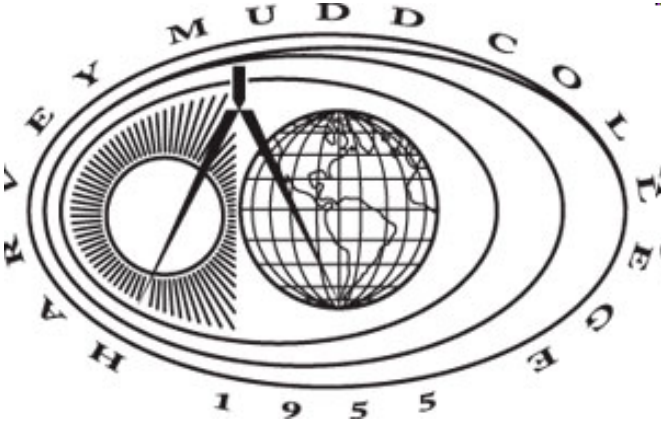
The Adoption of Modern Grid Tied Solar Arrays for Mali

Mali Symposium on Applied Science
Bamako, Mali
August 3, 2010

Prof. Adrian Hightower
Department of Engineering, Harvey Mudd College,
Claremont, CA 91711 USA
hightower@hmc.edu
http://www3.hmc.edu/~hightower/



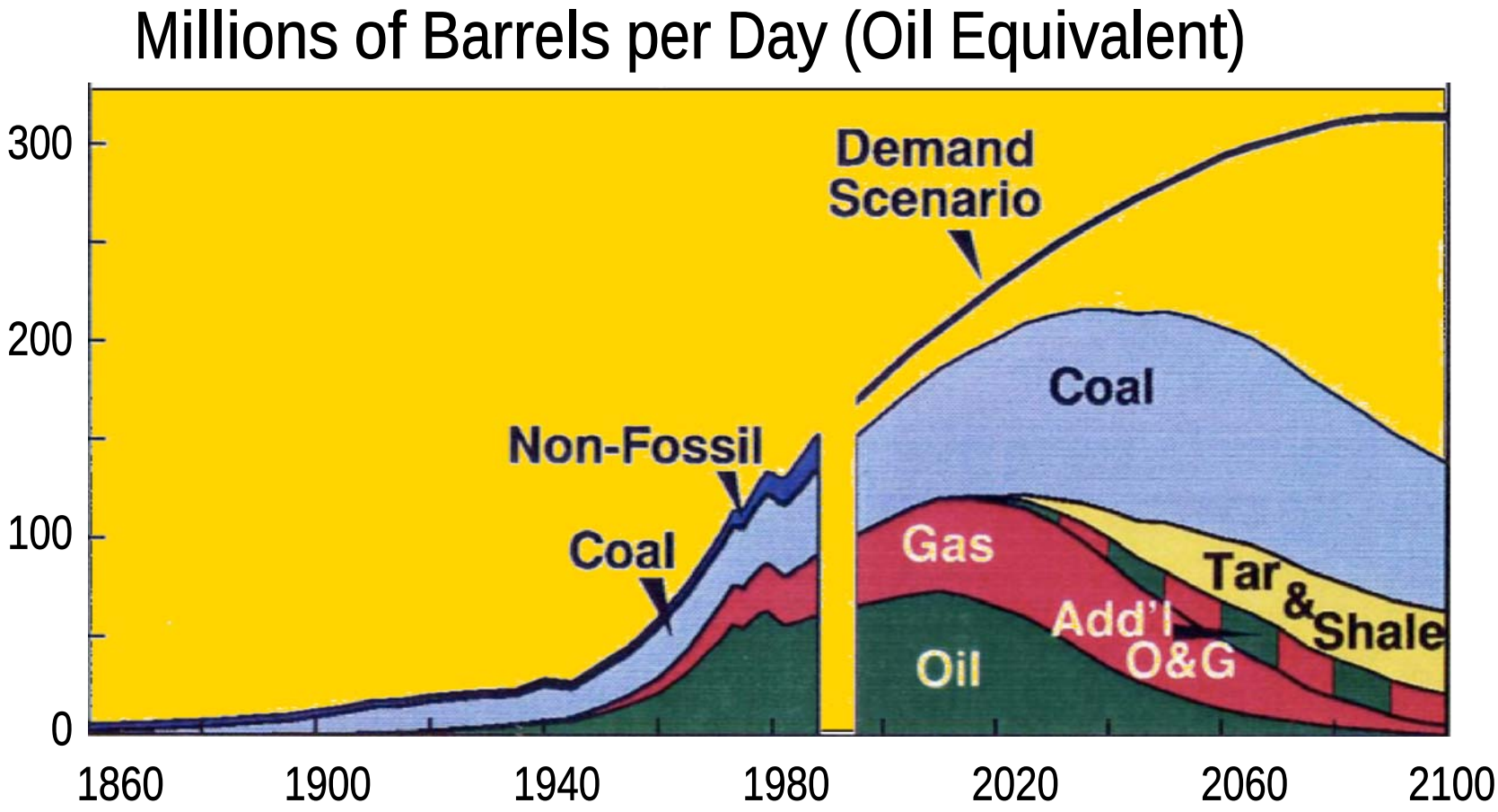
Acknowledgements

- Colleagues
  - Prof. Arona Coulibaly, L'ENI
  - Prof. Ousmane Soumaoro, L'ENI
  - Boubacar Kane, EDM
  - Daniele Dembele, AfriPower
  - Dr. Tom Burrell, Mali Folke Center
  - Dr Adama Tolofoudye, FAST
  - Abdoulaye Doucoure, PALL Inc
  - Michael Farcy, PALL Inc
  - Dennis Bilodeau, USAID, Mali
  - Jim Barry, Caltech
- Metropolitan Water District of Southern California
- USAID, Bamako, Mali
- TUV Rhienland PTL (Photovoltaic Testing Laboratory)
- Harvey Mudd College, Engineering Department
- University of Ghana
- Occidental Office of Community Based Learning

Outline

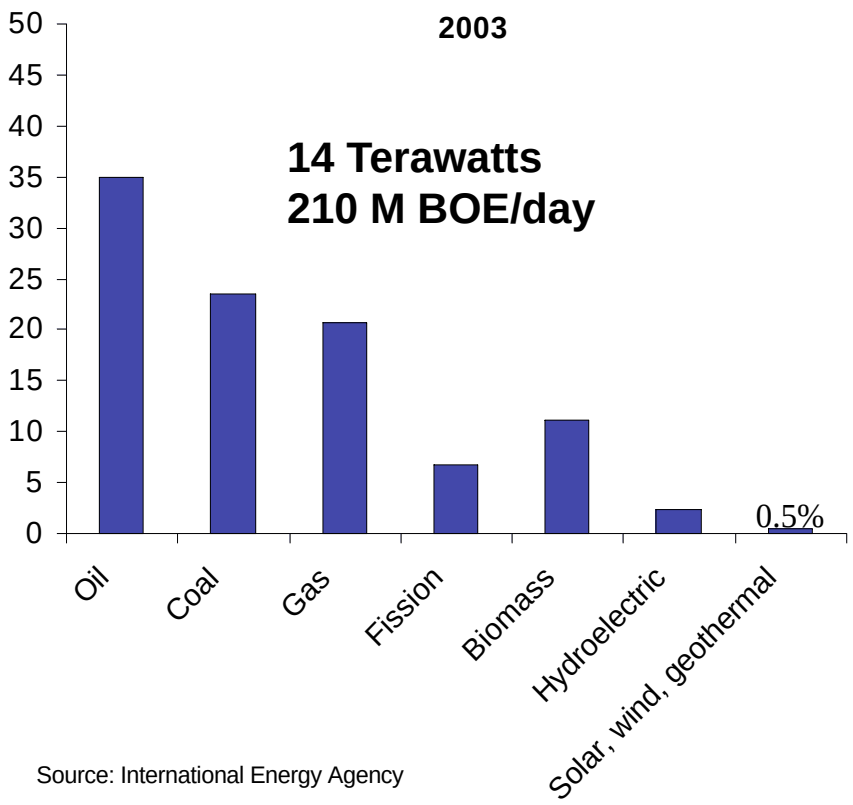
1. The Motivation Solar in Mali
2. Grid Tied Solar Strategies and Technologies
3. Opportunities for Grid Tied Solar in Mali
4. Conclusion

Projected Fossil Fuel Supply and Demand

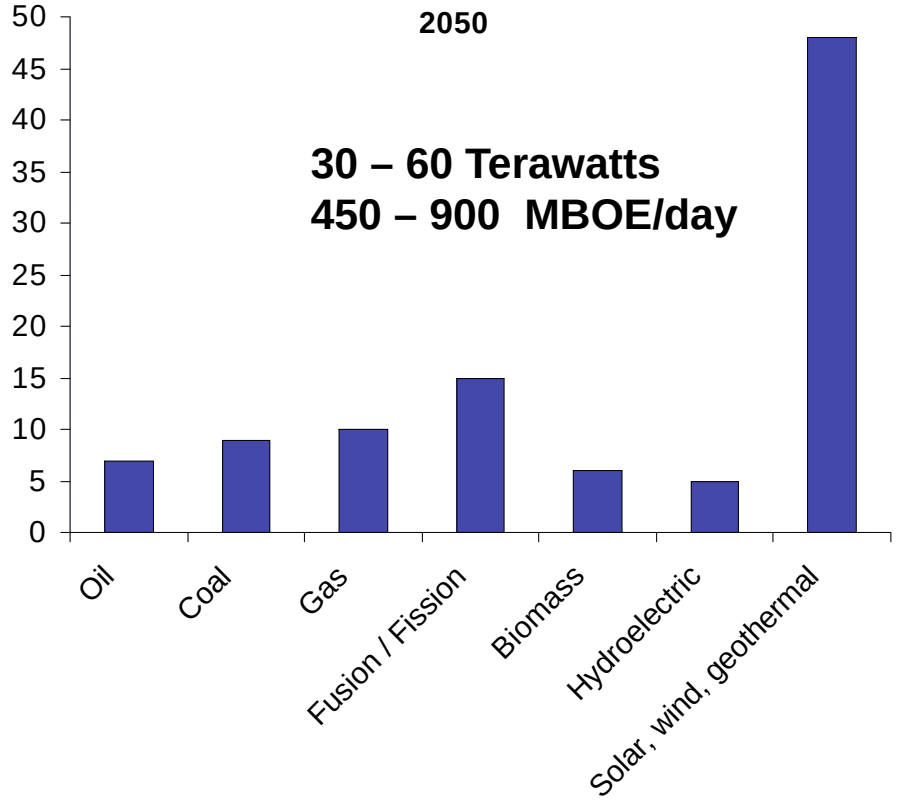


Source: Richard Smalley, John F. Bookout (President of Shell USA) ,"Two Centuries of Fossil Fuel Energy" International Geological Congress, Washington DC Episodes, vol 12, 257-262 (1989).

