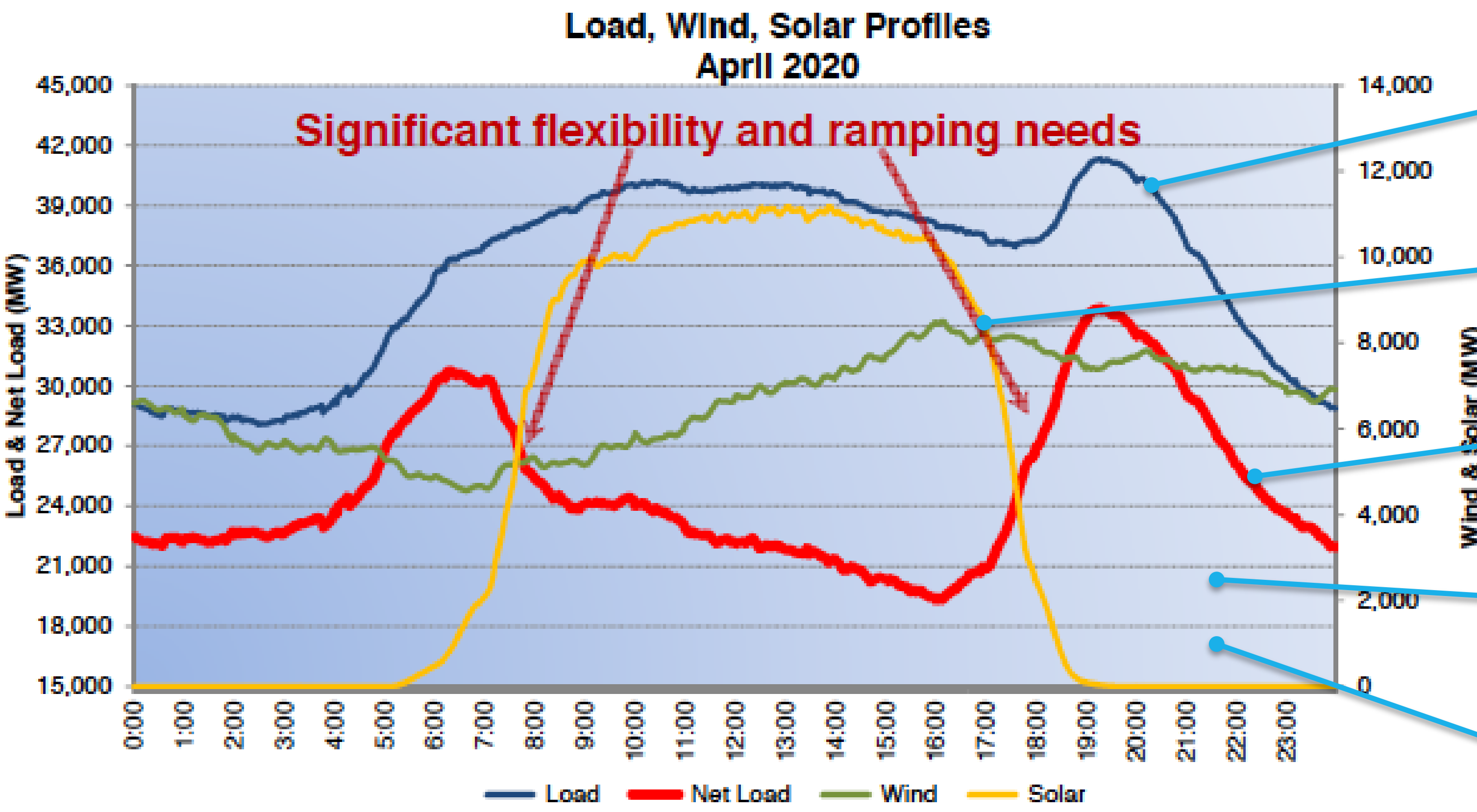
Dr. Patrick McGrath, ARPA-E

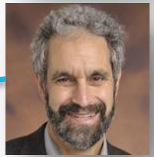
Dr. William Regan, ARPA-E

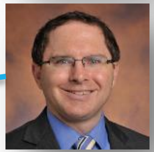
Technology Acceleration Model

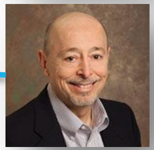


Impact of PV – Wind on Base Load.









Mark Rothleder, CAISO, "Operational Flexibility Analysis," presented at the CPUC Operational Flexibility Workshop, June 4, 2012 0

Decrease in base load requires significant reserves to offset high ramps.

CHANGING WHAT'S POSSIBLE

Integrating Distributed Generation & Storage into the Grid

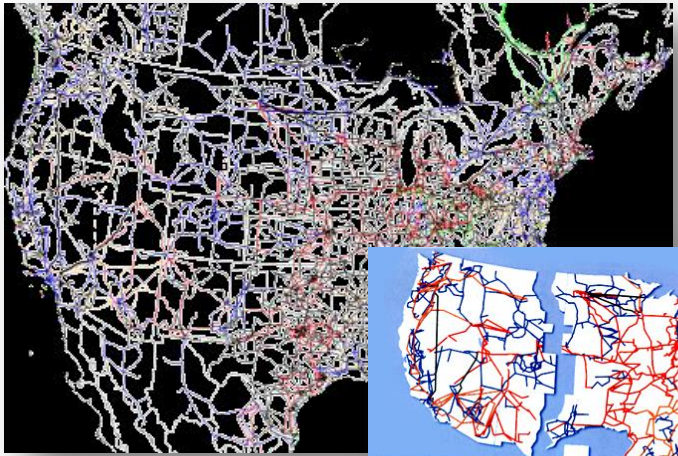
Providing Energy When and Where it is Needed

Dr. John Lemmon, Program Director

U. S. Electric Grid - Big with Several Players

- 157,000 miles of high-voltage electric transmission lines.
- Over 15,000 generating units.
- 143 million customers

- **Total Electricity Revenues in 2009:** $353B

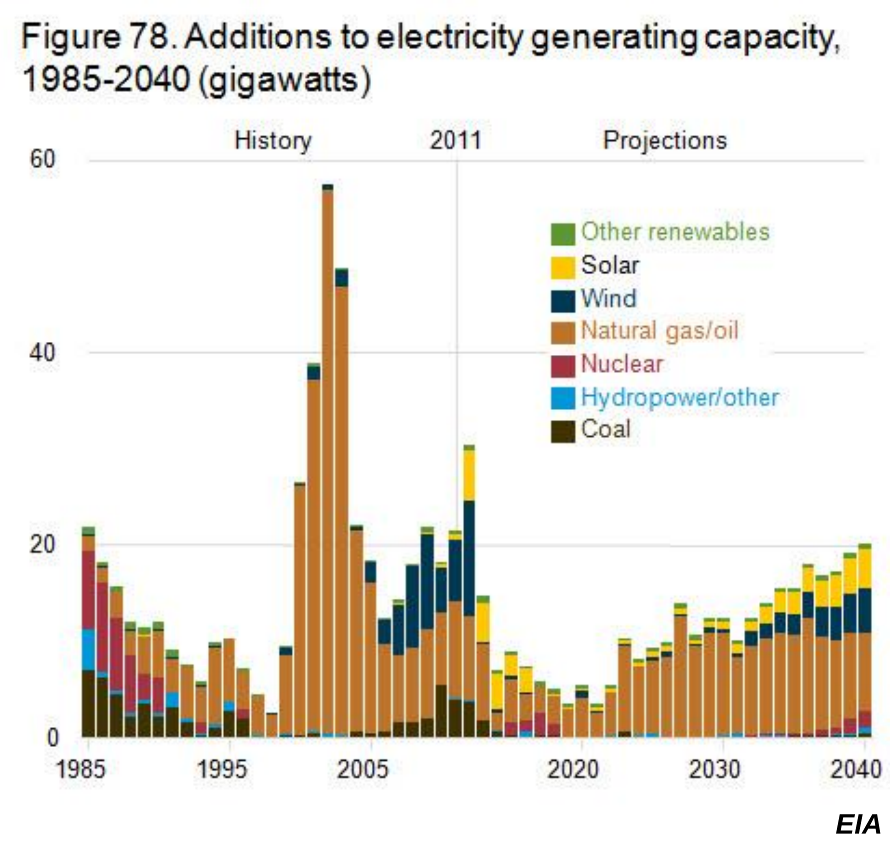


- **Over 3100 electric utilities in the U.S**.
  - 213 stockholder owned – provide 73% of electric power.
  - 2000 public utilities, state and local government - provide 15% electric power.
  - 930 electric cooperatives- provide about 12% electric power.
  - 2100 nonutility power producers, including both independent power companies and customer-owned distributed facilities.

Current Trends: Stationary Power

Electricity Demand

- Projected electricity demand increases by 2040
  - US: 18-42% (EIA)
  - Developing countries: 65% (Exxon)
- Large portion of new demand will be met by NGCC (η ~ 55%, HHV)

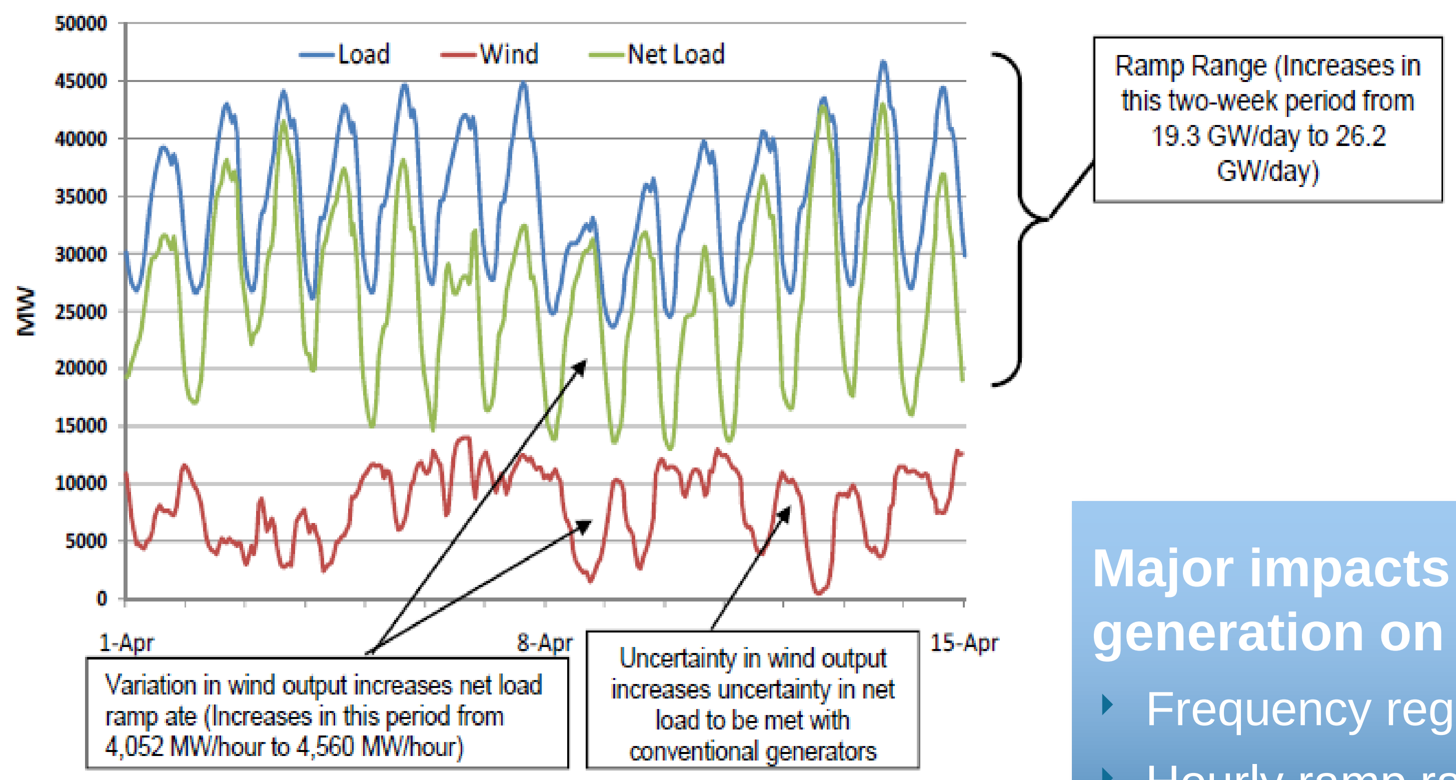


Issues

- T&D congestion, losses
- Renewable integration challenging
- NG price uncertainty
- Regulation uncertainties make large capex projects difficult to plan

