AHEAD Energy's CLEAN FOSSIL Agenda for Economic and Climate-Friendly Energy Systems for the Next 50 Years

James Grieve, Eleanor Rusling

AHEAD Energy 501(c)(3)

Rochester, New York

www.aheadenergy.org Seminar presented at the Golisano Institute for Sustainability, Rochester Institute of Technology 2014/2/26

Outline

BACKGROUND

- Global Energy Trends
- Limits to Renewables

CLEAN FOSSIL VISION

- Stranded gas and coal to make carbon-free fuels and CO2
- Comparison of H2, NH3 and other alternative fuels
- Upstream technologies
- Downstream Technologies

AHEAD Energy 501(c)(3)

- History, 3 phases
- Current role and vision
- Next Steps

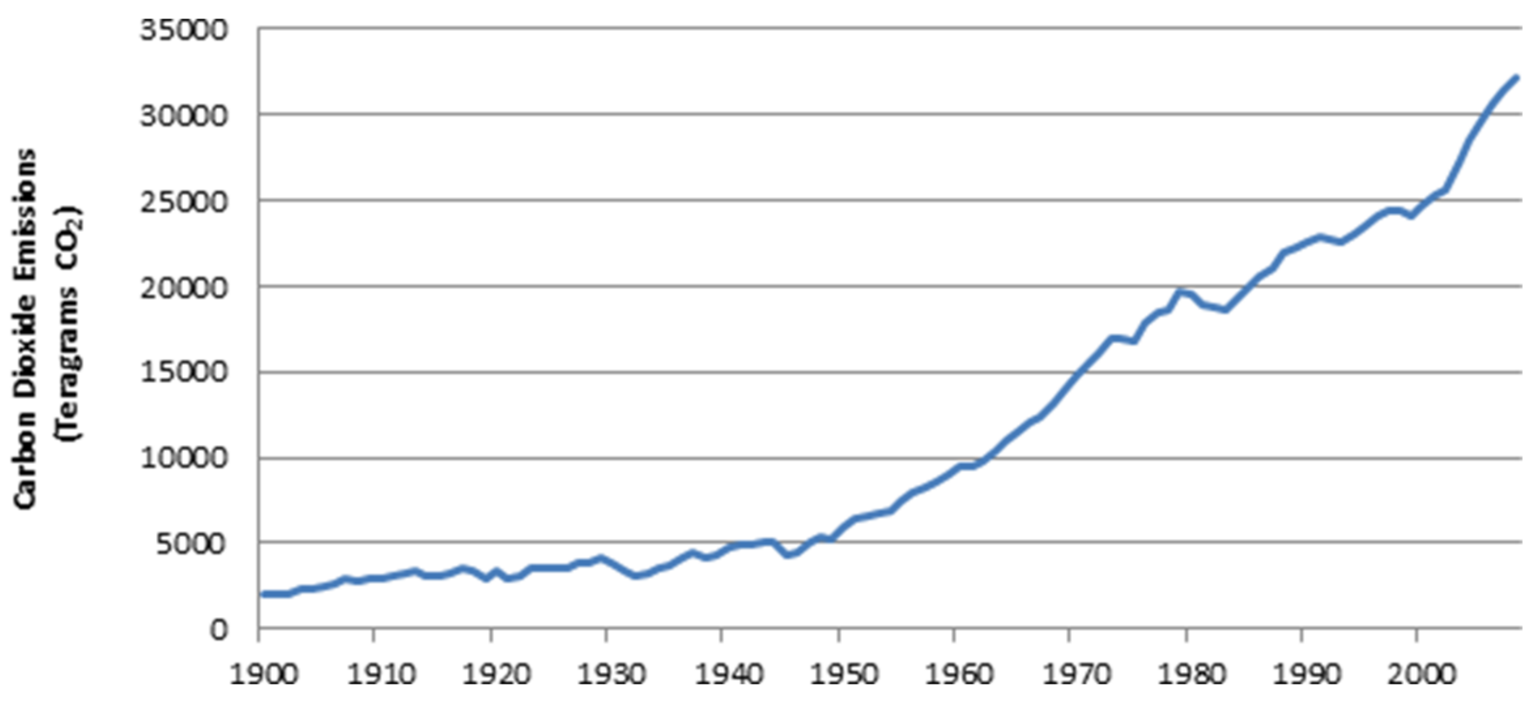
SUMMARY

BACKGROUND

WORLD ENERGY SYSTEM AND RENEWABLES

Rising Carbon Emissions [1]

Global Carbon Dioxide (CO_2) emissions from fossil-fuels 1900-2008

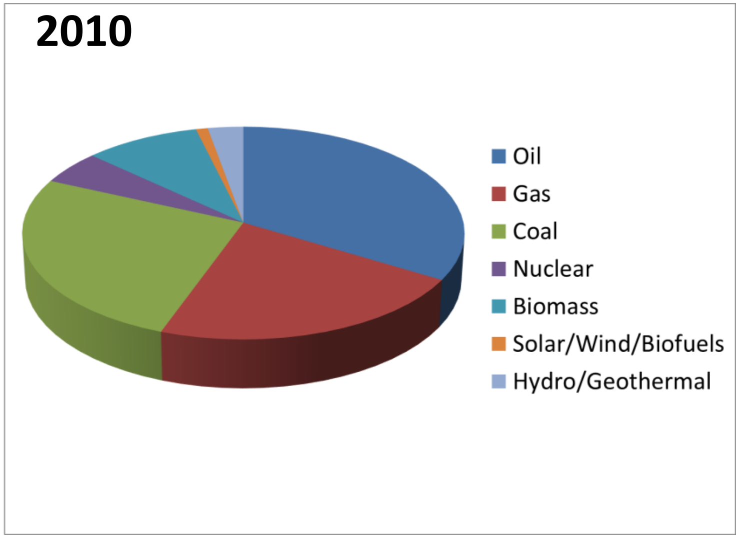


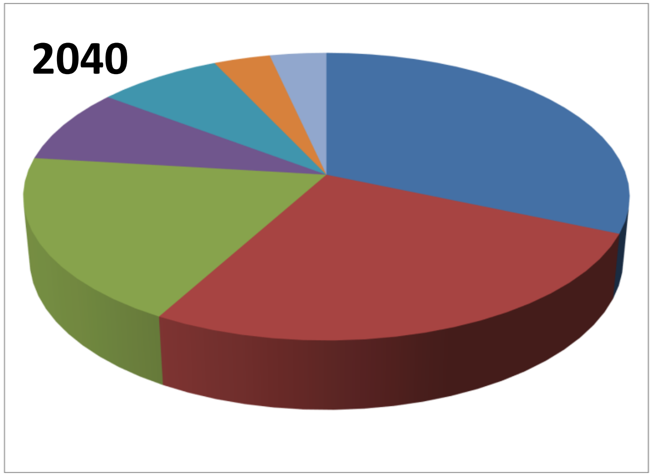
Source of data: Boden, T.A., G. Marland, and R.J. Andres (2010). Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2010.

Note that the only time the curve isn't rising is during economic depressions.