The Energy Revolution: The Terawatt Challenge



Source: International Energy Agency



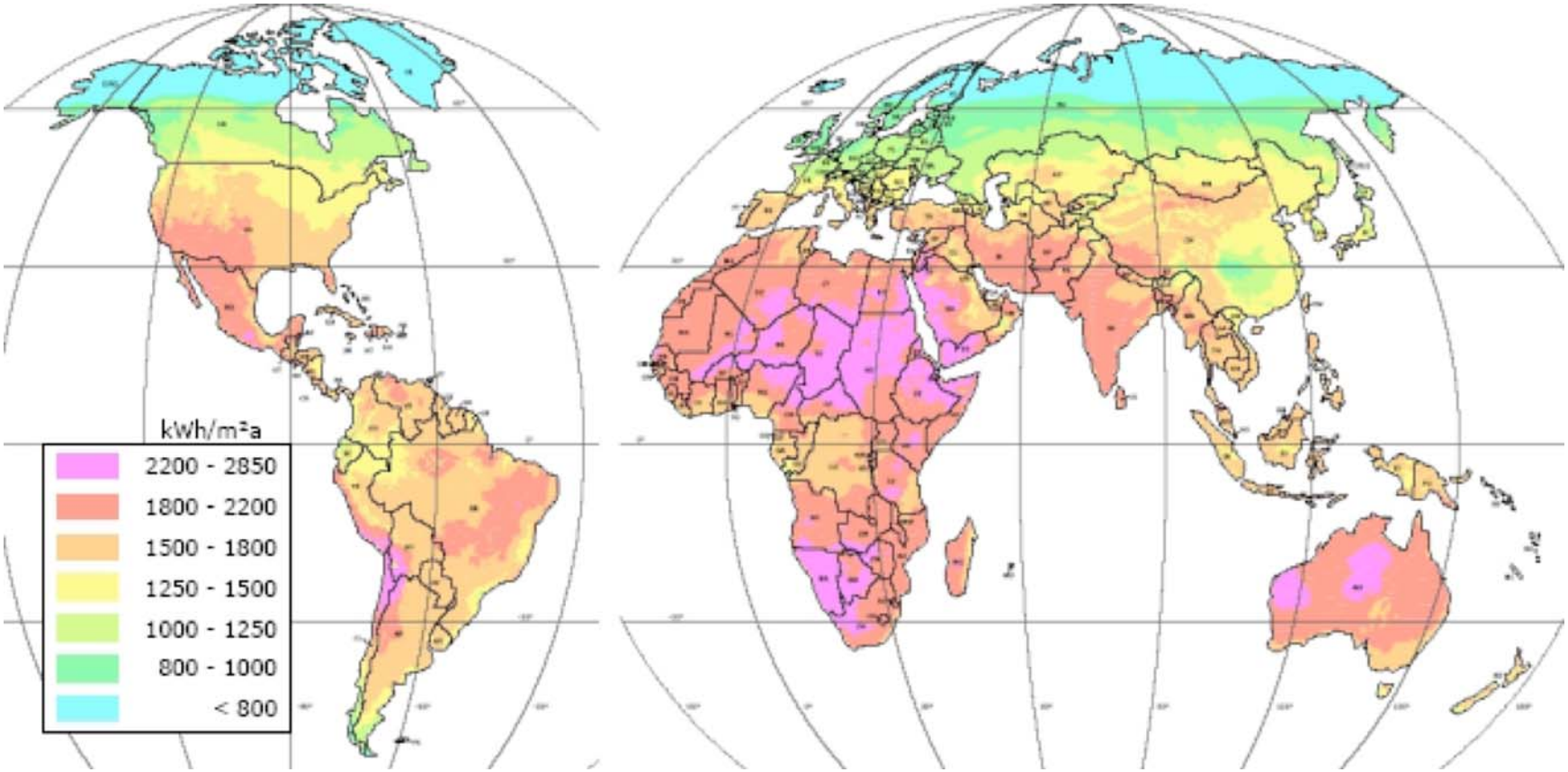
Source: Richard Smalley, University of Columbia International Energy Agency

Environment - Global Warming

- Earth warming from raising CO_2 is simple science.

- The rate at which the Earth will warm is not.

Where's the Sun



- Leading Solar Energy Markets
  - Germany, Japan, United States, China

Water Energy Nexus
Energy Requires Clean Water

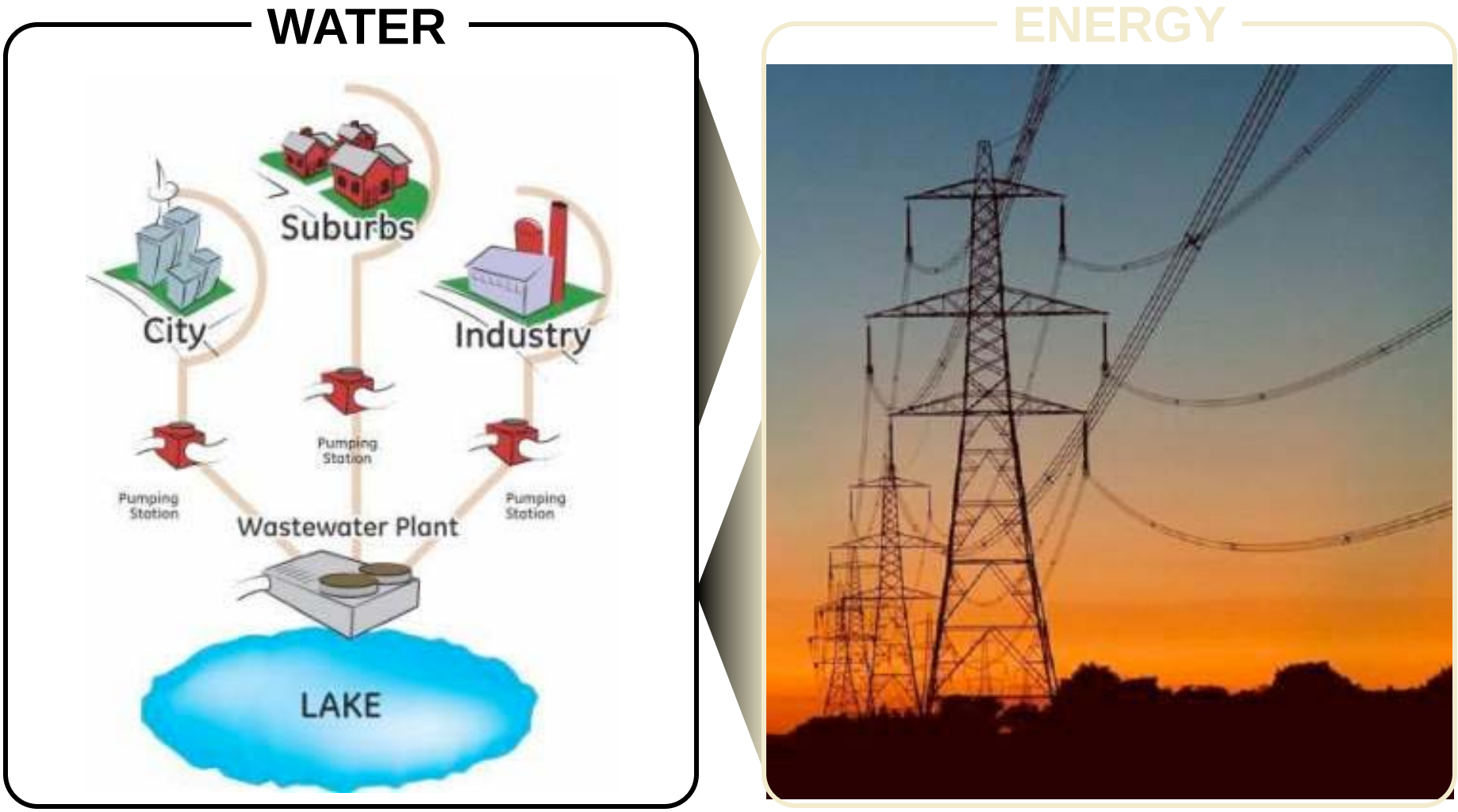
WATER

>50% of global industrial water consumption is used to generate power

ENERGY

Adrian Hightower, Harvey Mudd College Engineering Department

Water Energy Nexus
Clean Water Requires Energy



6-18% of city's electricity used to produce, treat & transport water

Declining Rainfall Reduce Hydro Capacity

WATER

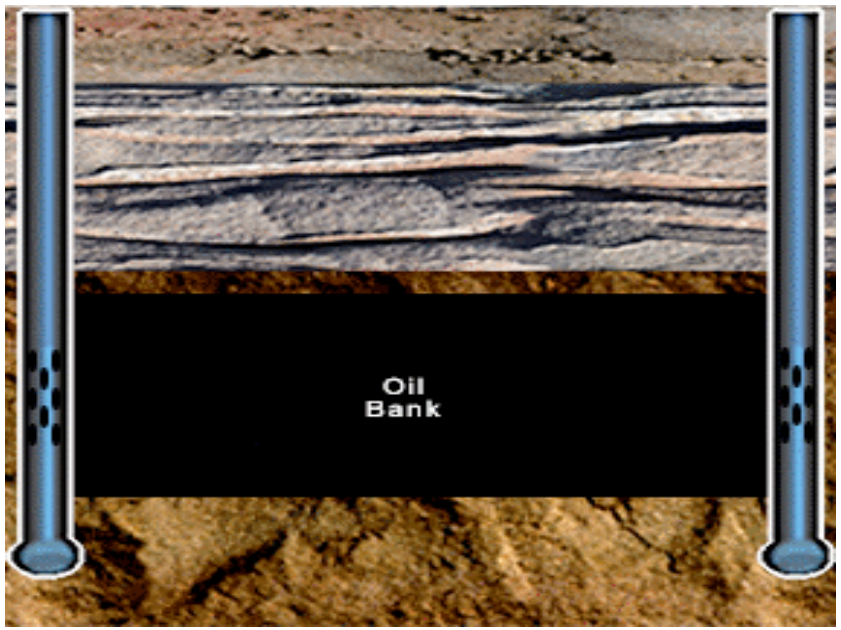
ENERGY

Mali's electricity portfolio 64% Hyrdroelectric and 36% Combustion

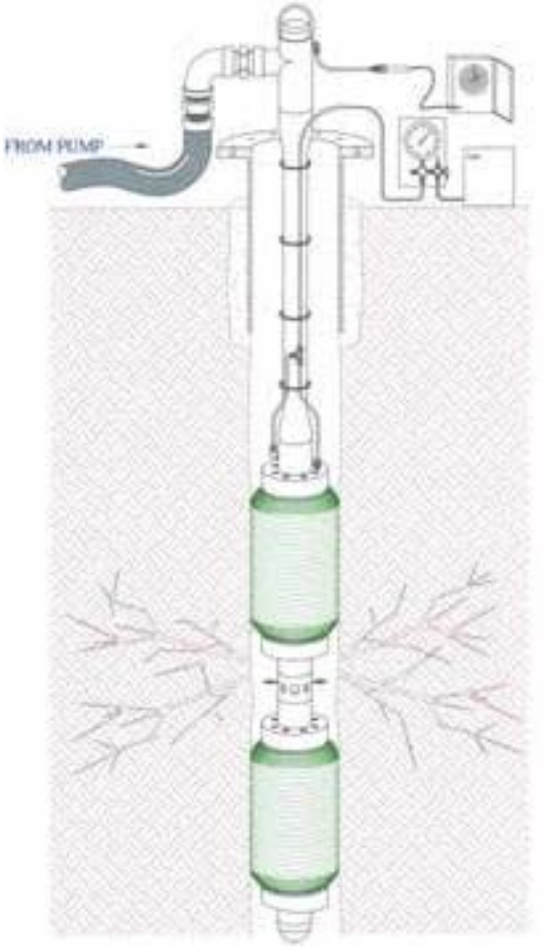
Adrian Hightower, Harvey Mudd College Engineering Department

Energy exploration & production generates large quantities of wastewater

WATER



ENERGY



2010 SONATRACH (Algereia) and Selier Energy (Canadian) invest $ millions to explore Taoudeni basin (Mali) for oil and gas.