Future generation dominated by NGCC and increasing renewables

Impact of Renewables on the Grid

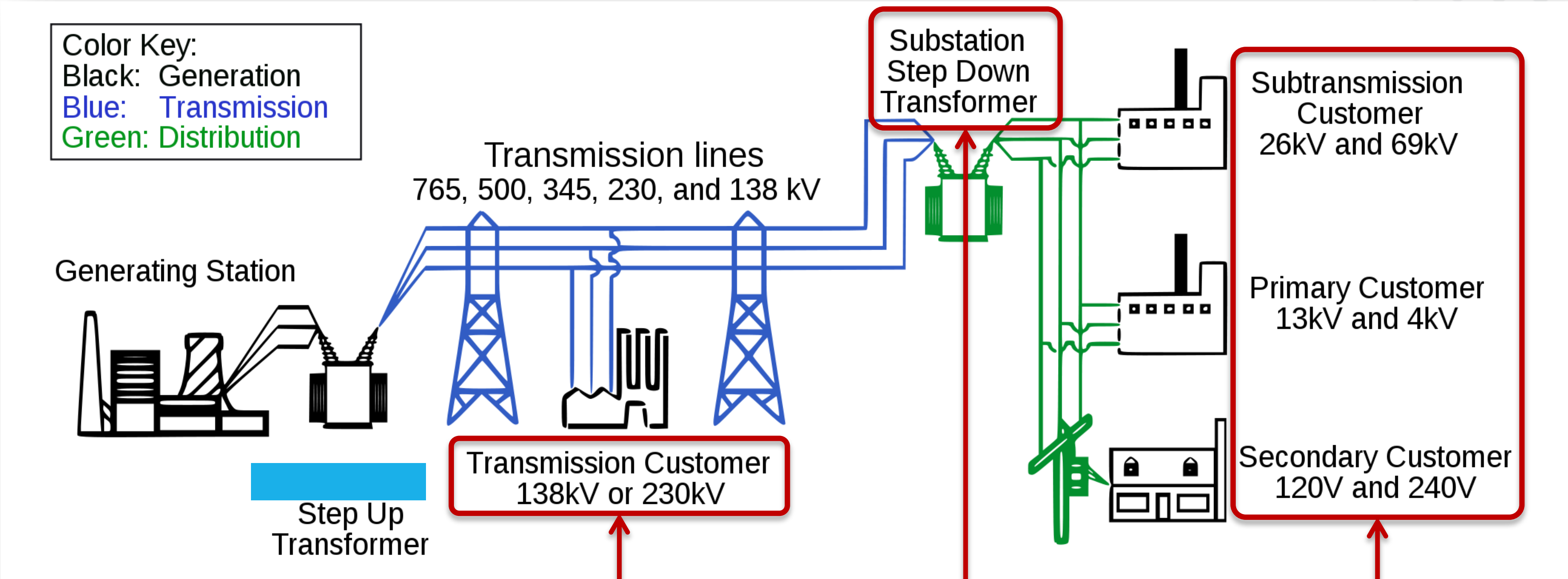


Major impacts of variable generation on the grid:

- Frequency regulation
- Hourly ramp rates
- Uncertainty in net load
- Ramp range

Source: CCIA Energy Storage March 2012: NREL, Role of Energy Storage with Renewable Electricity Generation – K. Smith, P. Denholm

Energy Loss in Today's Grid



Typical losses on Transmission level: 2.5% - 5%

Typical losses on Substation level: 1.0% - 2.5%

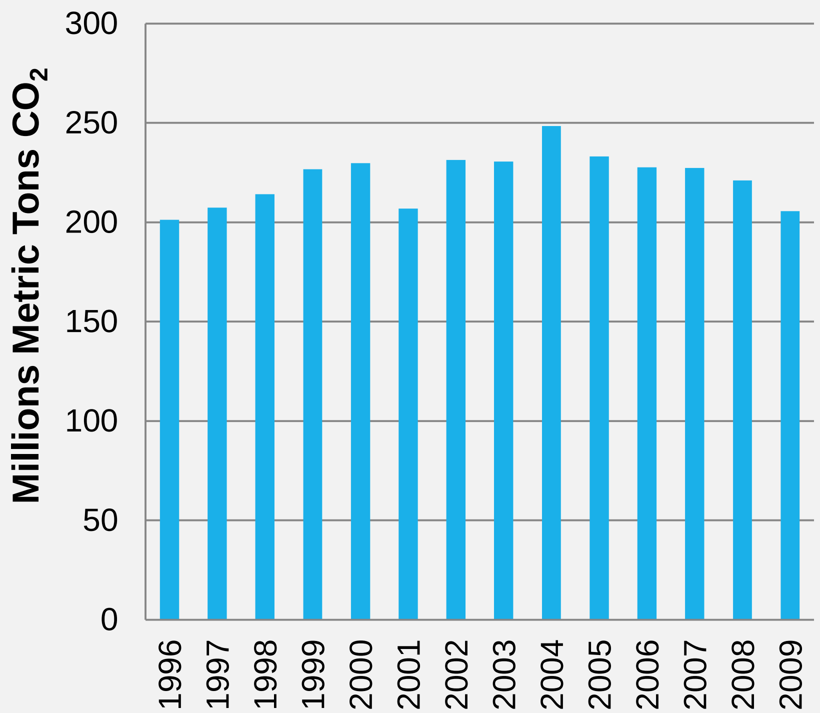
Typical losses on Distribution level: 6.0% - 8.0%

Note: The losses above are at peak load, based from a study of AEP'sT&D system. The ranges above do not directly correlate to the previous page due to differences in source data

The majority of the losses are in the distribution level

Source: Nourai, et al; "Load Leveling Reduces T&D Line Losses", IEEE Transactions on Power Delivery, 2008

Impact of Efficiency Losses in T&D



Impact of Capturing Losses

200 million tons of CO_2 =
output of 56 coal plants

Reducing 200 million tons of CO_2 emissions =
removing 38.5 million cars from the road

375,000 GWh[1] =
enough to power 8.9 million of homes for a year

These losses equate to a significant amount of CO_2

(1) EIA 2009 data of GWh generated (less direct use) and GWh consumed

Grid Issues Become Drivers for DG & DS

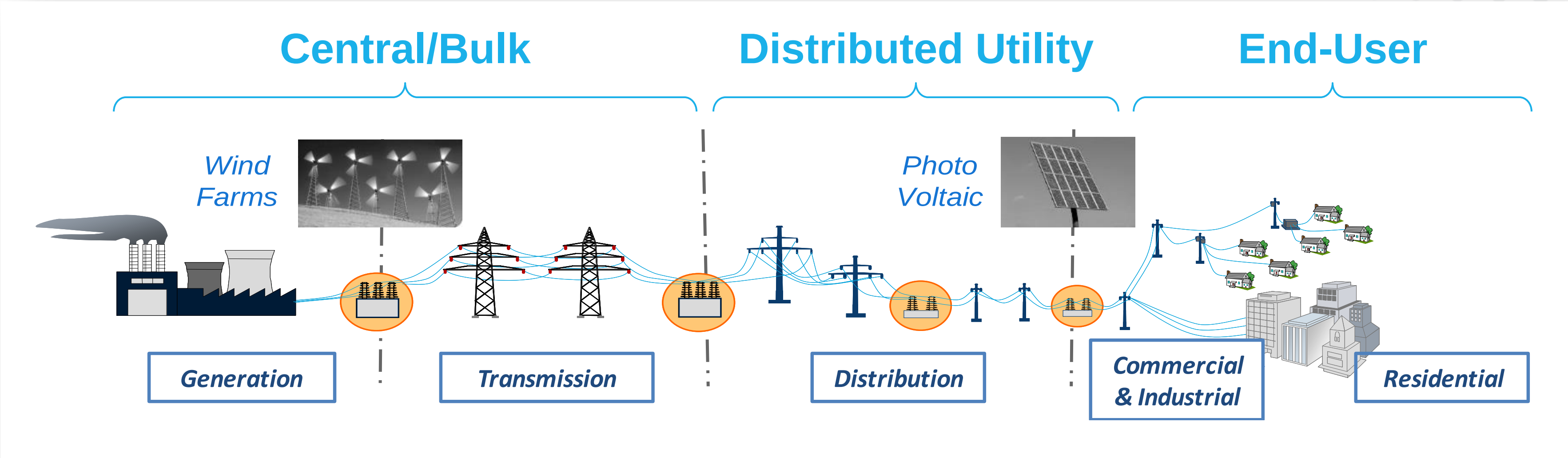
- Cheap natural gas
- Renewable integration
- Retirement of coal plants
- T&D Constrained areas and load pocket
- High retail rates
- Economic development
- Smart grid infrastructure