Source: [1] www.epa.gov/climatechange/ghgemissions/global.html#three

Global Energy Trends



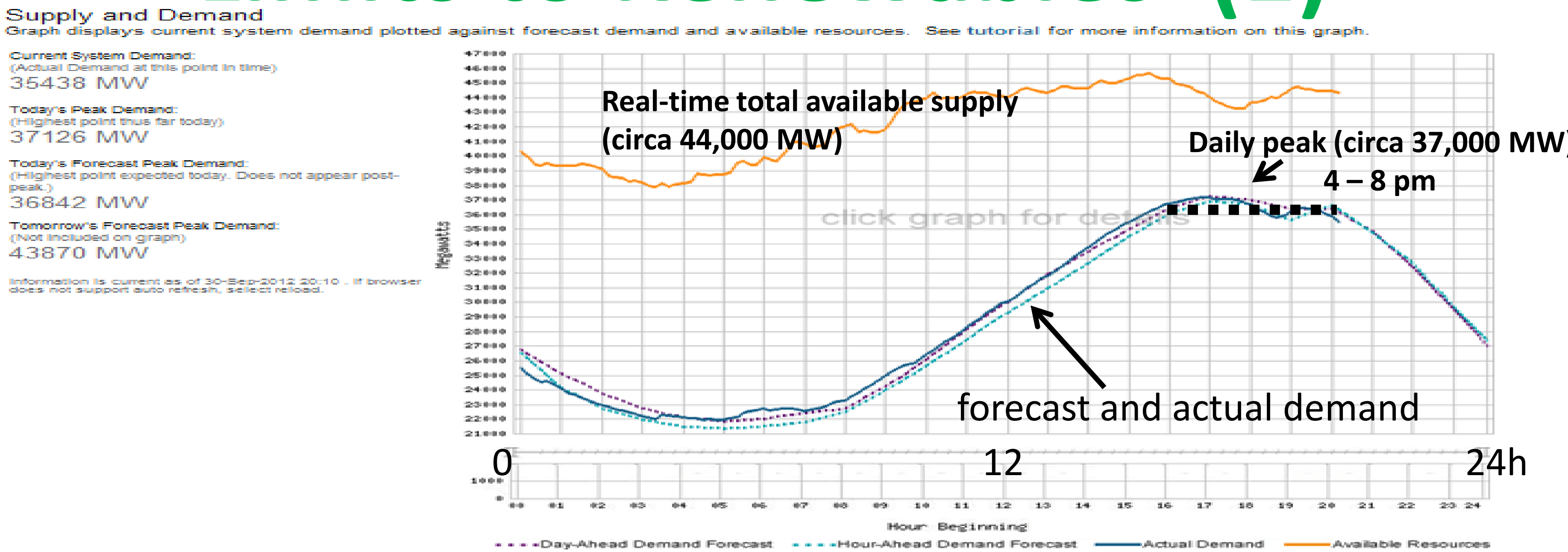


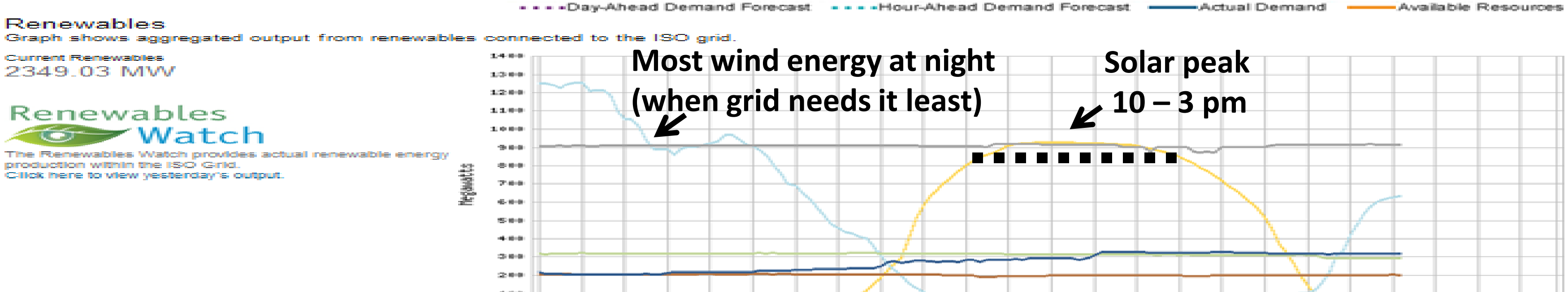
- World Energy Portfolio:
  2010 and 2040 projections [2]
  - Global Primary Energy grows by 36% (vs. population growth of 25%)
  - High CAGR of renewables (solar, wind and biofuels) but share remains insignificant (<3% share in 2040)
  - Oil, Gas and Coal continue to dominate (77% share in 2040)