Electricity Consumes Water

Power Generation Technologies	Efficiency (L/1000 KWh)
Hydroelectric	260
Geothermal	1680
Solar thermal	2970–3500
Fossil fuel thermoelectric	14 200–28 400
Nuclear	31 000–74 900

Fuel Source	Efficiency (liters per 1000 kilowatt-hours)
Natural gas	38
Synfuel: coal gasification	144–340
Tar sands	190–490
Oil shale	260–640
Synfuel: Fisher-Tropsch	530–775
Coal	530–2100
Hydrogen	1850–3100
Liquid natural gas	1875
Petroleum/oil-electric sector	15 500–31 200
Fuel ethanol	32 400–375 900
Biodiesel	180 900–969 000

Mali's electricity portfolio 64% Hyrdroelectric and 36% Combustion

Adrian Hightower, Harvey Mudd College Engineering Department

IEEE Spectrum:, W. D. Jones, April 2008

Simple Equation

Solar Abundance

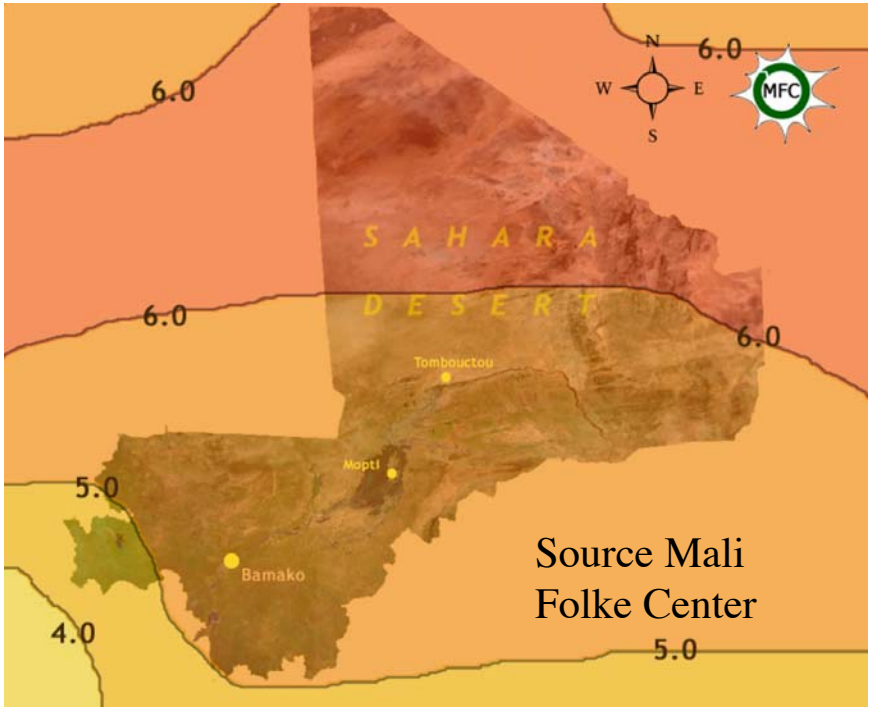
+

Limited Water

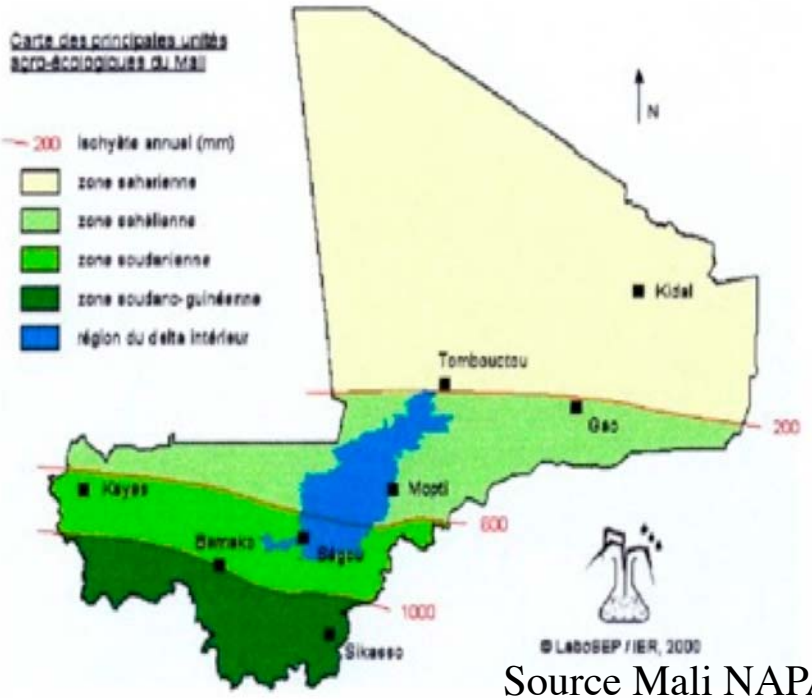
||

Base Load Electricity
- Photovoltaic
- Solar Thermal

Peak Load Electricity
- Hydroelectric
- Biofuels



Source Mali
Folke Center

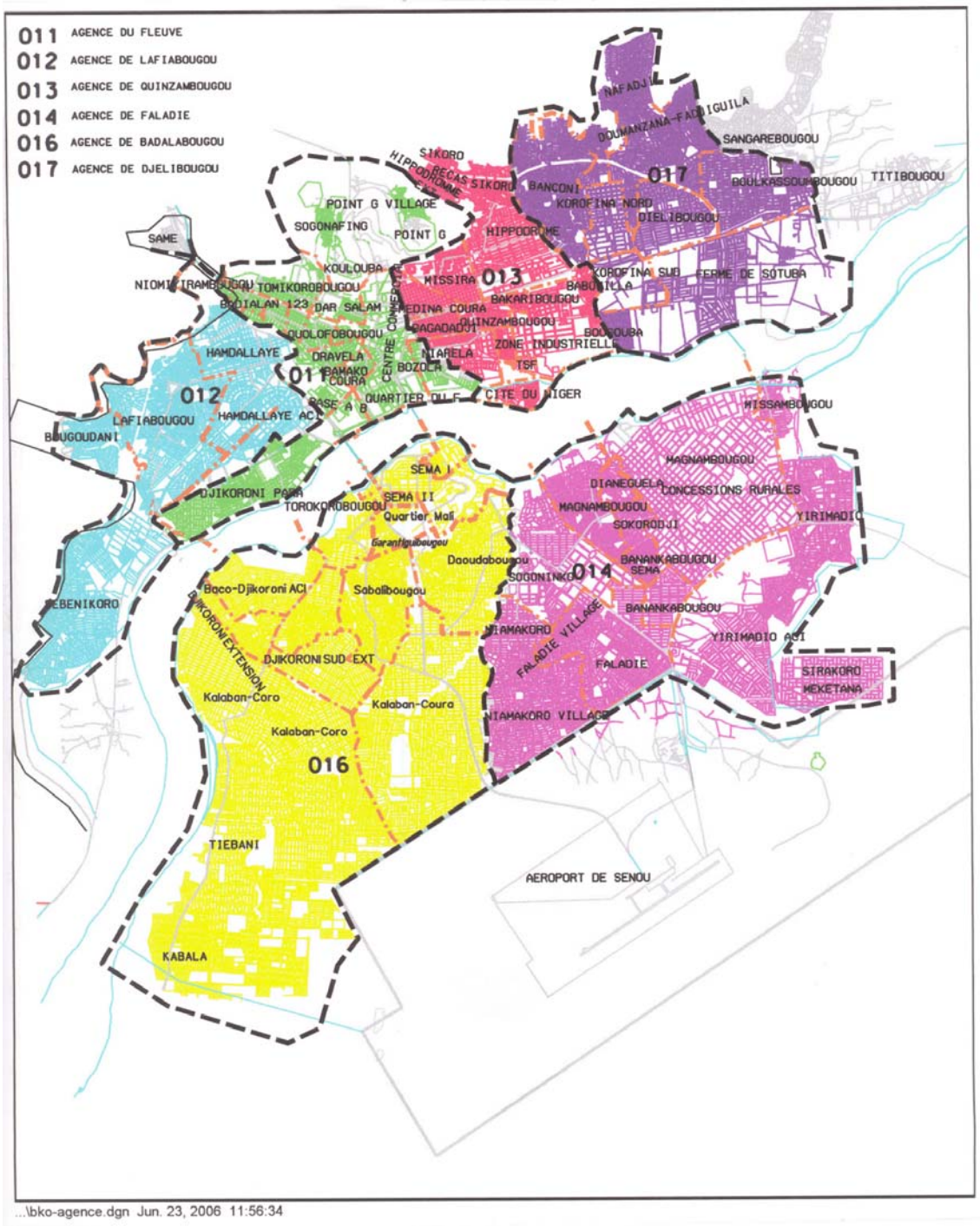


Source Mali NAPA

300 MW Solar In Bamako?

Solar $0.17/kWh
Offshore Wind $0.15/kWh
Diesel $0.15/kWh
Coal $0.07/kWh
Nuclear $0.07/kWh
Natural Gas $0.06/kWh