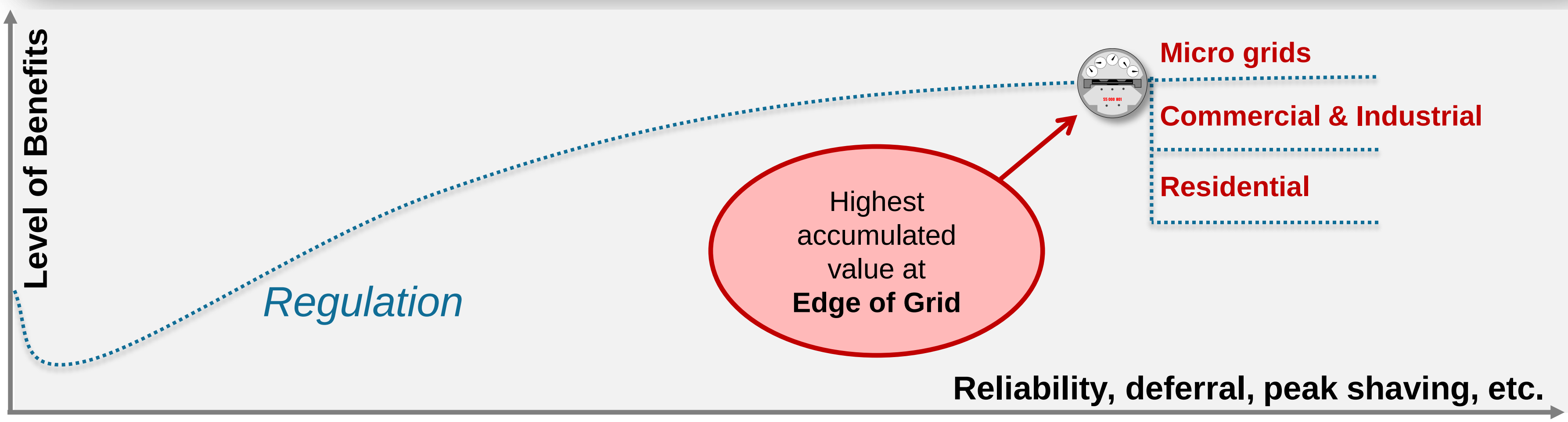




CHANGING WHAT'S POSSIBLE

The Value of DG





Distributed Generation Markets – Impact of Future Fuel Cell Applications, DNV KEMA report prepared for ARPA-E (2013). Cost-Effectiveness of Distributed Generation Technologies, Iton, submitted to PG&E, 2011

Reliable Electricity Based on ELectrochemical Systems

Released: November 30, 2013

- Transformational electrochemical technologies to enable low-cost distributed power generation.
- Aims to enhance grid stability, increase energy security, and balance intermittent renewable technologies

Live FOA – "quiet period" – cannot discuss

Path to Market

Reliable and flexible generation / storage needs

Residential DG
$1,000-1,500 / kW

Alaska & Hawaii
$1,500-$2,000 / kW

Telecom / Data Centers
$3,000-5,000 / kW

DoD
$8,000+ /kW

Establish manufacturing, supply chains via early markets

Willingness to pay premium

CHANGING WHAT'S POSSIBLE

Solar When the Sun Doesn't Shine

Dr. Howard M. Branz, Program Director

The Good and the Bad of Solar Energy

- Photovoltaic solar electricity below grid parity in many locales
  - $100 billion/year PV business growing rapidly
  - Will generate 3% of California electricity by 2015

- The 'Knock' on Solar:

  - Germany suffers *oversupply* of solar electrons when the sun is bright
  - California and the U.S. Southwest approaching PV oversupply soon

ARPA-E Solar Thrusts

- **Reduce the cost of concentrated sunlight**
  - OPEN FOA 2012

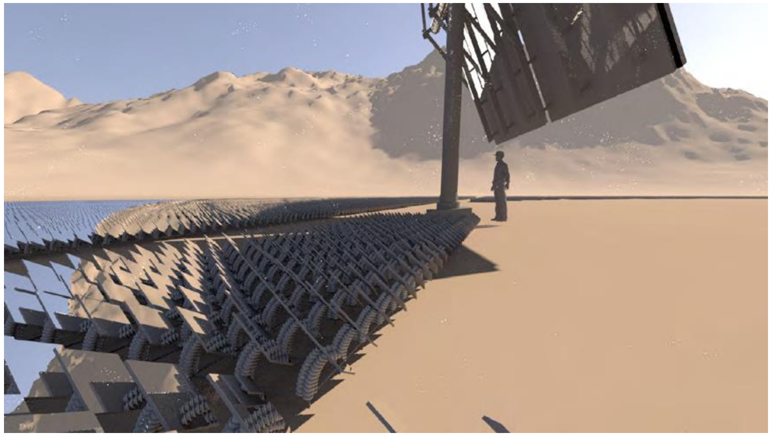
- **Raise temperature of solar heat to 800 – 1500 °C**
  - HEATS and METALS Programs, OPEN FOA 2012

- **Hybrid solar energy systems**
  - FOCUS Program
    - Dispatchable energy
    - Maximum exploitation of entire solar spectrum

ARPA-E Solar Thrusts

- **Reduce the cost of concentrated sunlight**
  - Low-cost photons help every type of solar energy
- **Raise temperature of solar heat to 800 – 1500 °C**
- **Hybrid solar energy systems**

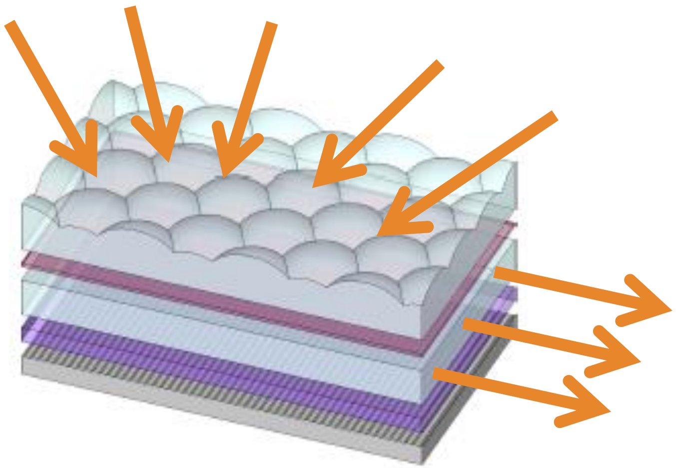
Air-Driven Solar Tracking for Mirrors or PV



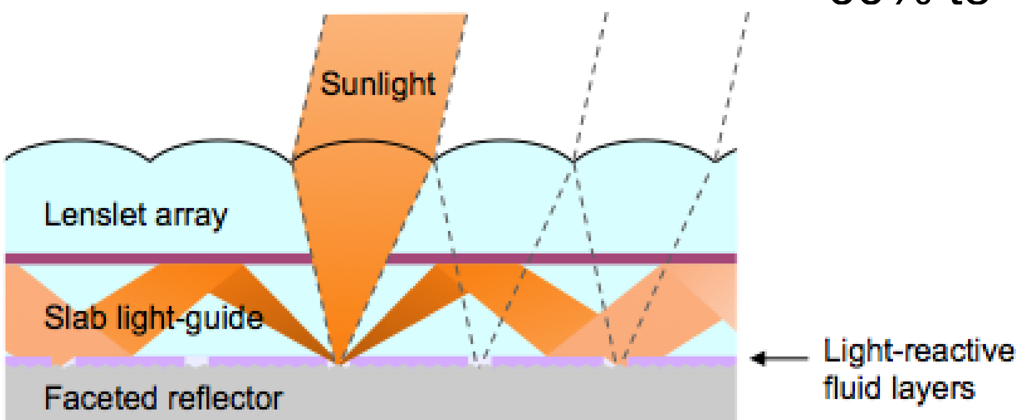
- Meter-scale mirrors for solar concentration
  - **10X smaller** than today's mirrors
- Low profile reduces wind-load and structural requirements
  - **~ 75% lower cost** than today's fields
- Pneumatic actuation in low-cost plastic
  - Replaces heavy-duty motors and precise gears

Otherlab

Self-tracking Concentrating Photovoltaics



- Automatic tracking at 30-1000X without expensive mechanical trackers
  - Thermally-actuated fluids react to light
  - High precision tracking mounted on crude 1-axis tracker
- Photovoltaic (PV) electricity reduced by 60% to ~4¢/kWh



GLINT PHOTONICS

ARPA-E Solar Thrusts

- Reduce the cost of concentrated sunlight
- **Raise temperature of solar heat to 800 – 1500 °C**
  - Increases usable fraction of collected energy
  - Increase efficiency of electricity generators
- Hybrid solar energy systems

High T solar heat provides more usable energy

- Electricity from solar heat stored in fluids up to 1100°C
  - Molten glass
  - Liquid metal
  - Molten salt

- Fuel or metals by reducing metal oxides at 1200 - 1500°C
  - Split water to make H_2
  - Split CO_2 to make CO

- Technical Challenges
  - Corrosion
  - Containment

Halotechnics - Haloglass

ARPA-E Solar Thrusts

- Reduce the cost of concentrated sunlight
- Raise temperature of solar heat to 800 – 1500 °C
- Hybrid solar energy systems: FOCUS Program

FOCUS Awards Announced in February!

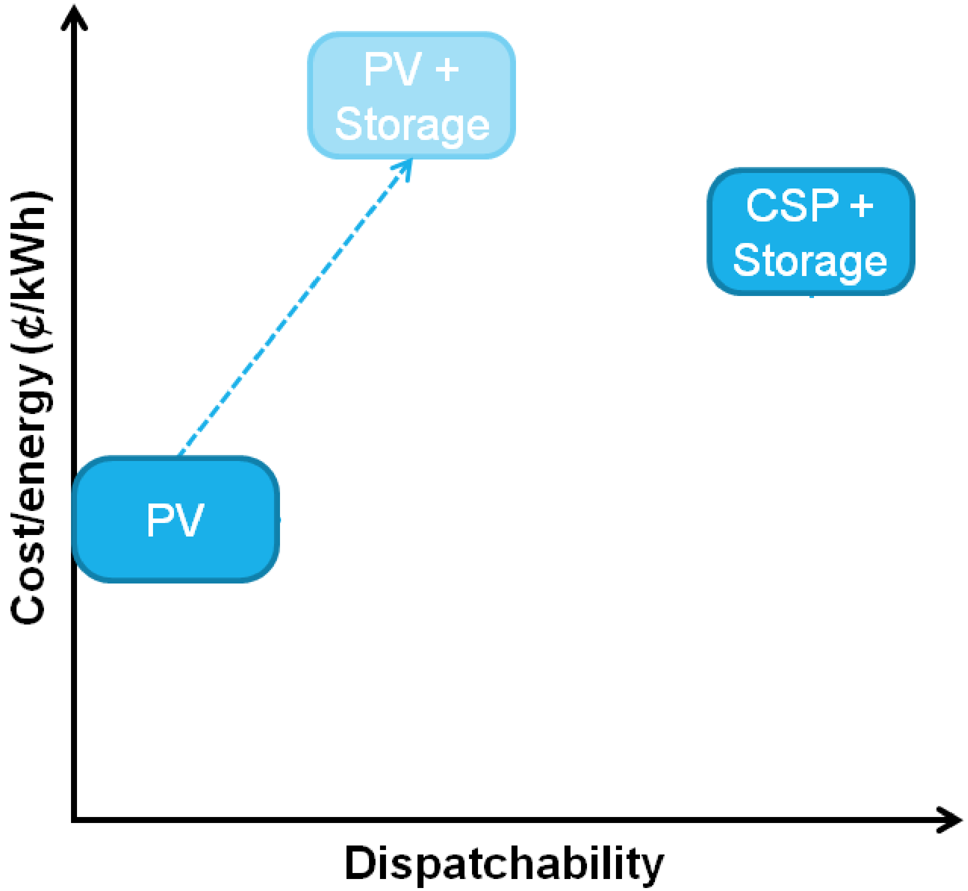
Full-Spectrum Optimized Collection and Utilization of Sunlight