- AHEAD has a focus on a CLEAN FOSSIL
  - Low cost, low carbon utilization of OIL, COAL and NATURAL GAS
    - **Carbon-free electricity and synthetic fuels**
    - **High end-use efficiency**
  - Renewables (where they add value)

[2] Exxon Mobil 2013 World Energy Outlook
http://www.slideshare.net/MarcellusDN/exxonmobil-2013-the-outlook-for-energy-a-view-to-2040
(DOE projections are similar)

Limits to Renewables (1)





CALIFORNIA [3]:

- Wind and Solar often don't coincide with PEAK LOAD
- Value to grid is little more than Avoided Cost (marginal fuel savings, plus a little more)
- **Renewables plus Storage plus Fuel-based Back-up Generation is a triple investment compared to Conventional Peaking Power Plants.**

[3] Source: http://www.caiso.com/outlook/SystemStatus.html

Limits to Renewables (2)

- **DENMARK**
  - 20% wind share (kW-h generated over the year)
  - CO_2 emissions did not decrease
    - Coal plants keep running anyway
    - Wind energy is exported or less Hydroelectric (Norway) or Nuclear (France) is imported.

- **GERMANY**
  - Massive subsidies for wind and solar, but early closure of Nuclear Plants has resulted in increased COAL consumption and higher CO_2 emissions!
  - Large increase in consumer and industrial electric tariffs (stifling economic growth)
  - Most of GREEN JOBS have moved to China

- **MAUI**
  - 50% of wind generation is often curtailed (it is of no value to the grid). Not enough PHEVs?

CLEAN FOSSIL VISION

Coal and Stranded Gas

- **Coal and Natural Gas are clearly the low cost primary energy sources for the next 50 to 100 years.**
- **Conversion to Synthetic Fuels increases value:**
  - Liquid Fuels are easier and **cheaper** to transport, store and use
  - Synthetic Fuels are **cleaner** (inherent air quality benefits)
  - Synthetic Fuels are **more efficient** and attractive for distributed generation which supports high end-use efficiency
  - **CO2 is a valuable by-product** at the wellhead (vs. expensive to capture and sequester in dilute exhaust of a conventional power plant)
- **Drop-in synthetic fuels are carbon intensive – so focus is better placed on carbon-free synthetic fuels.**

Alternative and Synthetic Fuels

LIQUID FUELS COMPARISON	Hydrogen	Ammonia	Propane	Methanol	Methane (LNG)	F-T Diesel (dodecane)
Formula	H2	NH3	C3H8	CH3OH	CH4	C12H26
Temperature, at 1 atm pressure [deg C]	-253	-33	-42	N/A	-162	N/A
CO2 intensiveness ratio (vs. F-T Diesel)	0	0%	93%	101%	79%	100%
Density [kg/L]	0.072	0.673	0.582	0.725	0.424	0.749
Energy Density [MJ/kg]	120.0	18.6	46.4	19.5	50.0	44.49
Energy by Volume [MJ/L]	8.6	12.5	27.0	14.1	21.2	33.3
CO2 Intensiveness [kg CO2/kW-h LHV]	0.000	0.000	232.9	254.4	197.9	251.3
SAFETY	-	+	0	0	- -	+
INFRASTRUCTURE COSTS	- -	0	0	+	- -	++