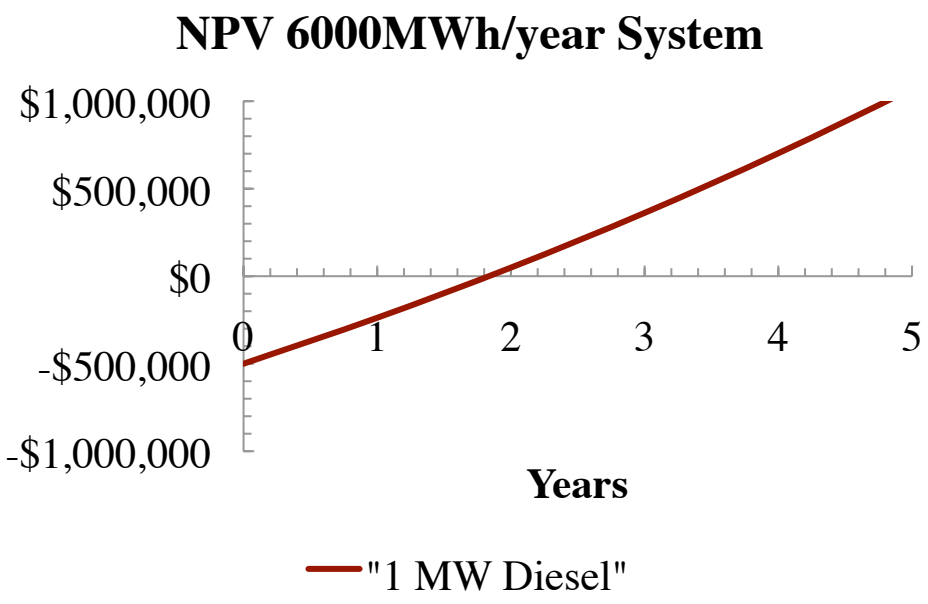
Source: Reuters
Image Source: EDM

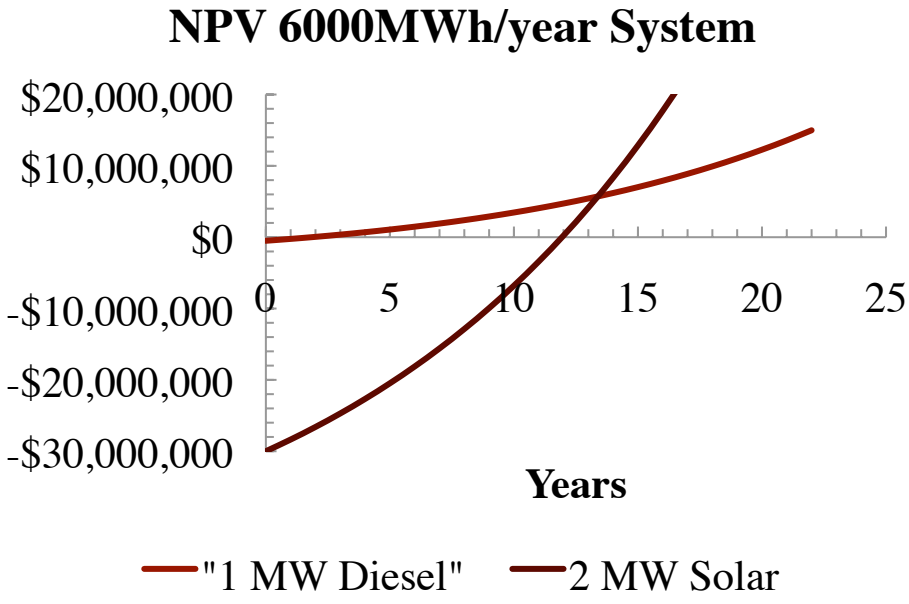


Solar Costs

1 MW Diesel		
Assumptions		
	Annual Operation, hours	6000
	Power, MW	1
	Annual Energy Production, MWh	6000
Costs Annual		
	System Capital Cost, $	500000
	Maintainence, $/MWh	10
	Operating cost, $/MWh	200
	Fuel Price increase, %	7.5
Revenue		
	Energy, $/MWh	250

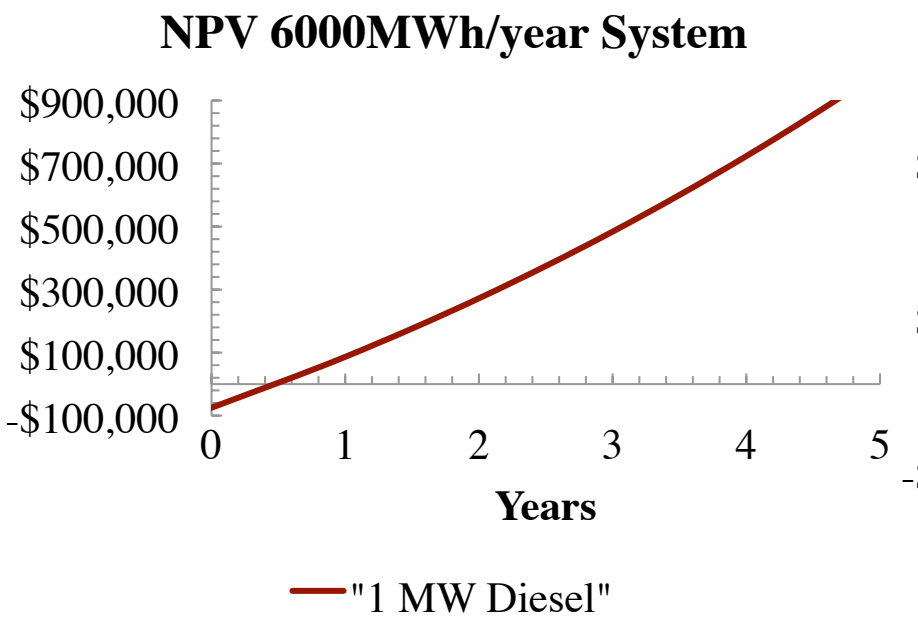
2 MW Solar		
Assumptions		
	Annual Operation, hours	3000
	Power, MW	2
	Annual Energy Production, MWh	6000
Costs Annual		
	System Capital Cost,$	30000000
	Annual Maintainence, $/MW	6000
Revenue		
	Energy, $/MWh	250
	Carbon Credit, $/MWh (REC)	5

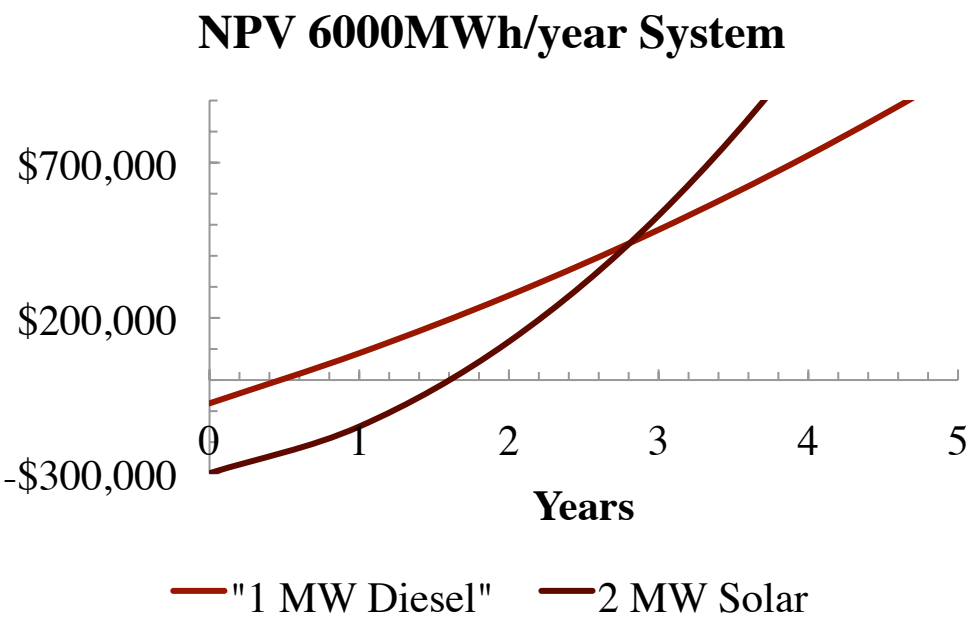




1 MW Diesel		
Assumptions		
	Annual Operation, hours	6000
	Power, MW	1
	Money Down, %	15
	Annual Energy Production, MWh	6000
	Loan Years	5
	Loan Interest, %	7
Costs Annual		
	System Value, $	500000
	System Capital Cost, $	75000
	Loan Amount, $	425000
	Maintainence, $/MWh	10
	Fuel cost, $/MWh	200
	Fuel Price increase, %	7.5
	Monthly Financing cost	8,415.51
Revenue		
	Energy, $/MWh	250

2 MW Solar		
Assumptions		
	Annual Operation, hours	3000
	Power, MW	2
	Money Down, %	1
	Annual Energy Production, MWh	6000
	Loan Years	40
	Loan Interest	4
Costs Annual		
	System Value	30000000
	System Capital Cost	300000
	Loan	29700000
	Maintainence	5000
	Monthly Financing cost	124,127.73
Revenue		
	Energy, $/MWh	250
	Carbon Credit, $/MWh	5





Outline

1. The Motivation Solar in Mali
   - Water + Sun – Fuel = Solar
   - Financing not Technology
2. Grid Tied Solar Strategies and Technologies
3. Opportunities for Grid Tied Solar in Mali
4. Conclusion

Outline

1. The Motivation Solar in Mali
2. Grid Tied Solar Strategies and Technologies
3. Opportunities for Grid Tied Solar in Mali
4. Conclusion

Off-grid Photovoltaic

Pros

Operation without Sun

Cons

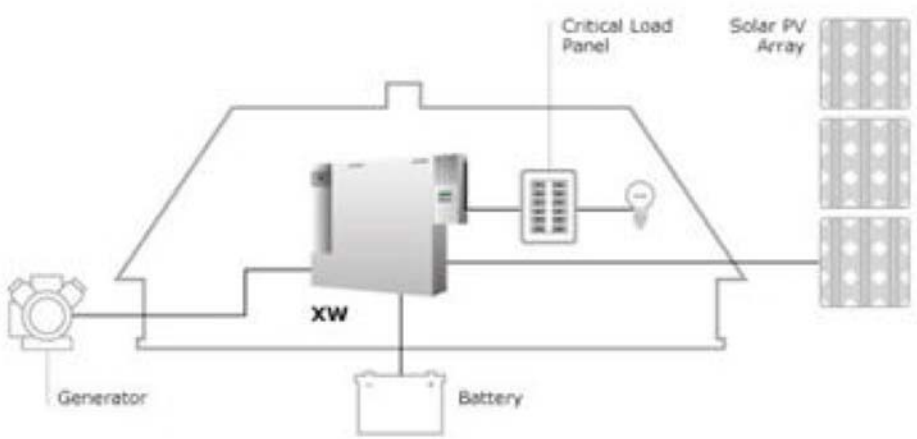
Efficiency Losses, 80%

Battery Management

Battery Life, 5 years

Battery Costs, 10%

Scale <25kW



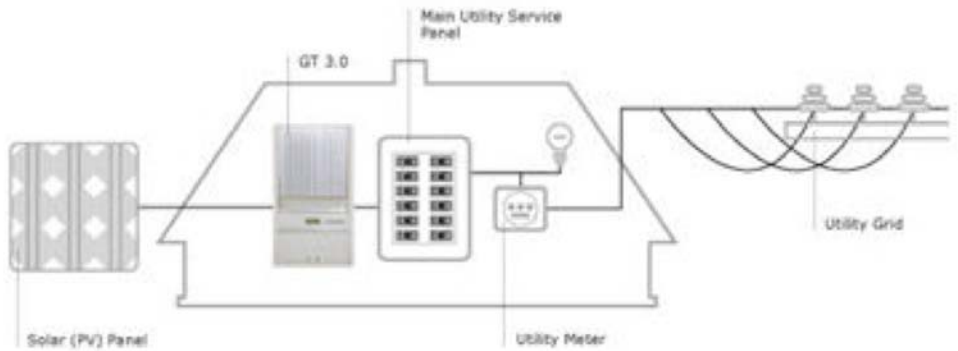
Adrian Hightower, Harvey Mudd College Engineering Department

www.xantrex.com

Modern Grid-tied Photovoltaic System

Pros

Operation without Sun
High Efficiency, 92 - 97%
Scale 100kW – 10 MW
Net Metering
Smart Grid