- Inexpensive Hybrid Solar Converters
  - Maximum energy from all wavelengths in solar spectrum
  - Solar heat collection for energy when the sun doesn't shine

- 12 Projects

- ~ $30 million in funding

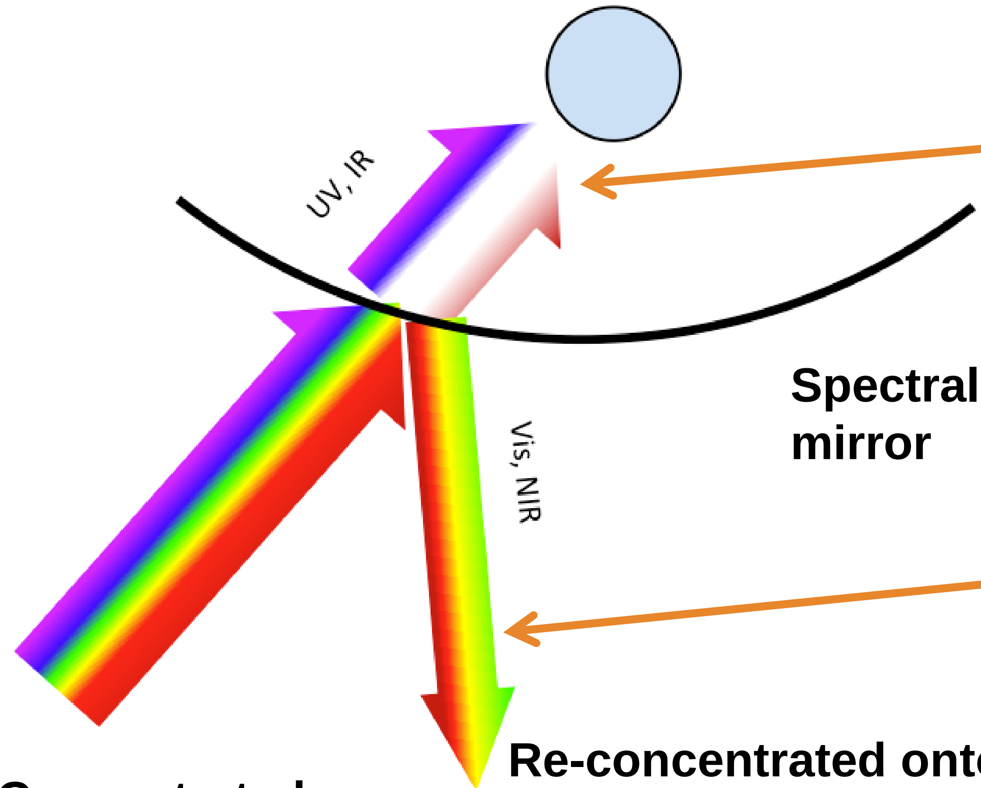
FOCUS Systems Transcend PV & CSP Paradigms



Heat cheaper to store than electricity

High-Concentration Full-Spectrum Solar Energy System

Dispatchable electricity from collected heat



Bad wavelengths for PV are used for heat

Spectral-filtering mirror

Wavelengths PV converts most efficiently

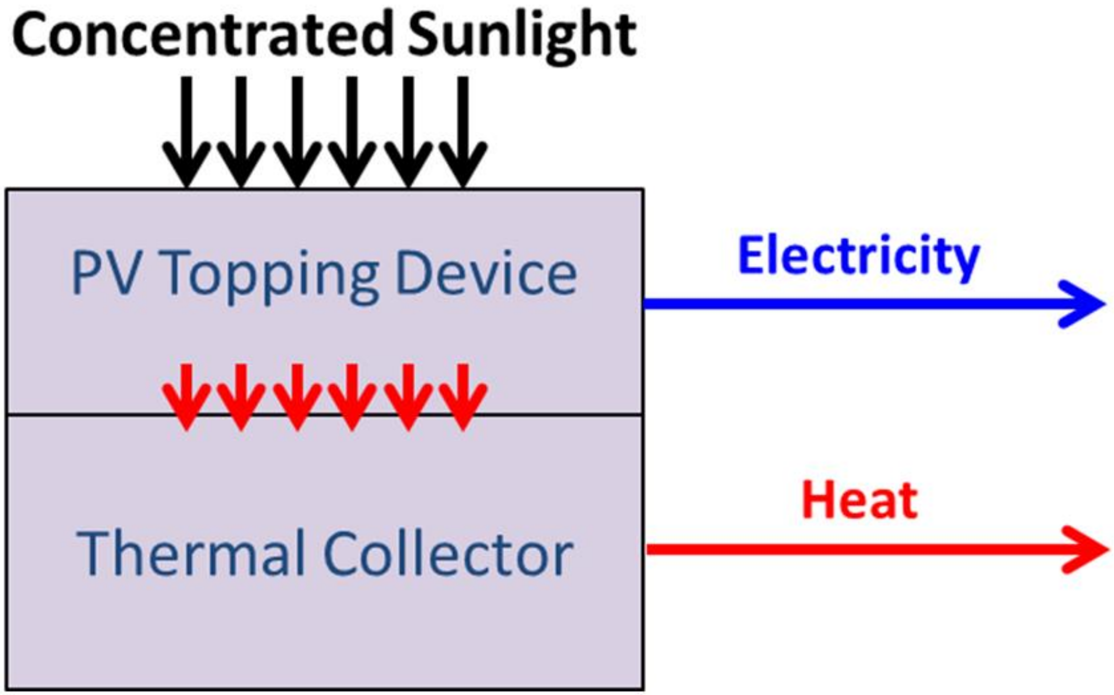
Re-concentrated onto PV cell for electricity

Concentrated sunlight

SHARP LABORATORIES OF AMERICA

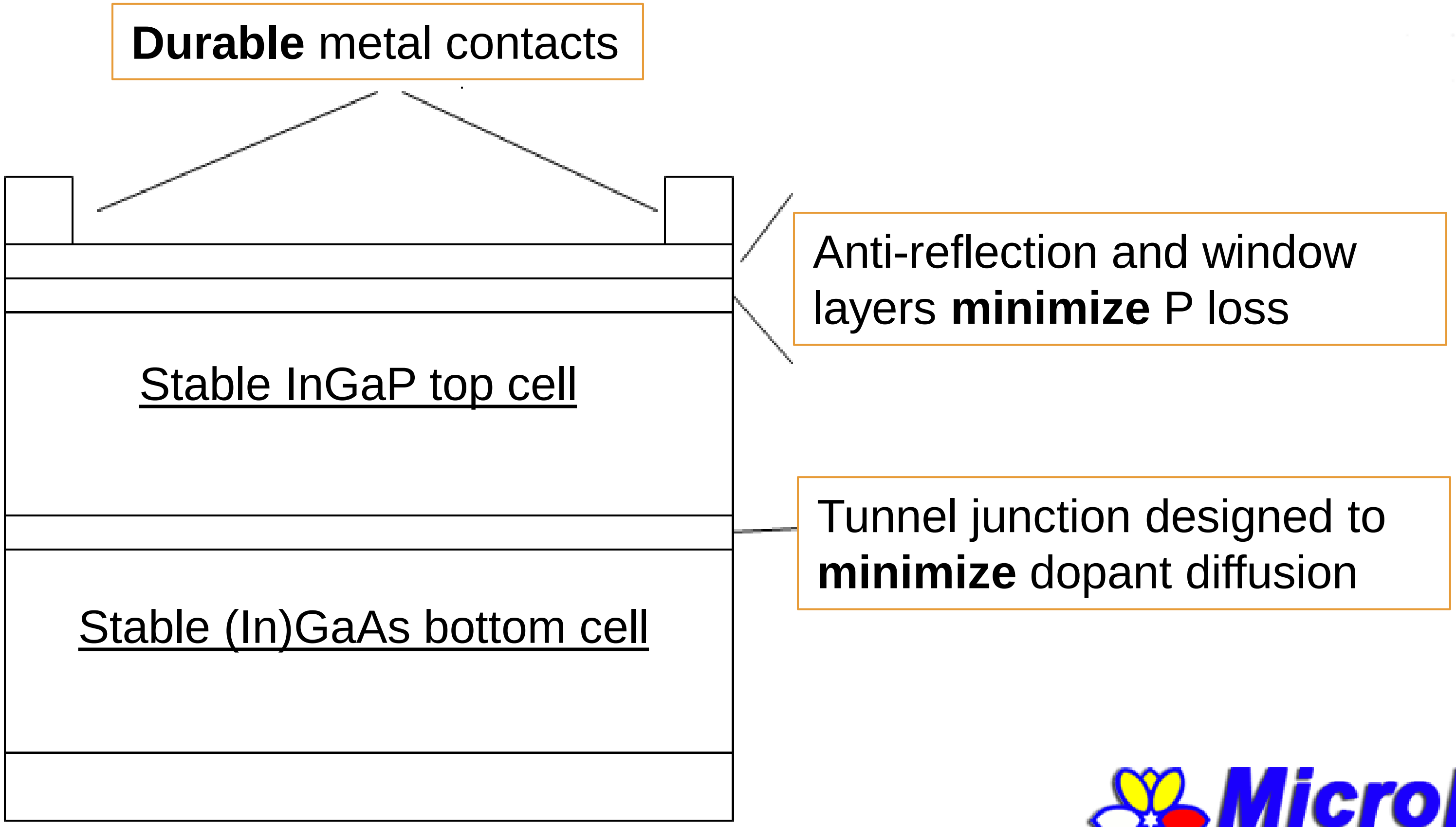
Topping Photovoltaic (PV) cells

- **Exploit the high energy of solar photons**
  - Don't waste exergy from 5500 °C sun
  - Capture PV losses as heat