COMPRESSED FUELS COMPARISON	Hydrogen	Ammonia	Propane	Methane (CNG)
Formula	H2	NH3	C3H8	CH4
Pressure, at 20 deg C [bar]	700	8.38	8.25	250
CO2 intensiveness ratio (vs. F-T Diesel)	0	0%	93%	79%
Density [kg/L]	0.042	0.605	0.500	0.201
Energy Density [MJ/kg]	120.0	18.6	46.4	50.0
Energy by Volume [MJ/L]	5.0	11.3	23.2	10.1
CO2 Intensiveness [kg CO2/kW-h LHV]	0.000	0.000	232.9	197.9
SAFETY	- -	-	-	0
INFRASTRUCTURE COSTS	- -	0	0	+

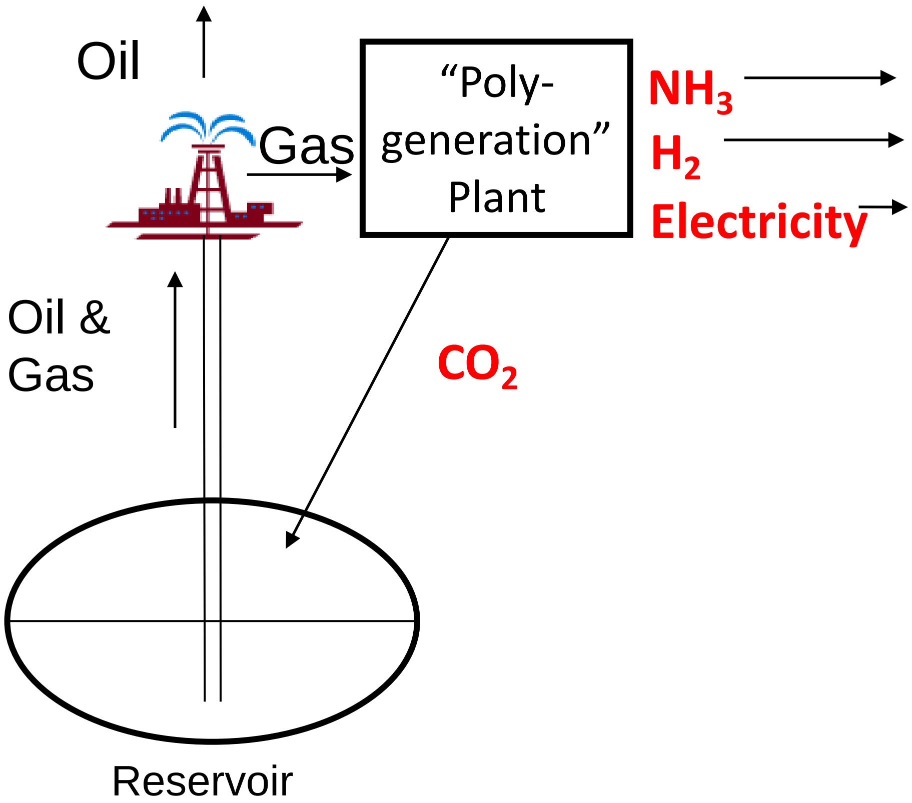
Textbook material properties for pure components are shown. Well to tank analysis would make CH4 look much more CO2 intensive due to high losses in compression and liquefaction.

Ammonia has similar energy density to methanol and similar storage and handling properties to propane.

UPSTREAM

Carbon-free Synthetic Fuels with CO2/EOR

- **ELECTRICITY, HYDROGEN and AMMONIA** can be produced
- CO2 sequestered in **CO2/EOR applications**.
- **AMMONIA**: Easy to transport, store and use. [4] The key to decarbonize power generation.