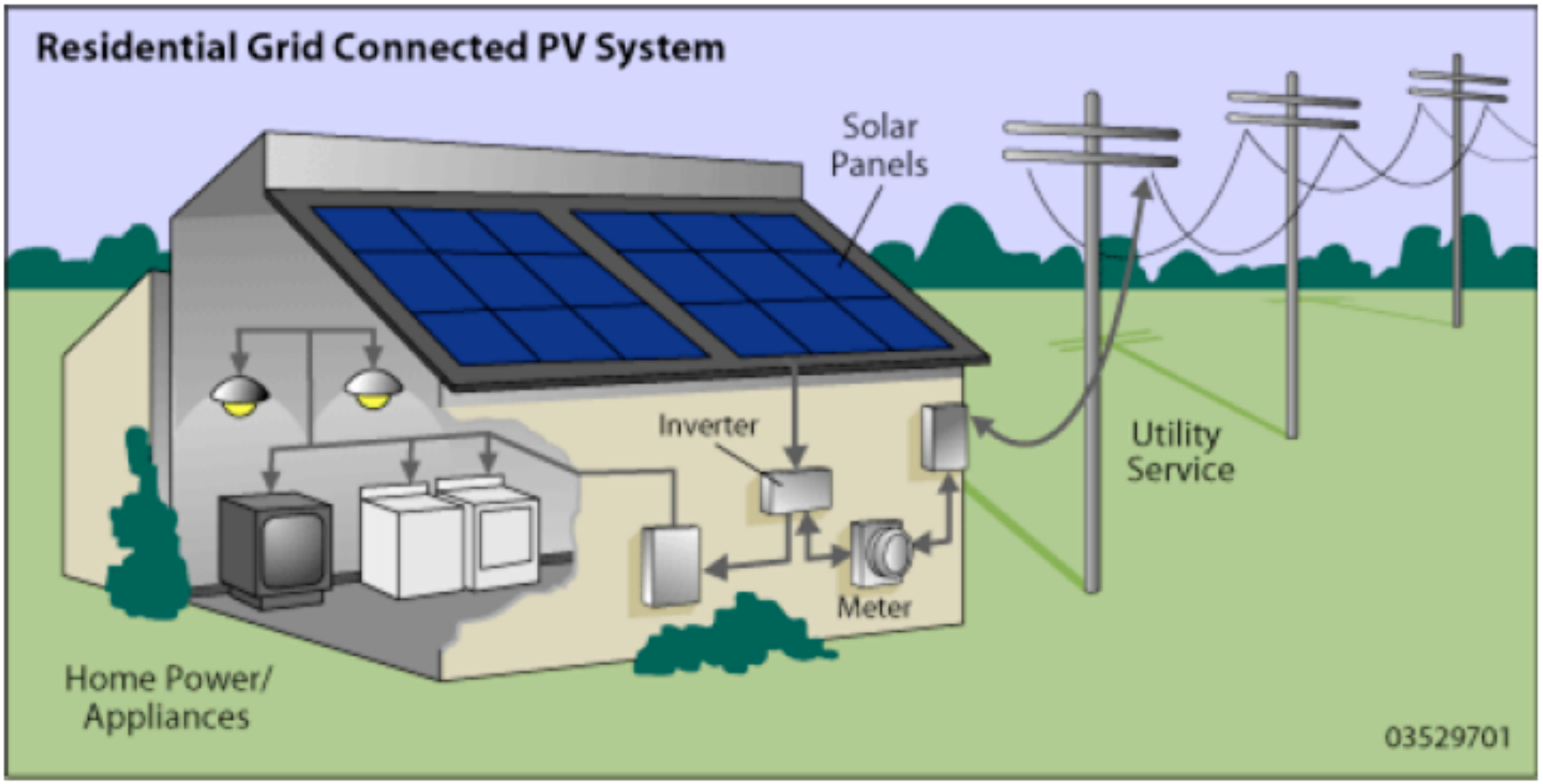
Cons

Grid Off➔System Off
Sophisticated Policies
Inverter Cost, 10% System

1MW Solar Array, Occidental College

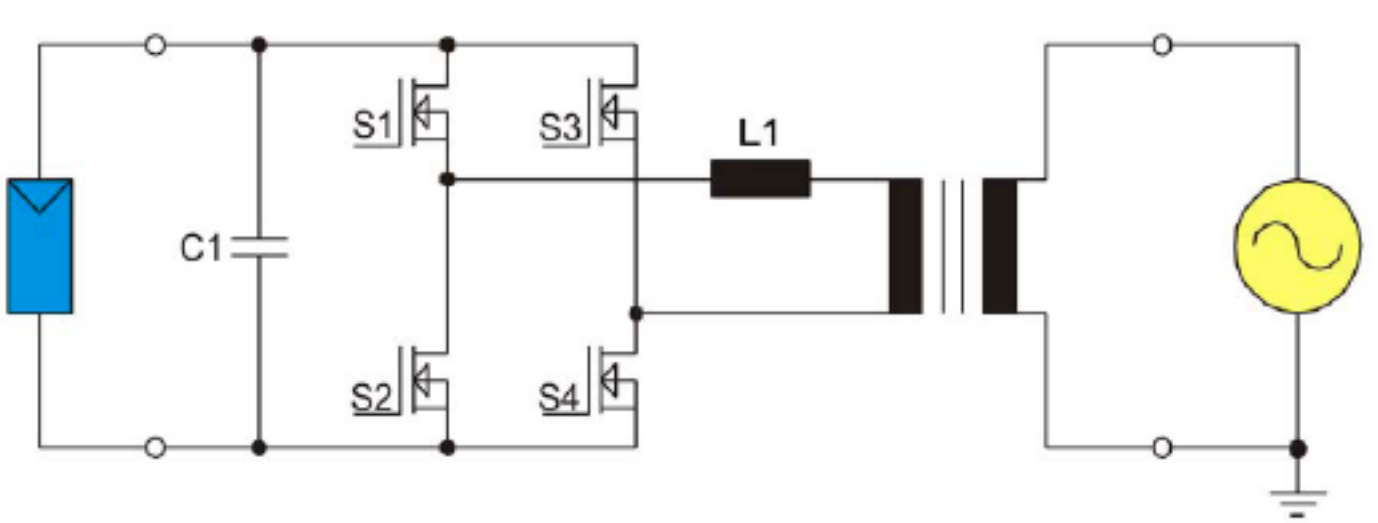
www.xantrex.com

Grid Tied Solar is the Standard



Net Metering allows Utilities to purchase energy from consumers!

Initial Transformer Based Inverter

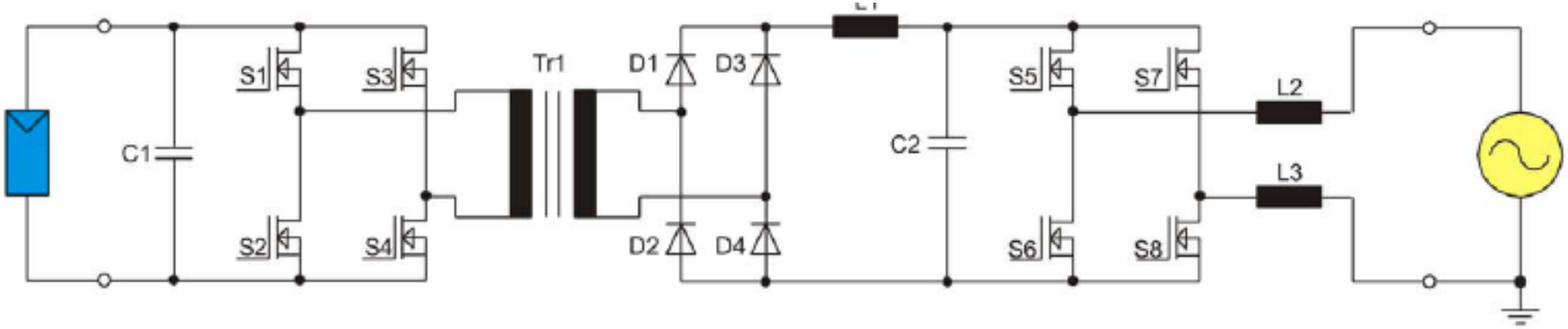


Advantages: Potentially fewer Inverter components

Disadvantages: Heavy transformer, Workmen's Comp liability, expensive to ship, may require two people to handle, lower efficiency which decreases at higher outputs and higher voltages

Source: Fronius Inc.

Modern HF Inverters

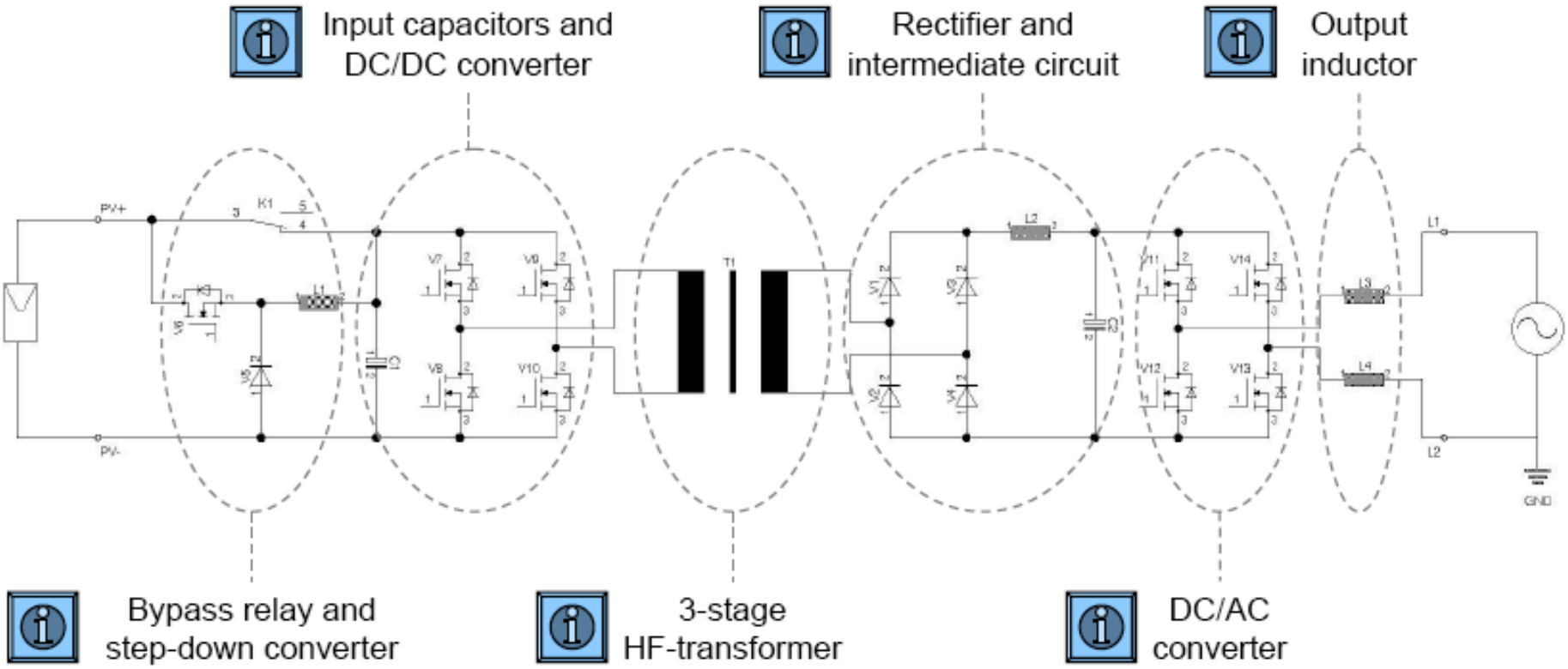


Advantages: Higher efficiency, lighter weight transformer.
Cost savings enabling savings to be spent on top quality name brand components. Proven topology.
No audible transformer noise