Durable 25%-efficient PV at 400°C

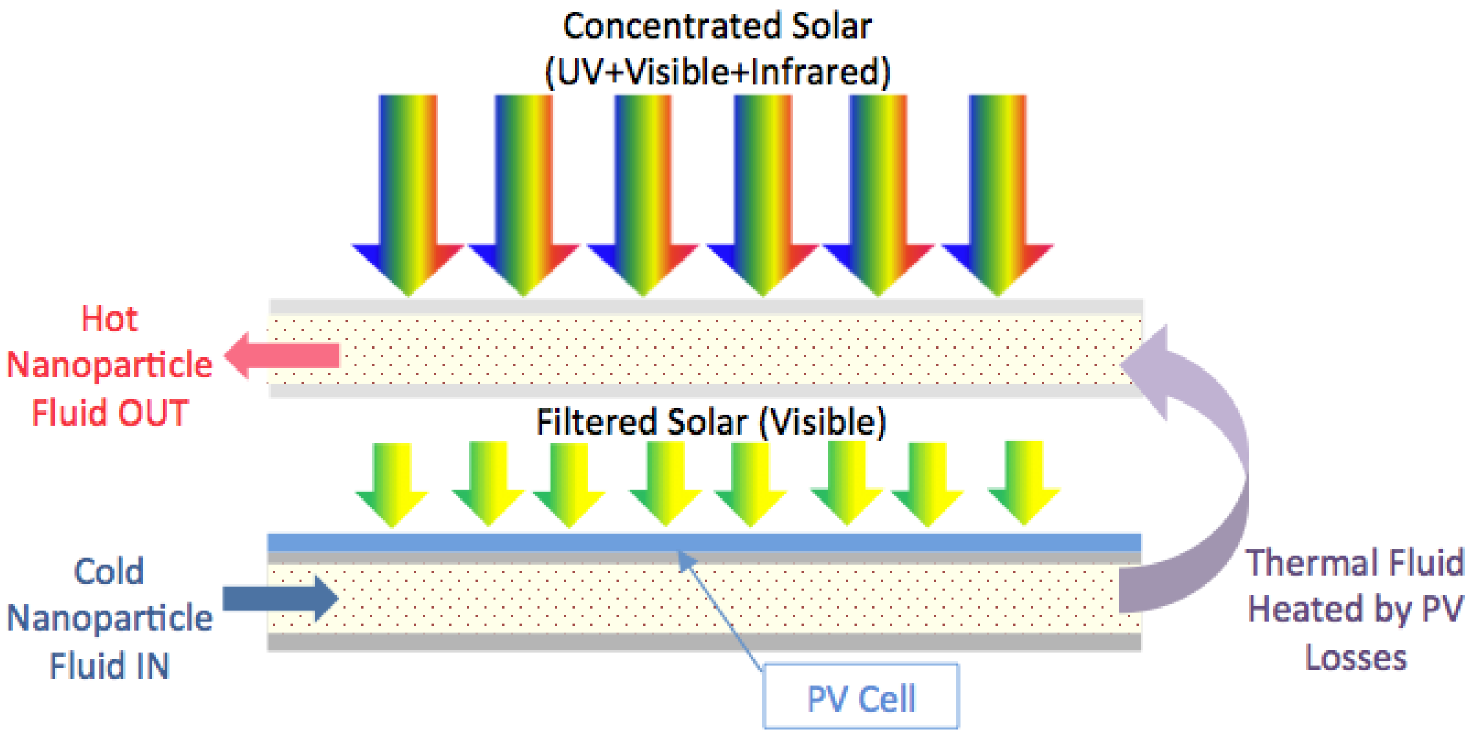
Epitaxial liftoff to reduce costs



MicroLink DEVICES

Liquid Filter with Plasmonic Nanoparticles

Spectrum splitting and PV-topping for inexpensive dispatchable electricity



THE UNIVERSITY of TULSA

COGENRA SOLAR

nanoComposix

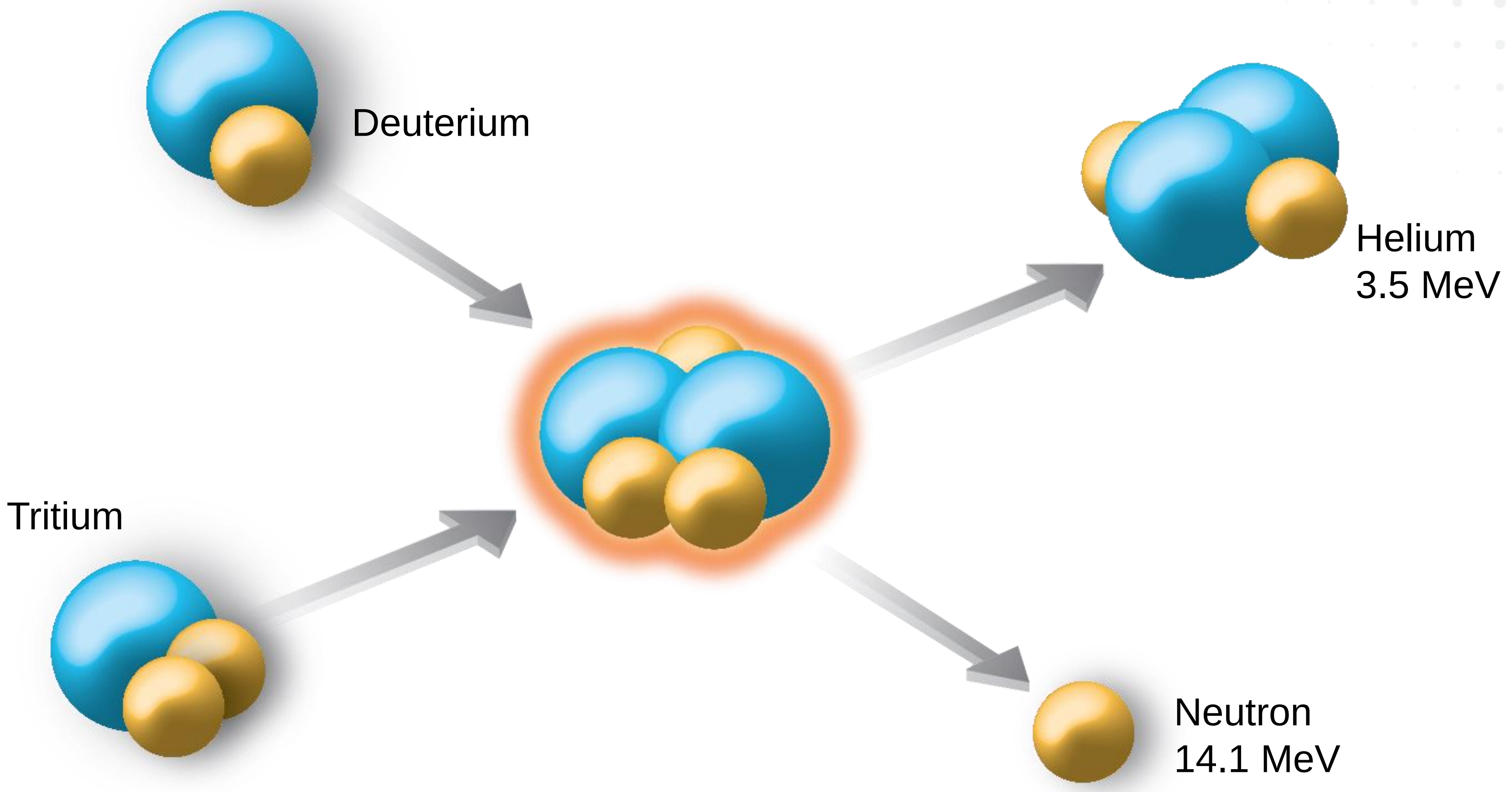
ARPA-E Solar Vision

- Inexpensive concentrated sunlight
- High temperature heat providing usable energy
- Solar when the sun doesn't shine: FOCUS

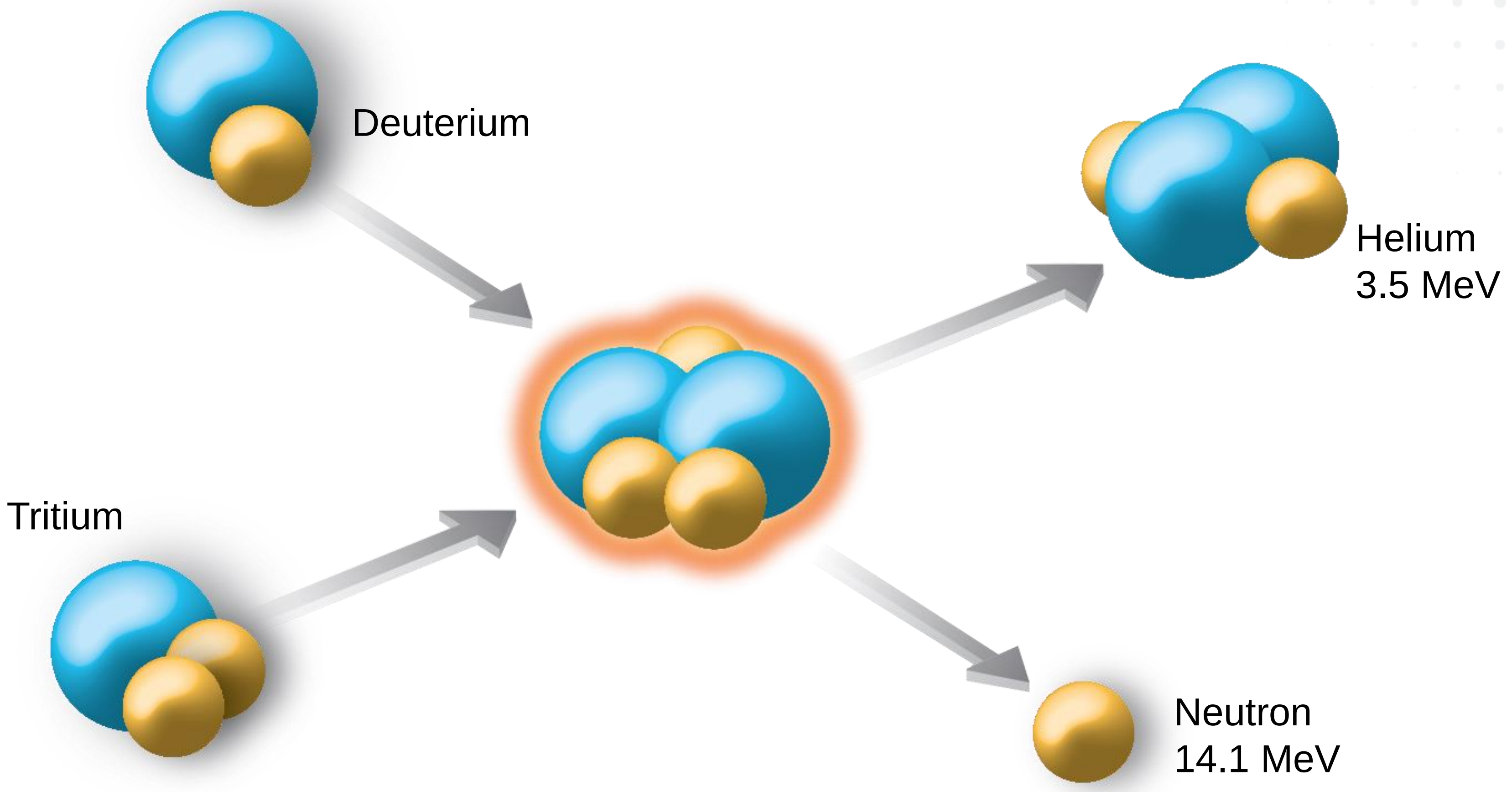
Fusion for the Next Next Generation of Generation?

Dr. Patrick McGrath, Program Director

What is fusion?



What is fusion?



Total energy out = 94 MWh/g fuel

Why look at fusion?