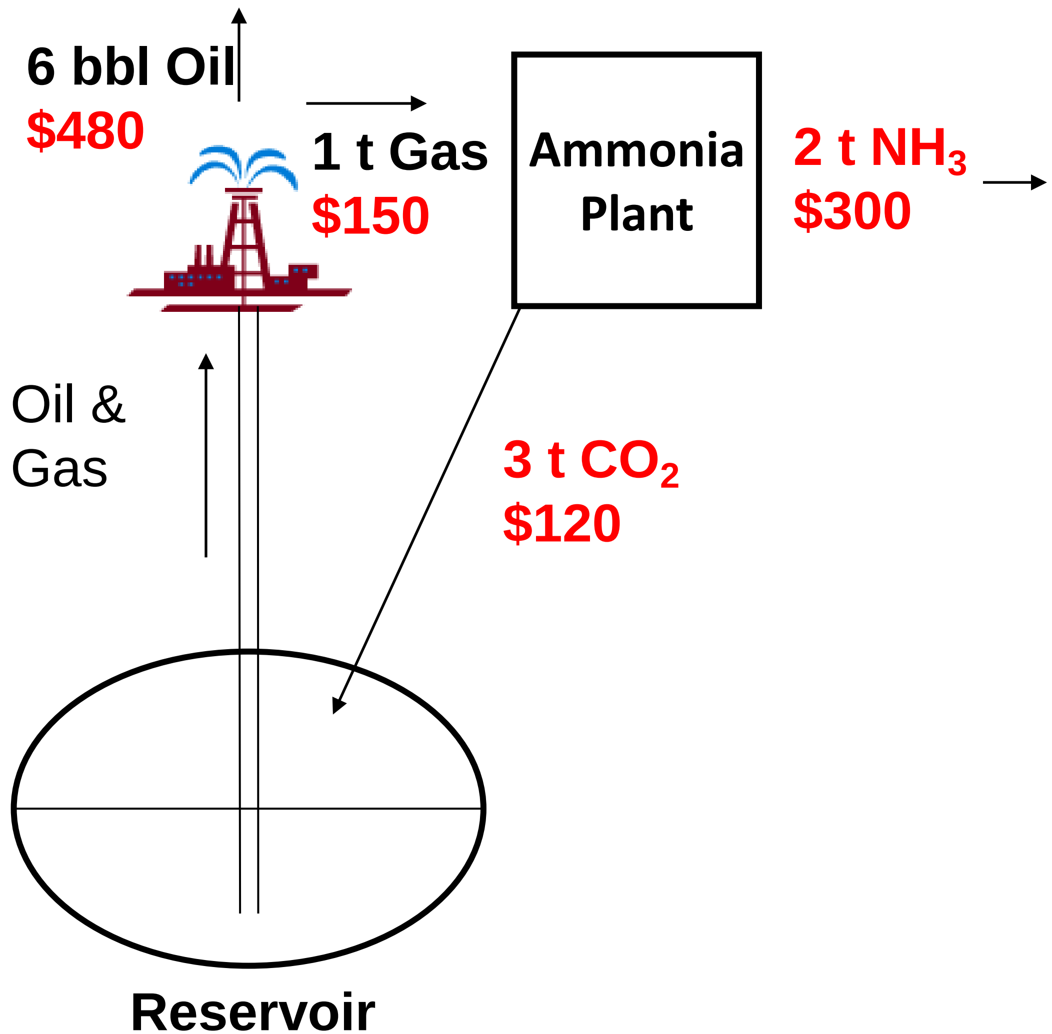
Note: Coal and water can be used as the input to the process instead of natural gas, if inexpensive natural gas is not available.
[4] Toyota paper from World Hydrogen Energy Congress 2012 – showing advantages of ammonia as an energy carrier. http://www.whec2012.com/wp-content/uploads/2012/06/ASR15-HirhoshiMiyagawa-3.pdf

ECONOMIC DRIVERS for CO2/EOR

TWO INTERLOCKING BUSINESS MODELS:

(1) Production of Ammonia and CO2 from Stranded Gas

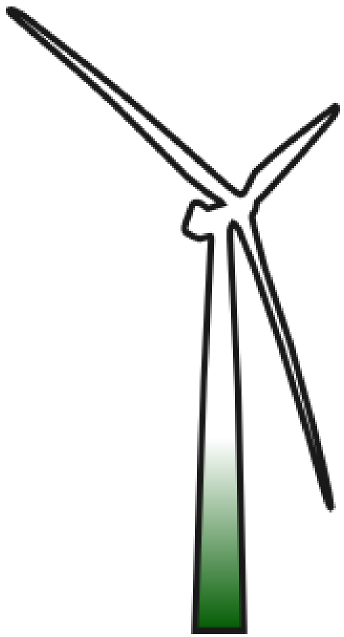
(2) CO2 to produce incremental oil and gas



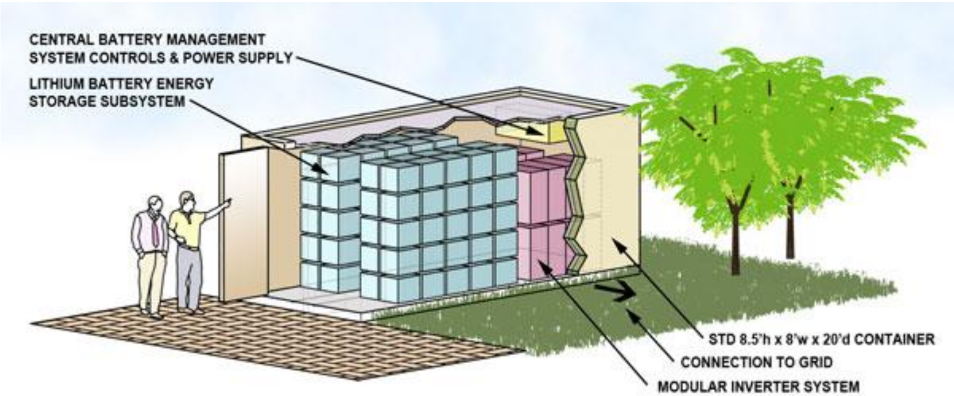
Notes:
With $3/MMBTU gas and 24 MMBTU of gas/tonne of NH3 cash costs are about $98/tonne of NH3, http://www.yara.com/tools/cashcost.html
A target selling price of $150/tonne of ammonia seems possible, especially in the context of the CO2 credit (sold for EOR)
A target selling price of $80/barrel of crude oil is in line with current market prices. $780 in products from $120 in material input!!
While the same CO2 emissions will result from the incremental oil production, the gas (or coal) is used essentially without carbon emissions and overall there is a close to 50% reduction in CO2 intensiveness compared to conventional oil and gas extraction.

DOWNSTREAM

Carbon-free HYBRID POWER SYSTEM [5]



(1) Renewables



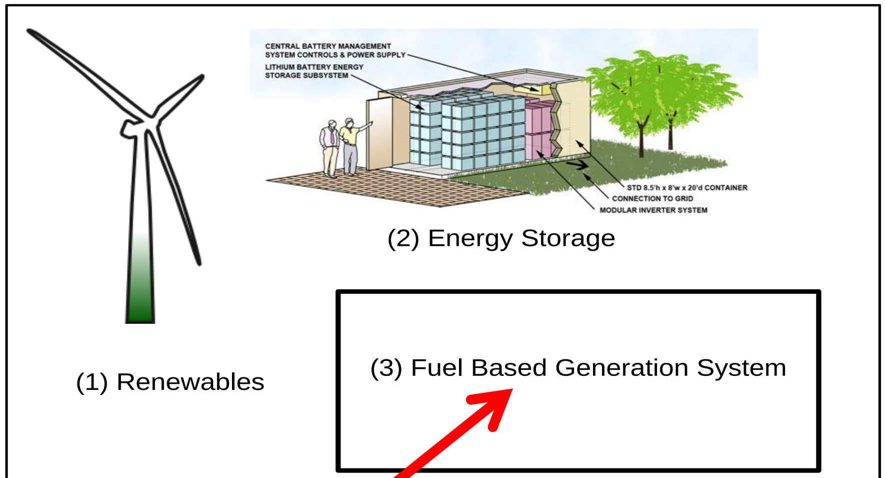
(2) Energy Storage

(3) Fuel Based Generation System

[5] Source: Merrill Rusling, LLC

DOWNSTREAM

CLEAN FOSSIL Generation (renewables and storage if value added)