Disadvantages: Potentially higher component counts

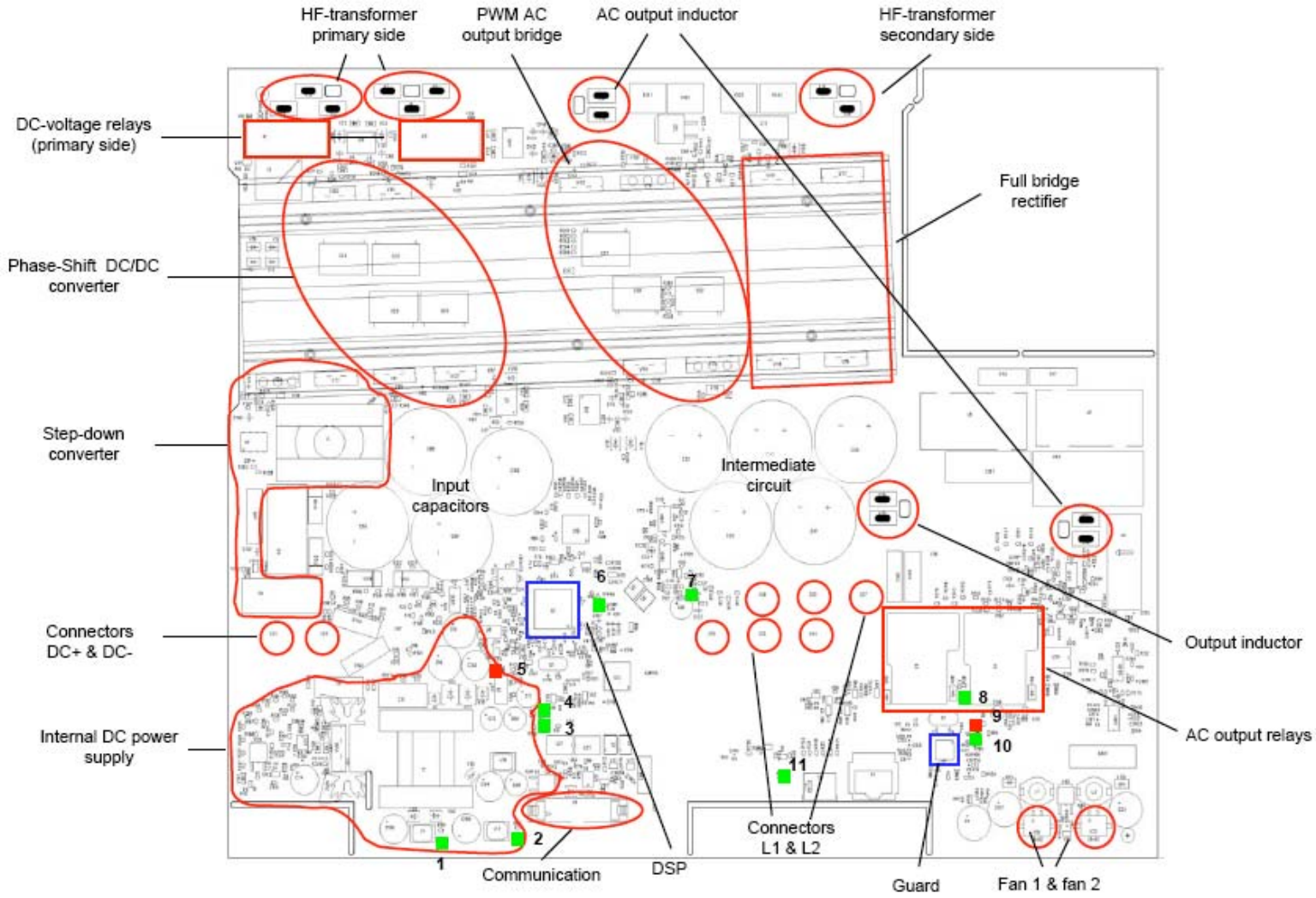
Source: Fronius Inc.

Modern HF Inverters



Source: Fronius Inc.

Mali Can Produce Grid Tied Inverters!



Source: Fronius Inc.

Outline

1. The Motivation Solar in Mali
2. Grid Tied Solar Strategies and Technologies
    1. Grid Tied Solar Systems are the industry standard
    2. Mali can produce a grid tied inverters (high end product).
3. Opportunities for Grid Tied Solar in Mali
4. Conclusion

Outline

1. The Motivation Solar in Mali
2. Grid Tied Solar Strategies and Technologies
3. Opportunities for Grid Tied Solar in Mali
4. Conclusion

Mali Grid and Microgrids

GRID

BAMAKO
KATI
KOULIKORO
DIOILA
FANA
SEGOU
MARKALA
YANFOLILA
SELINGUE
KALANA
KAYES
KITA
MANANTALI
KALABANKORO
MORIBABOUGOU
BAFOULABE
MAHINA
KANGANRE

Côte d'Ivoire

MICROGRIDS

NIORO DU SAHEL
OUELESSEBOUGOU
KANGABA
SAN
NIONO
TOMINIAN
SIKASSO
KOUTIALA
BOUGOUNI
KADIOLO
ZEGOUA
MOPTI
DJENNE
DOUENTZA
BANDIAGARA
GAO
TOMBOUCTOU
GOUNDAM
DIRE
NIAFUNKE
KIDAL

Adrian Hightower, Harvey Mudd College Engineering Department

Mali Focus on Microgrids

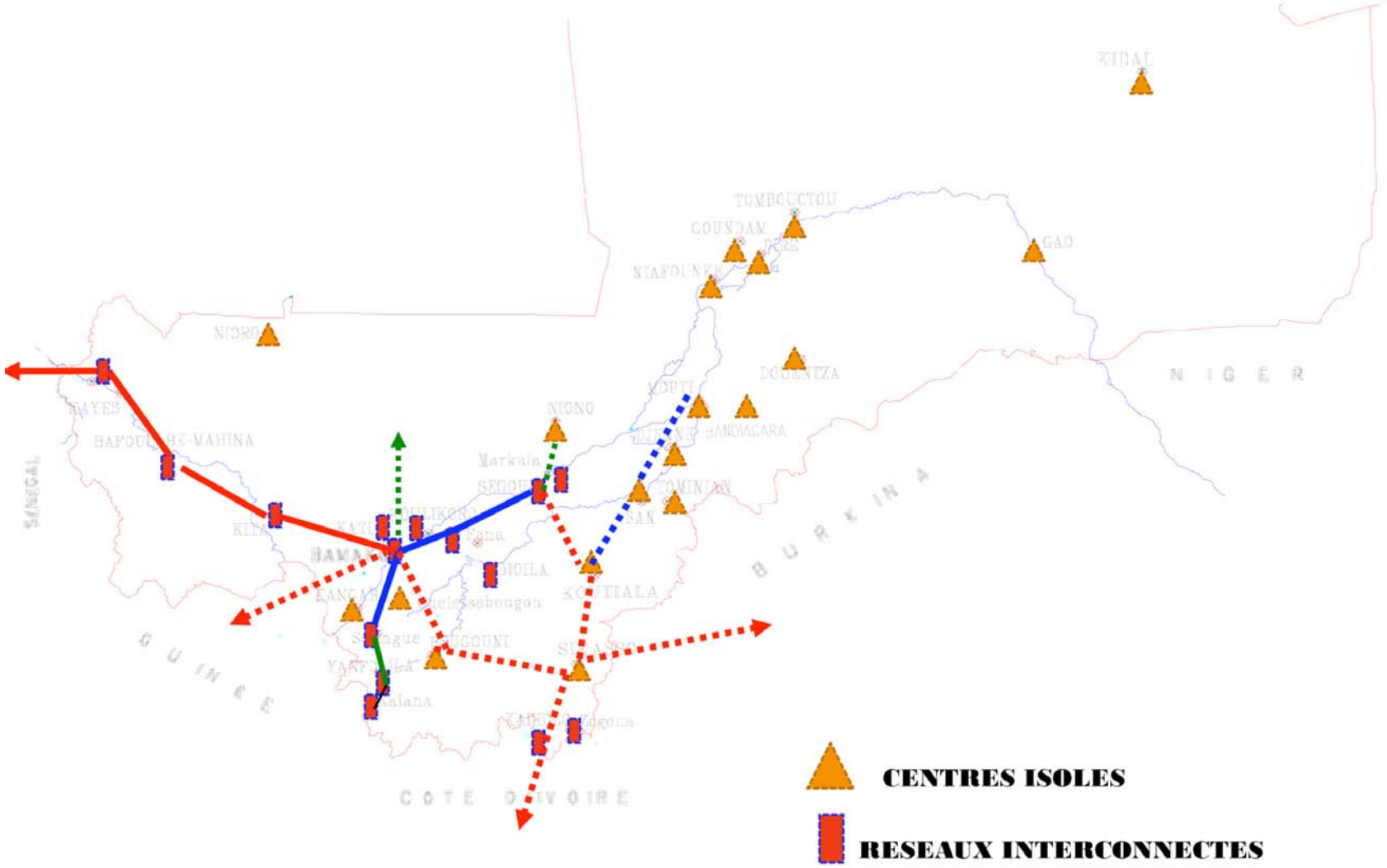
Micro Grids

- Can disconnect from traditional centralized grid to function autonomously
- Distributed Generation
- Renewable Energy
- Smart Grids

MICROGRIDS

NIORO DU SAHEL
OUELESSEBOUGOU
KANGABA
SAN
NIONO
TOMINIAN
SIKASSO
KOUTIALA
BOUGOUNI
KADIOLO
ZEGOUA
MOPTI
DJENNE
DOUENTZA
BANDIAGARA
GAO
TOMBOUCTOU
GOUNDAM
DIRE
NIAFUNKE
KIDAL

Mali Grid and Microgrids



Adrian Hightower, Harvey Mudd College Engineering Department

Energie du Mali (EDM) Annual Report 2008

1 MW Grid Tied Array

1 MW Array

- 5000 - 200W panels
- Area of one foot ball field
- $7 million or 3.5 billion CFA

- Energy Savings $200,000 per year
- Energy Savings increase ~4%/year
- Panels guaranteed 25 years, 35 year life
- Inverters guaranteed 10 years