	D-T Fusion	Natural Gas (USA)
Emissions (kg CO_2/kWh)	0.00001	0.55
Fuel Reserves (years)	100,000,000	250
Fuel Cost per kWh ($)	0.000001	0.02

http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf
http://physics.ucsd.edu/do-the-math/2012/01/nuclear-fusion/
http://www.iter.org/sci/fusionfuels
http://www.sigmaaldrich.com/catalog/product/aldrich/368407
http://www.eia.gov/tools/faqs/faq.cfm?id=58&t=8

** Includes proved and unproved reserves. <20 years of proved natural gas reserves.*
High-end of shale estimates could extend domestic natural gas reserves to 120 years

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Capital Cost per kW ($)	???	$978

http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf
http://physics.ucsd.edu/do-the-math/2012/01/nuclear-fusion/
http://www.iter.org/sci/fusionfuels
http://www.sigmaaldrich.com/catalog/product/aldrich/368407
http://www.eia.gov/tools/faqs/faq.cfm?id=58&t=8

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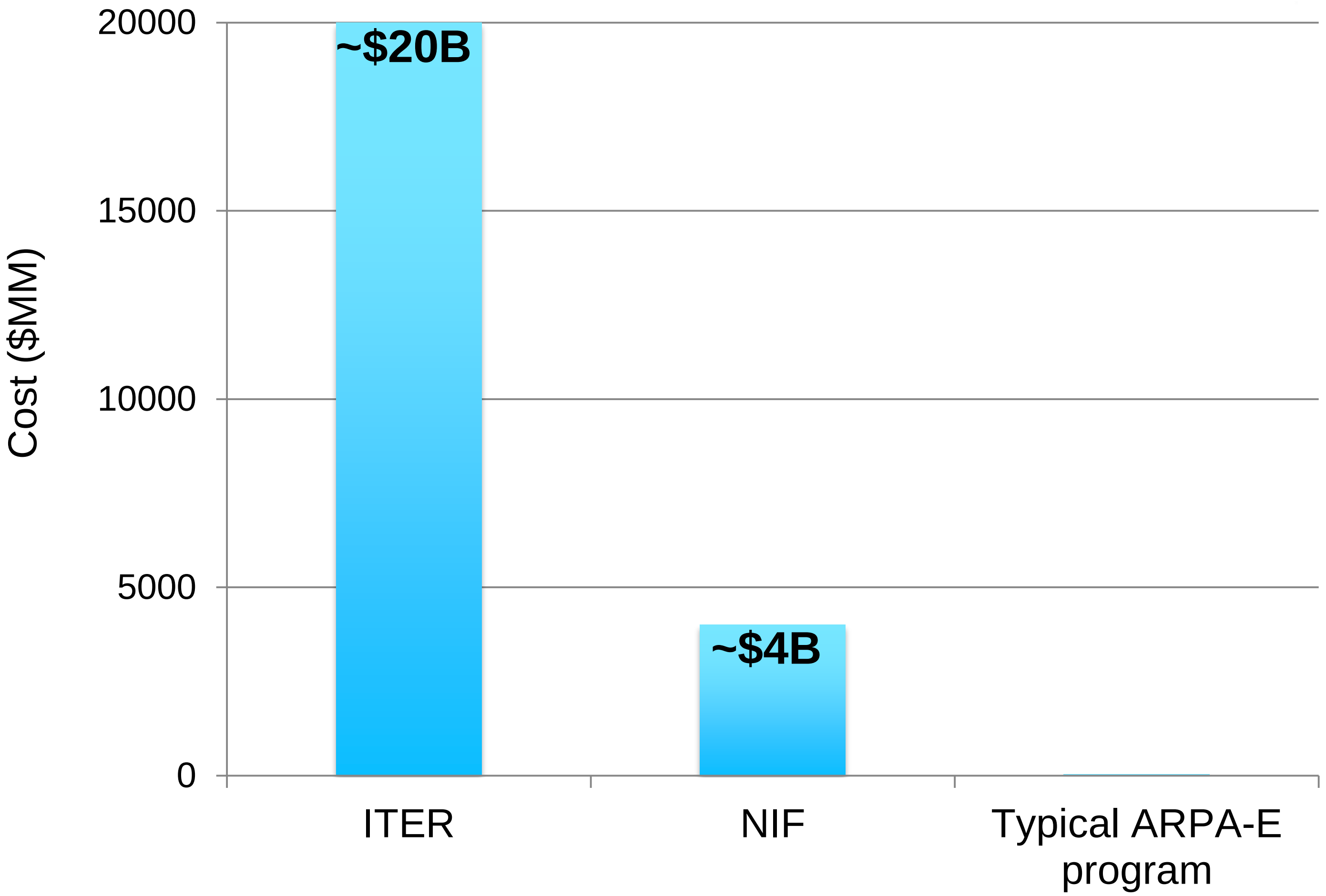
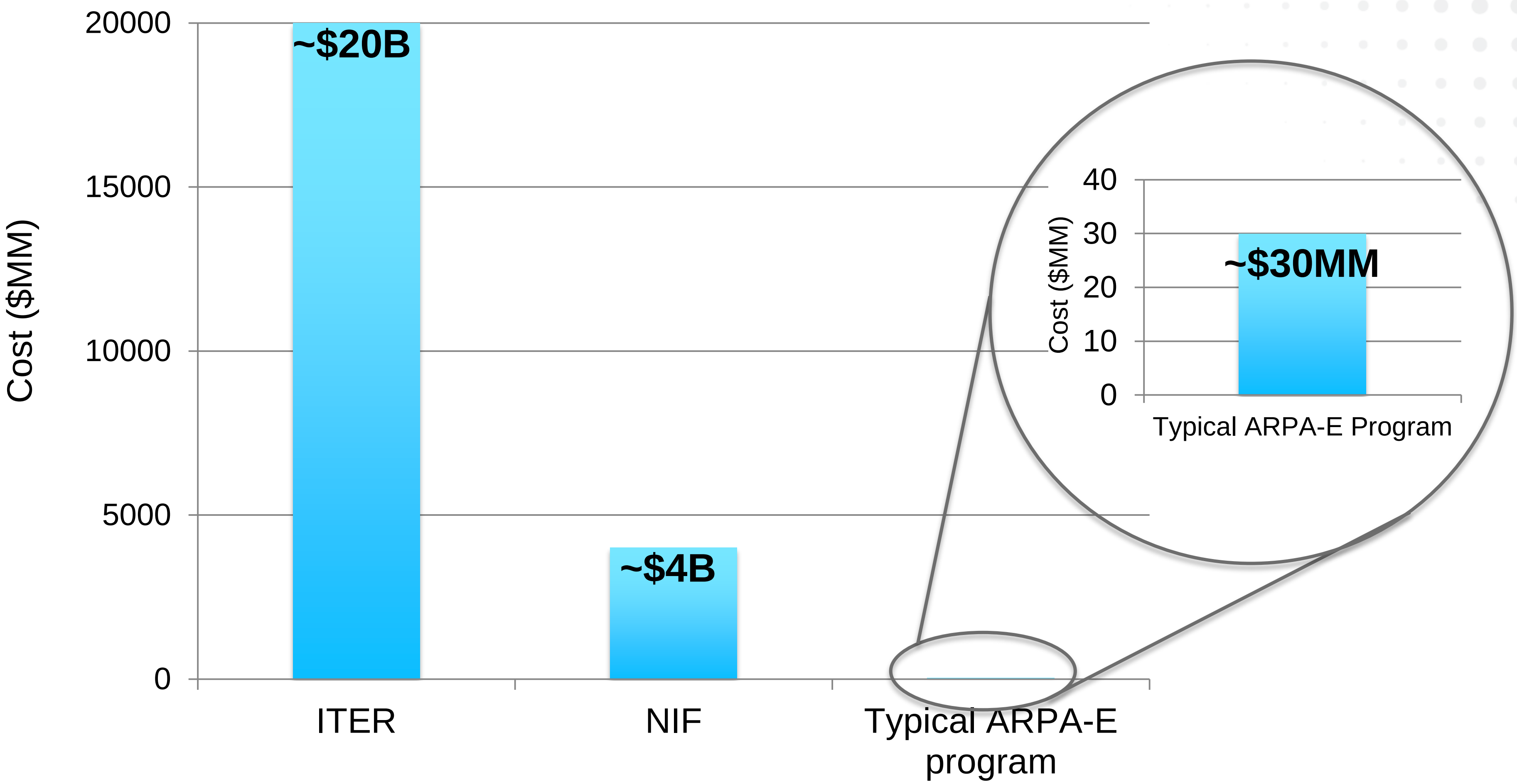
High-end of shale estimates could extend domestic natural gas reserves to 120 years

What can ARPA-E do in fusion?

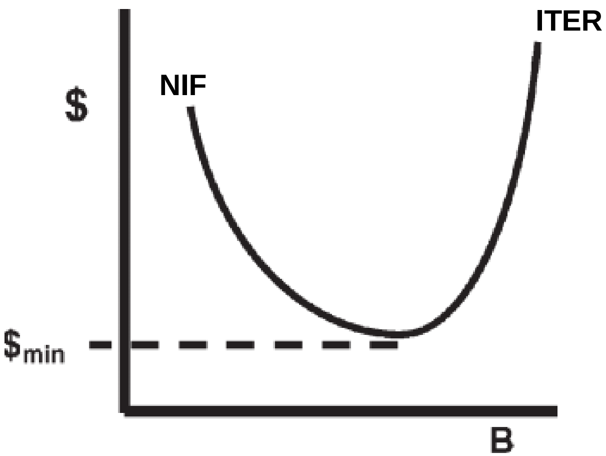


What can ARPA-E do in fusion?



What did we learn at the workshop?

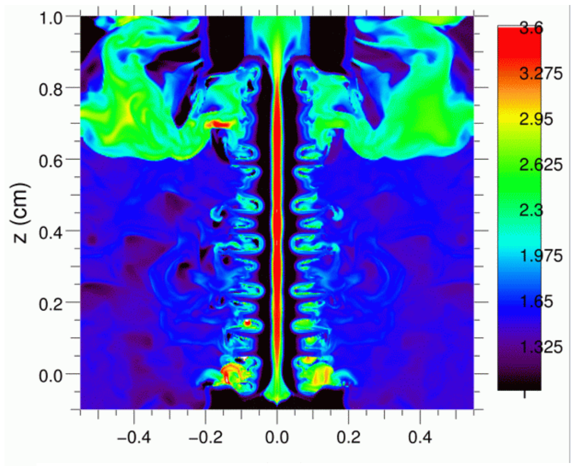
Low cost pathways to fusion



Facility cost vs. equivalent magnetic field

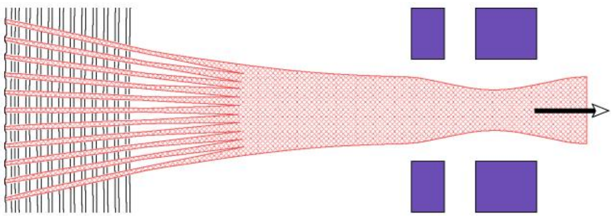
Ref. Turchi, *IEEE Transactions on Plasma Science*, 2008

Promising work in new fusion regimes



Temperature model from Sandia “MagLIF”

Low cost tools for fusion development



Merging beamlets concept (LBNL)

What could ARPA-E do to move the needle?

Low cost tools

Explore **new regimes** in fusion

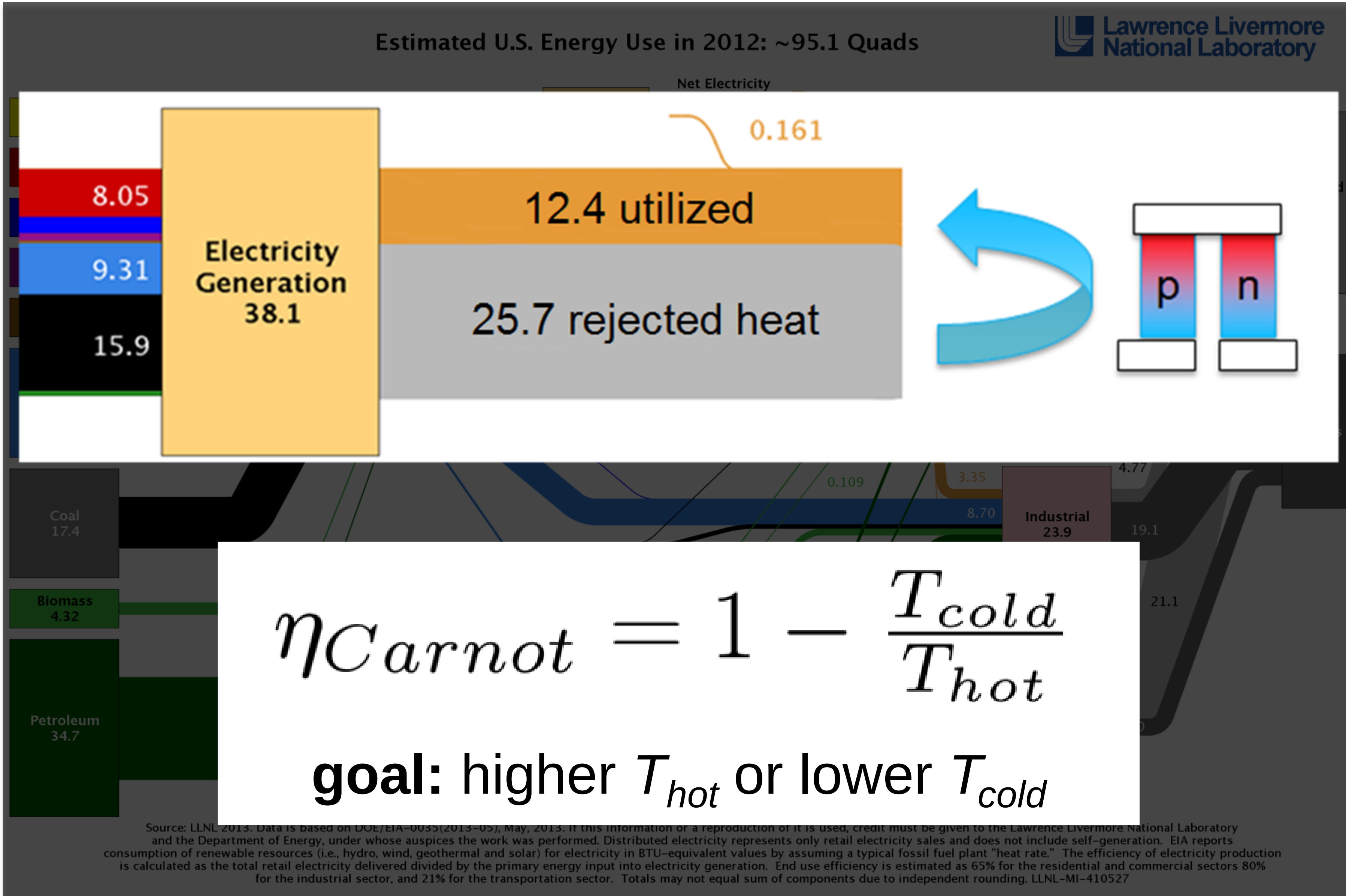
High shot rate to advance along learning curve

Stationary Stationary Generation:

Heat Engines with No Moving Parts

Dr. Will Regan, Fellow

Why avoid moving parts?

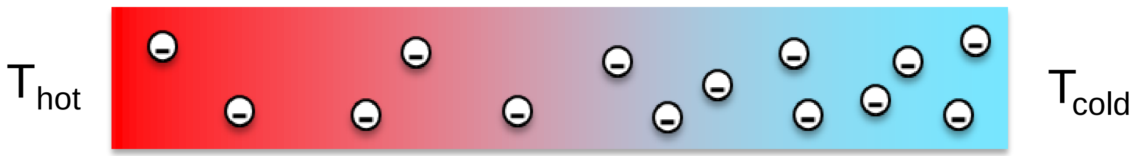


$$\eta_{Carnot} = 1 - \frac{T_{cold}}{T_{hot}}$$

goal: higher T_{hot} or lower T_{cold}

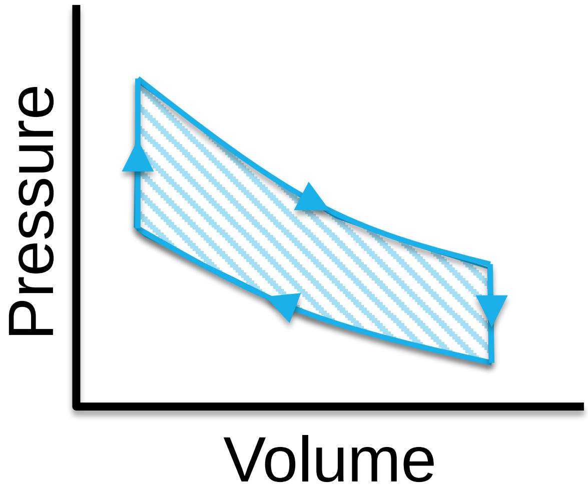
How do we make one of these?