Adrian Hightower, Harvey Mudd College Engineering Department

Outline

1. The Motivation Solar in Mali
2. Grid Tied Solar Strategies and Technologies
3. Opportunities for Grid Tied Solar in Mali
    1. Mali Develops Micro Grids using Grid Tied Solar
    2. Initial focus on existing Isolated Grids, Centres Isole
4. Conclusion

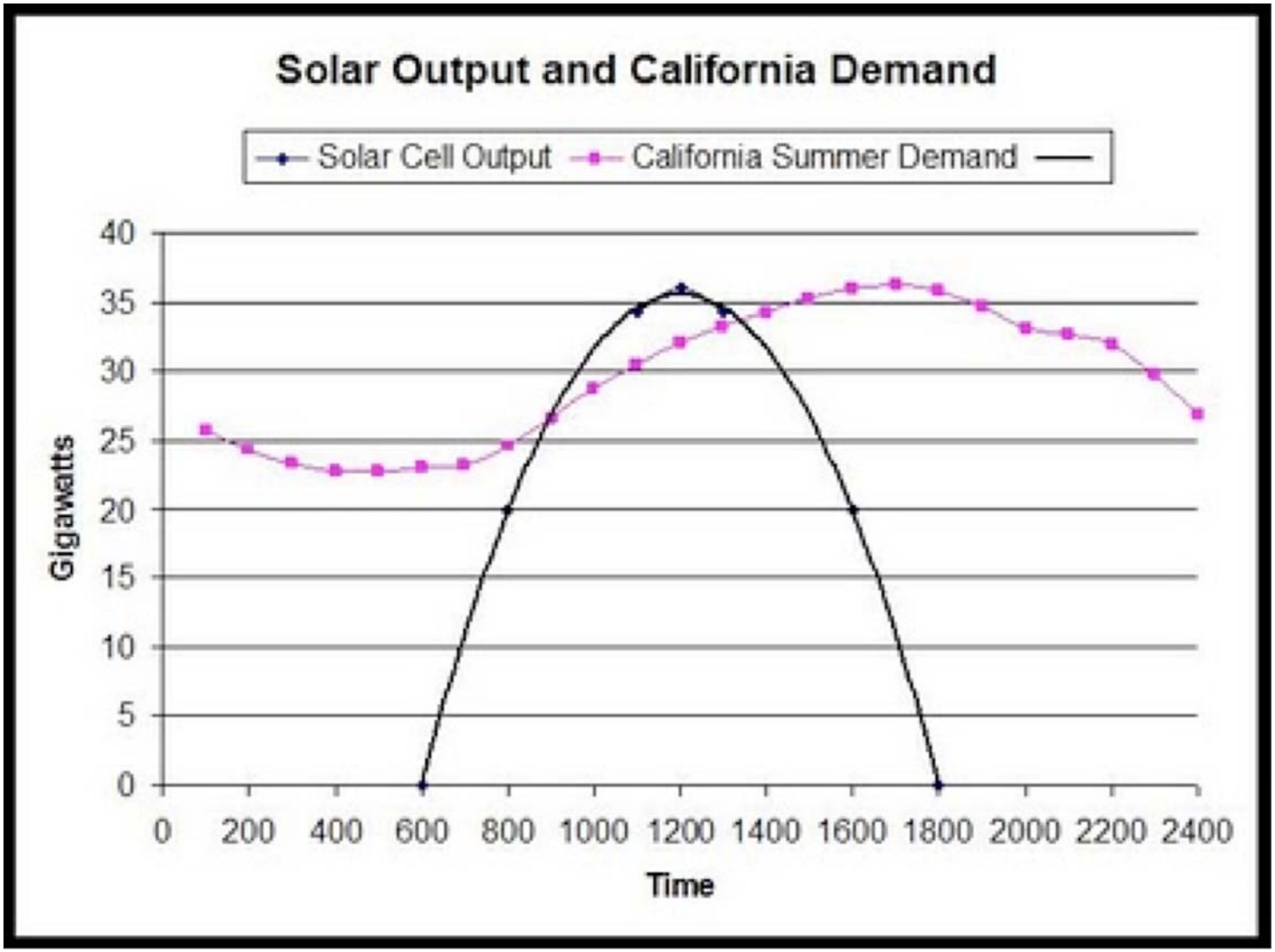
Outline

1. The Motivation Solar in Mali
2. Grid Tied Solar Strategies and Technologies
3. Opportunities for Grid Tied Solar in Mali
4. Conclusion

Conclusions

1. Water + Sun – Fuel = Solar
2. Financing not Technology
3. Grid Tied Solar Systems are the industry standard
4. Mali can produce a grid tied inverters (high end product)
5. Mali Develops Micro Grids using Grid Tied Solar
6. Initial focus on existing Isolated Grids, Centres Isole

Mali's Bright Future



What Must We Do?

- New Energy Sources
  - Solar, Wind, Geothermal, Hydroelectric, Biomass
- Conservation & Efficient Energy Systems
  - Modify Lifestyles - Mass Transit, Less Meat
  - Energy Smart Designs – Hybrid Vehicles
  - Recycling – Do it please
  - Energy Storage – Batteries
  - Energy Conversion – Fuel Cells

What About Developing Countries?

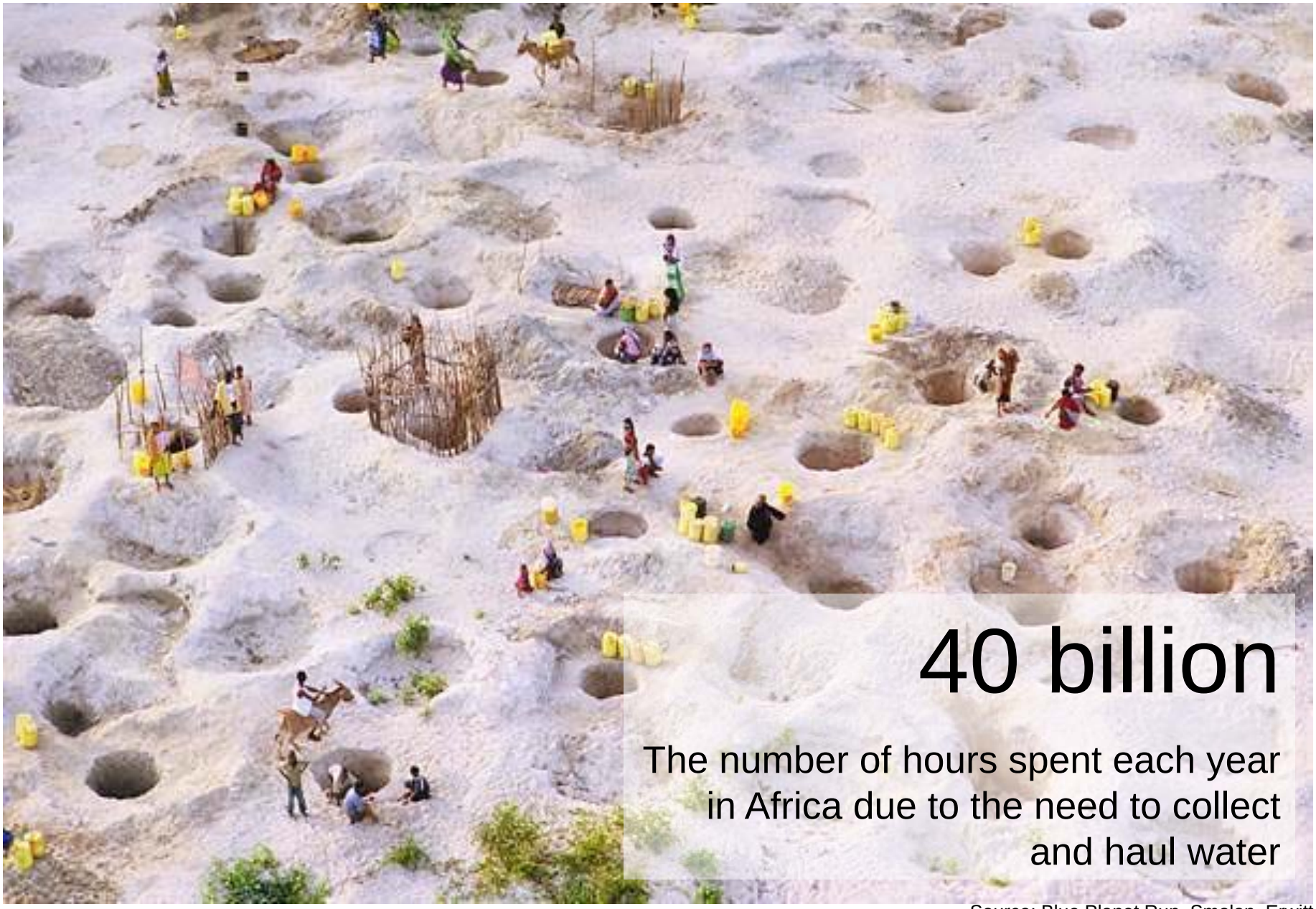
- Economic Effects More Pronounced
  - Limited Market Share
  - Lack of Diversified Energy Resources
- Environmental Effects More Pronounced
  - Limited Urban Planning
  - Limited Disaster Relief
  - Lack of Modern Transportation Infrastructure.

Why Should Developed Dountries Care?

- Economic
  - Moral Responsibility of Industrialized Nations
  - Migration of People Seeking a Better Life
- Environmental
  - Developing Countries as Environmental Resources
  - Migration of People Affected by Global Warming

Thank You Donors

- Velma Lucero and Luis Lucero
- Dolores Velasquez
- Ultra Soto-Rojas and Pedro Rojas
- Cardell Andrews
- Bertha G. Abrams
- Dorothyan Balsom
- Phillip Mathews
- Tony Ronzello
- Anna Martinez
- Sam Genis
- Jim Surina
- Dr. Gabrielle Foreman
- Enid A. Busser '58
- Pat Collum and Phil Collum
- Anonymous
- Susanna R. Anguiano
- Alice Hatcher and James Hatcher
- Donna M. Brittian
- Bernadine Hawthorne
- Sharon Lu and Matthew Morris
- Anderson Fellowship
- Paul K. and Evalyn E. Cook .Richter Family Trust
- Occidental College Undergraduate Research Center
-