1. Find a phenomenon that transduces $\Delta T \rightarrow \Delta\Phi$



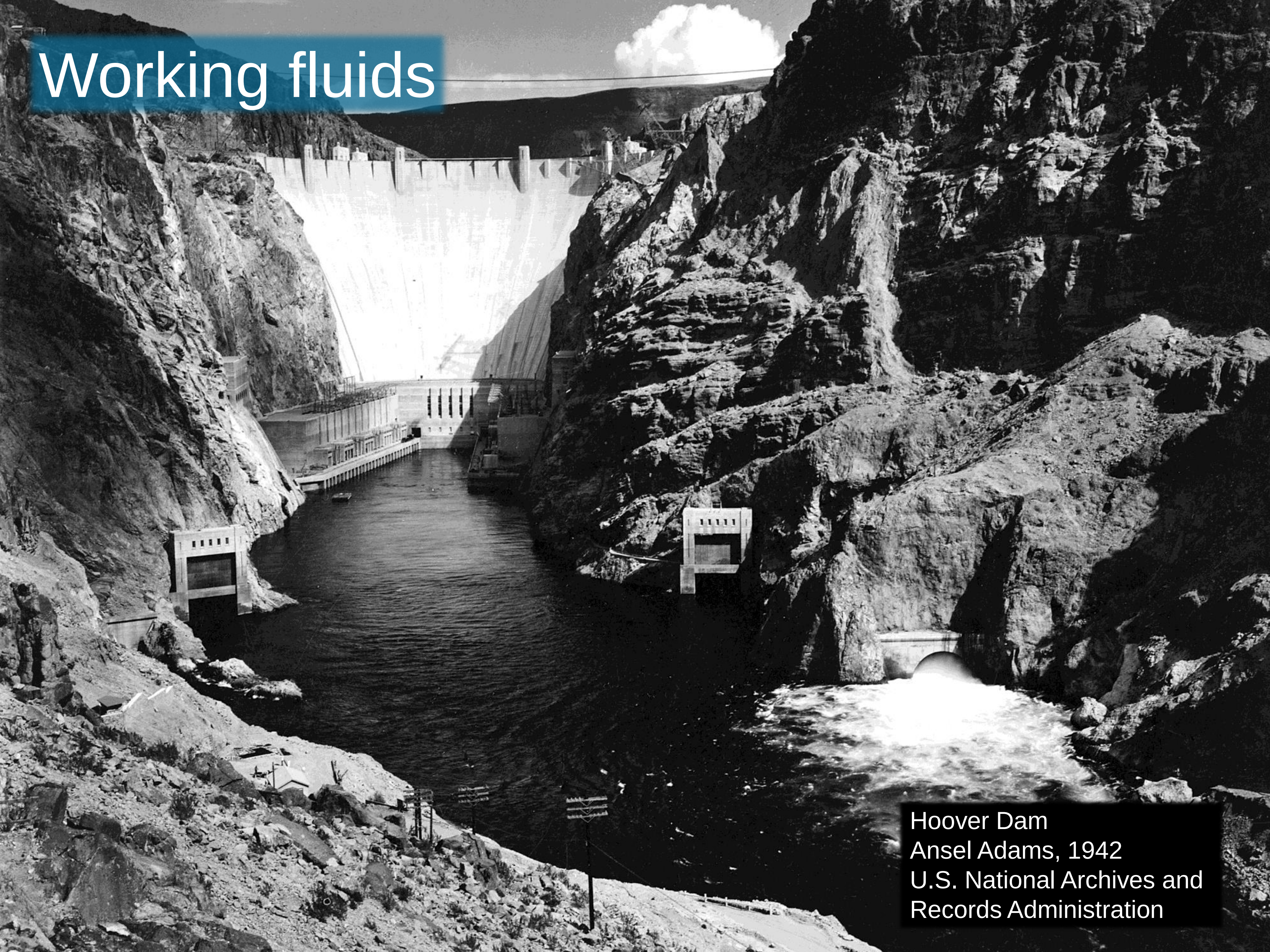
Seebeck effect in n-type material

2. Adapt effect to a cycle that results in net work out



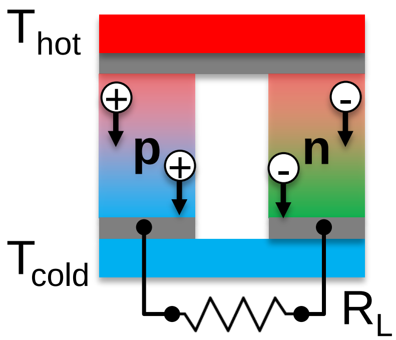
$$\oint y\,dx = W$$

Working fluids

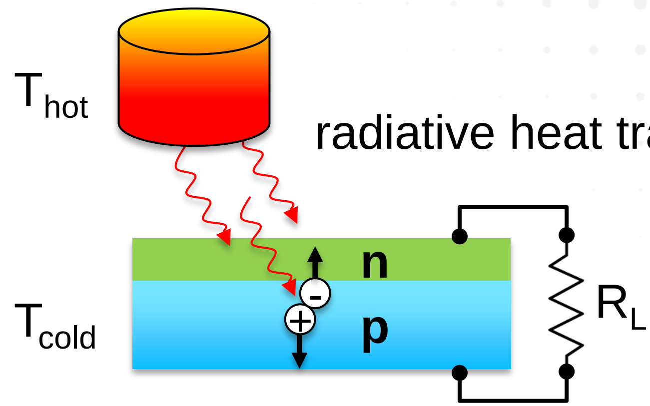


Hoover Dam
Ansel Adams, 1942
U.S. National Archives and
Records Administration

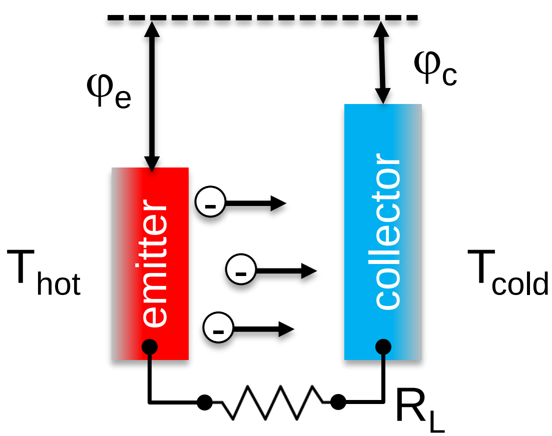
Electrons as working fluid



thermoelectrics

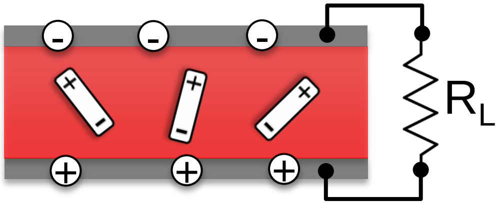


thermophotovoltaics

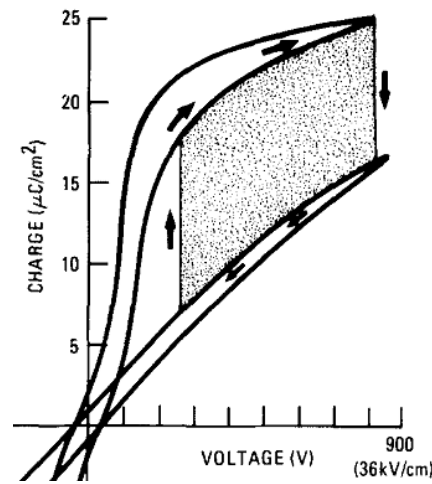


thermionic emitters

$$I = Ap\frac{dT}{dt}$$



pyroelectrics



lower right graph: R. Olsen and D. Evans *J. Appl. Phys.* 54, 5941 (1983)

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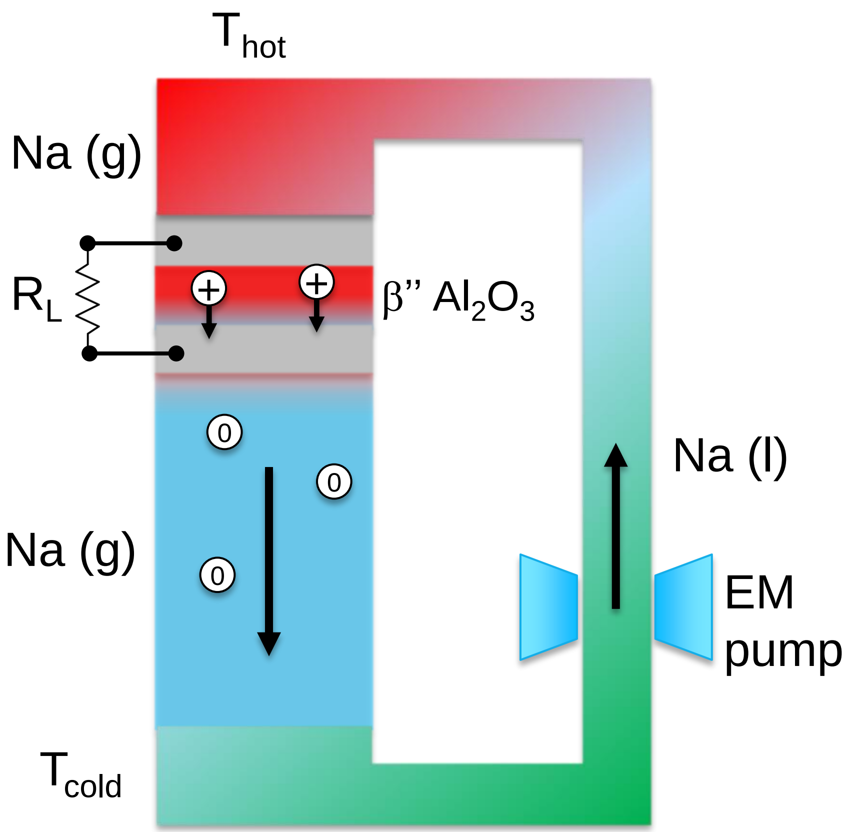
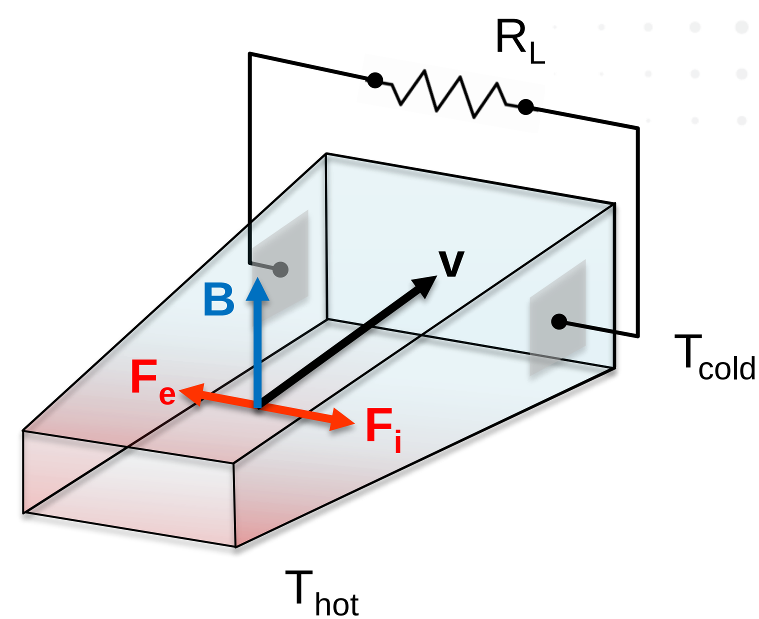
CHANGING WHAT'S POSSIBLE

Ions or plasmas as working fluid





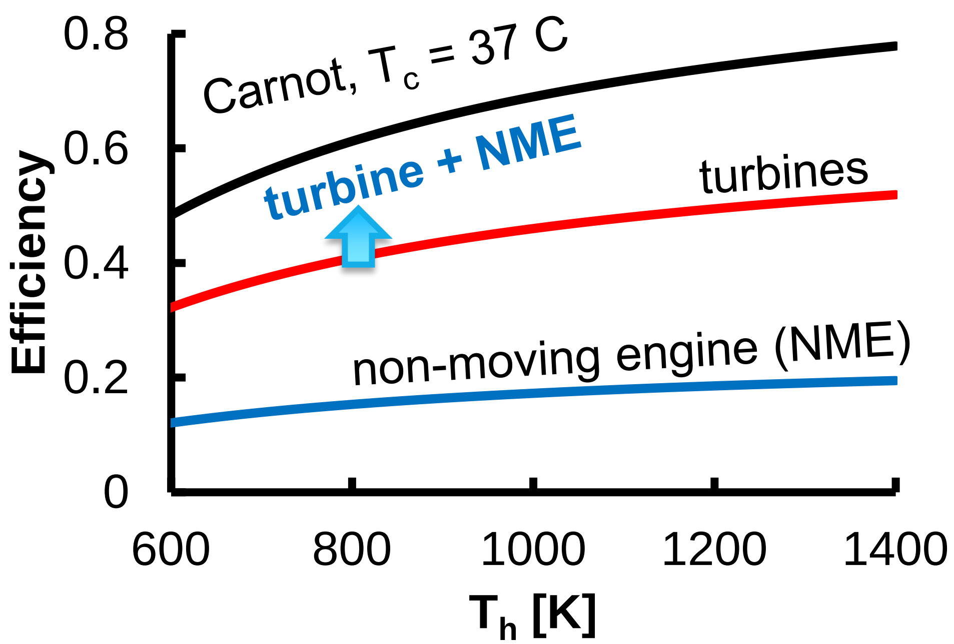
thermally regenerative electrochemical systems

magnetohydrodynamic (MHD) generators

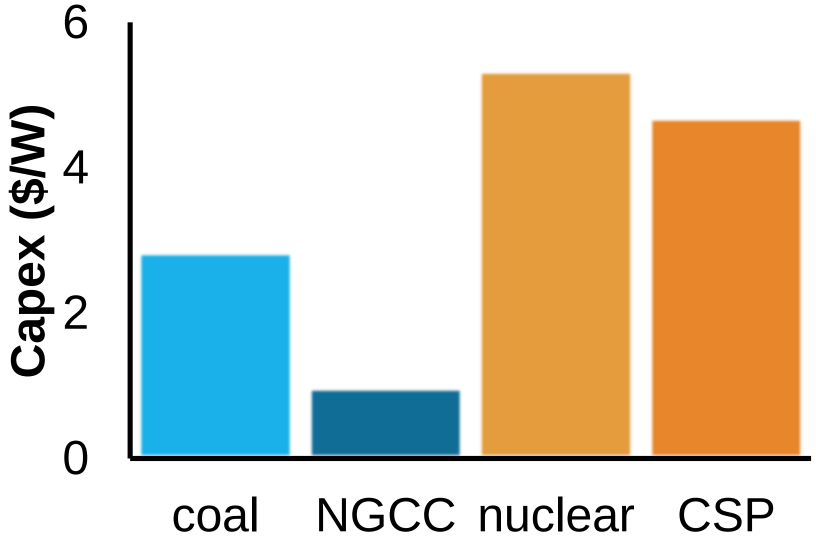
left: figure adapted from C. Vining et al *J. Electrochem. Soc.* 140 (10), 2760 (1993), AMTEC concept: Kummer and Weber (US 3,458,356)
right: figure adapted from talk by Y. Okuno “Research Activities on MHD Power Generation at Tokyo Institute of Technology” (2009)

What's needed for practical systems?

Efficiency and lifetime



Power density and cost



source for $/W values on right: "Updated Capital Cost Estimates for Electricity Generation Plants" US DOE-EIA (2010)

Thank You

John Lemmon
Program Director

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Stationary Stationary Generation

www.arpa-e.energy.gov