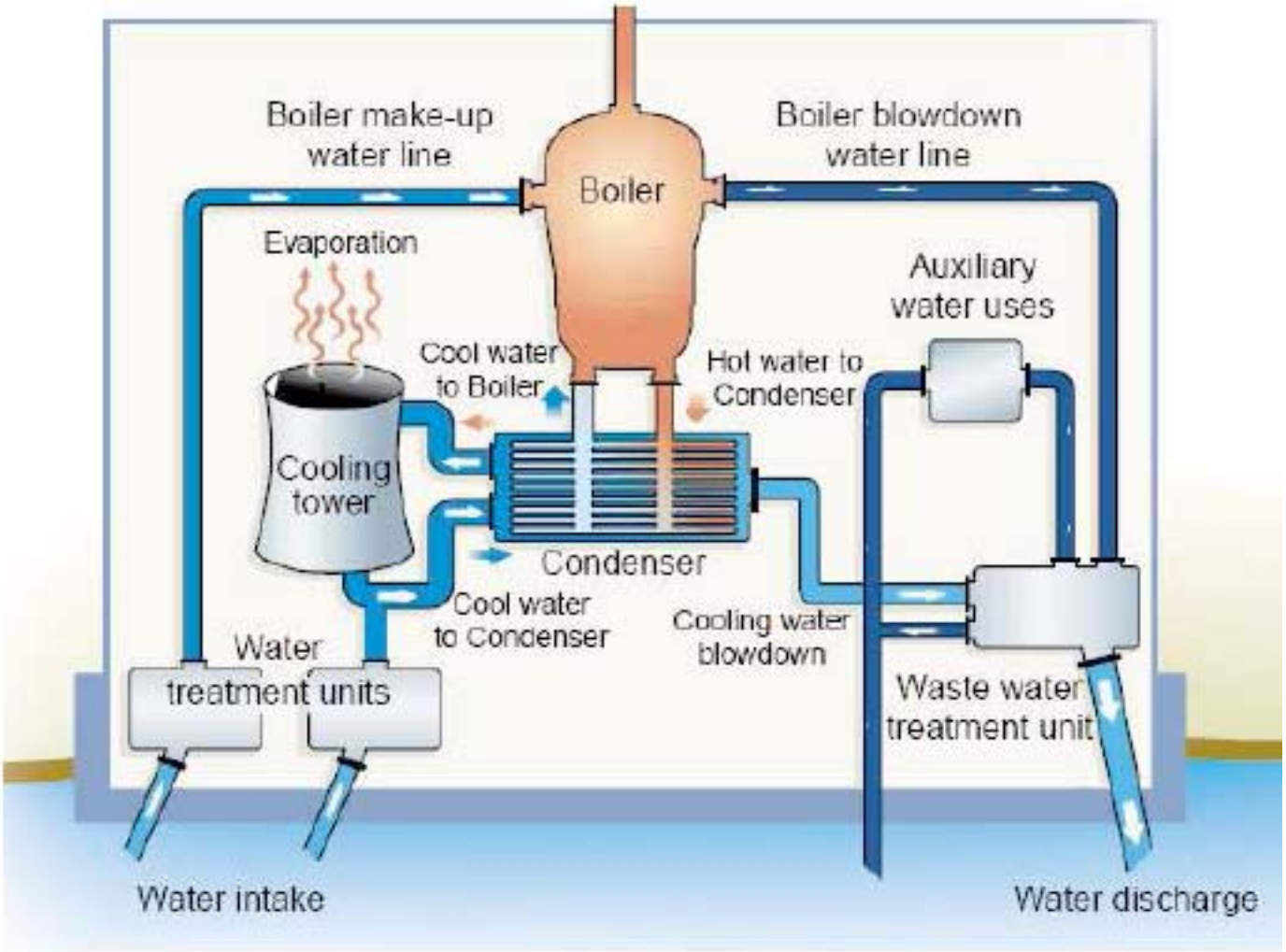


40 billion

The number of hours spent each year in Africa due to the need to collect and haul water

Source: Blue Planet Run, Smolan, Erwitt

Electricity Consumes Water



Recirculating wet cooling with the use of cooling towers (Baum et al., 2003).

California's Water Energy Nexus, B. Dennen, D. Larson, C. Lee, J. Lee, S. Tellinghuisen, 2007

Electricity Consumes Water

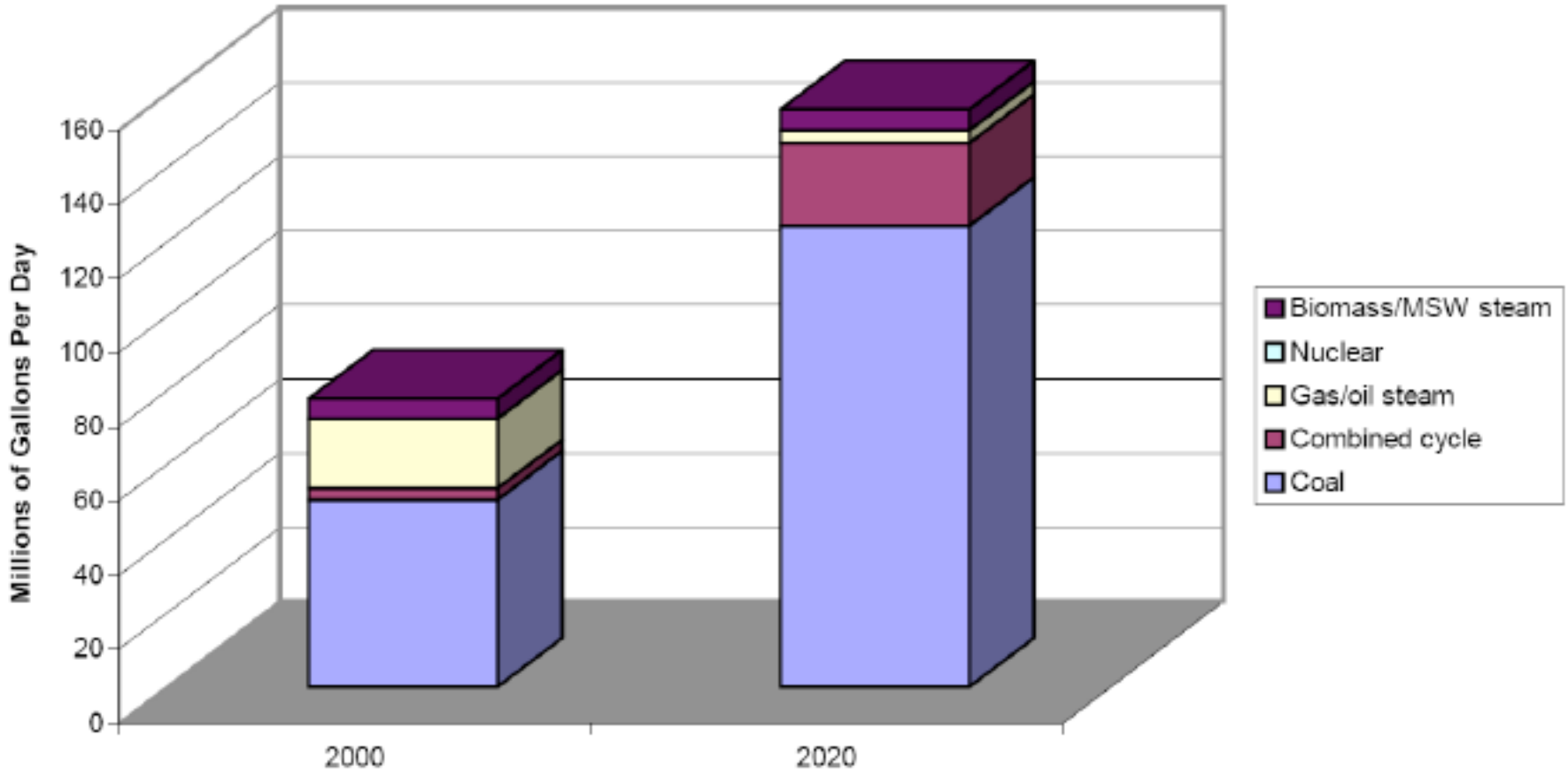
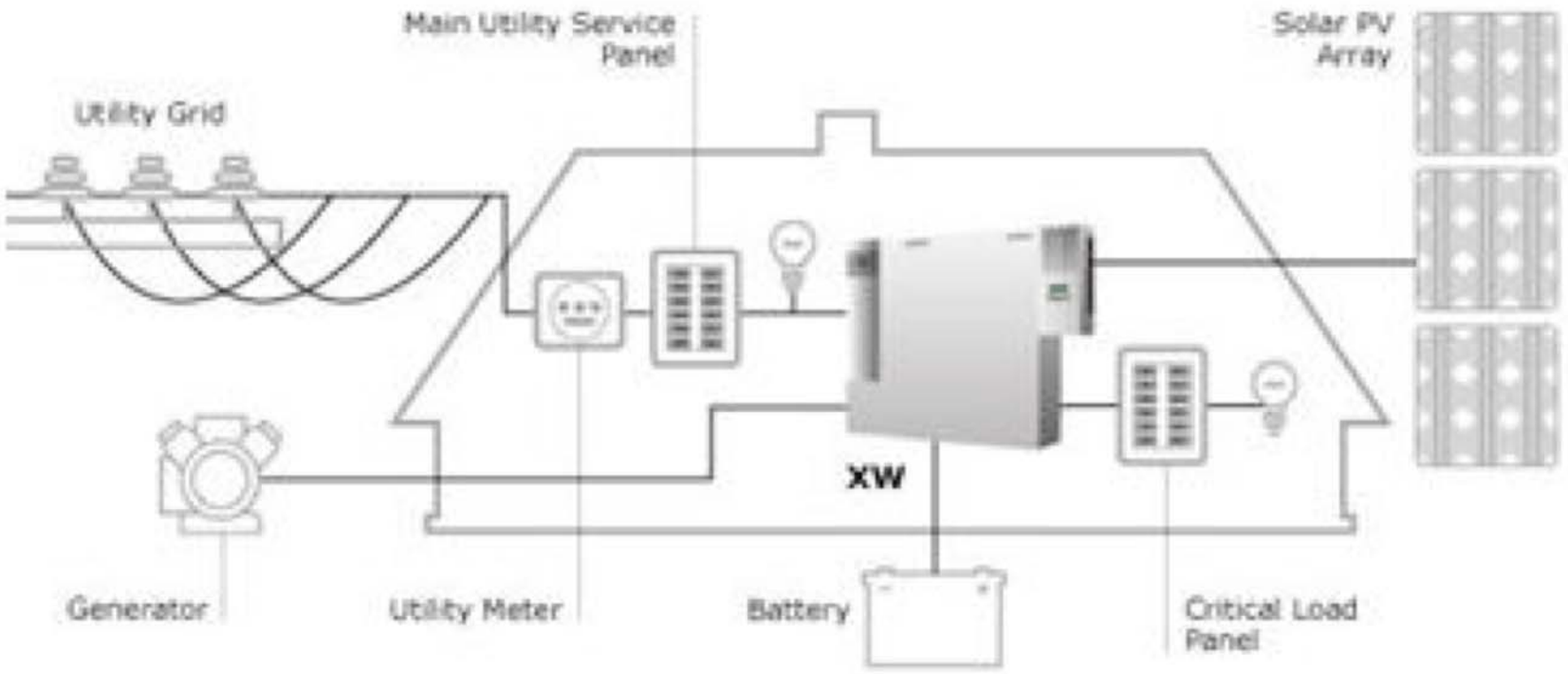


Figure 12. Power plant freshwater consumption (evaporation), by plant type, for 2000 and 2020, in the California and southern Nevada areas of NERC's WSCC region; DOE EIA AEO2000 Generation Projection (EPRI, 2002c).

California's Water Energy Nexus, B. Dennen, D. Larson, C. Lee, J. Lee, S. Tellinghuisen, 2007

Grid-tied Photovoltaic with Battery Bank



www.xantrex.com