LOGICAL FOCUS for R&D and product development

KEY ISSUES

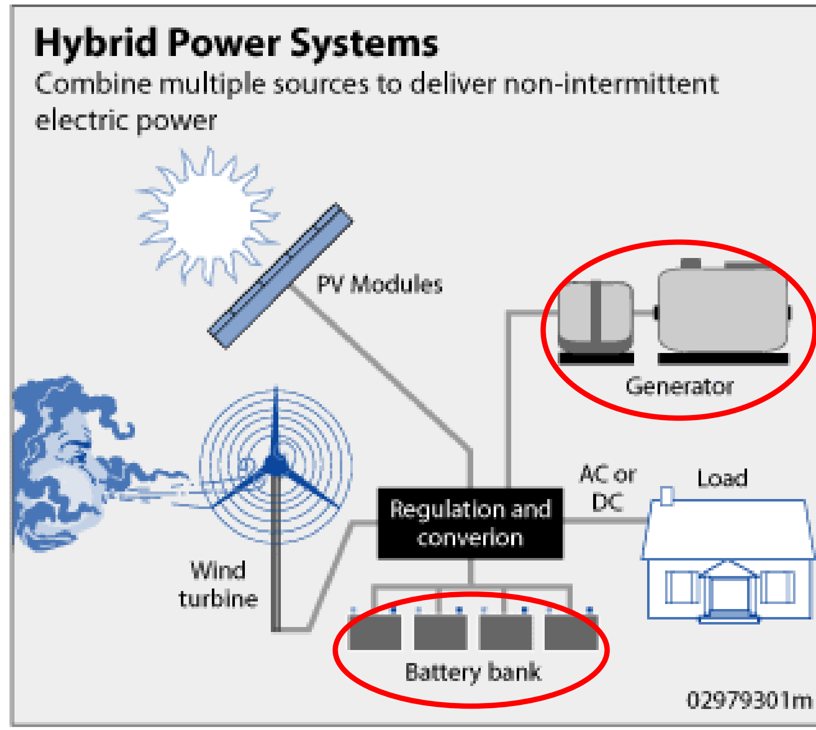
- **Technology** (ICE, GT, SOFC, PEMFC, hybrid systems, CCHP etc.)
- **Scale** (Utility, Industrial, Commercial, Residential)
- **Fuel Choice** (H2 where practical, NH3 nearly everywhere else)
- **Networking & Integration** (avoid spinning losses & spilled wind)

Downstream Technologies

Product Development for which AHEAD or partners seek funding

(1) Renewable Hybrid System [6]

- AHEAD and partners proposal to USAID
- DC generator using biomethane and NH3
- Lead Carbon Battery (to manage transients)
- Hybrid Vehicle Electronics



- NOT FUNDED
- Application for automotive derivative:
  - Engine Management System
  - 48 V generator
  - Mild hybrid batteries
  - Electronics

[6] Source of Diagram: USA Department of Energy (emphasis added)

Downstream Technologies

Product Development for which AHEAD or partners seek funding

(2) NH3 fueled SOFC micro Combined Heat and Power (CHP) system

- Academic and Industry work (primarily in Europe) has shown that ammonia is an excellent SOFC fuel. [7]
- Lower cost and complexity and higher efficiency than using carbon-based fuels
- Micro SOFC could be used for small scale electricity generation combined with relevant use of the byproduct heat:
  - Cooking
  - Water Purification
  - Distillation
  - Integration with Biodigester
  - Crop drying
  - Pasteurization

- PROJECT BEING DEFINED
- application for SOFC

[7] http://www.ecn.nl/docs/library/report/2005/rx05085.pdf

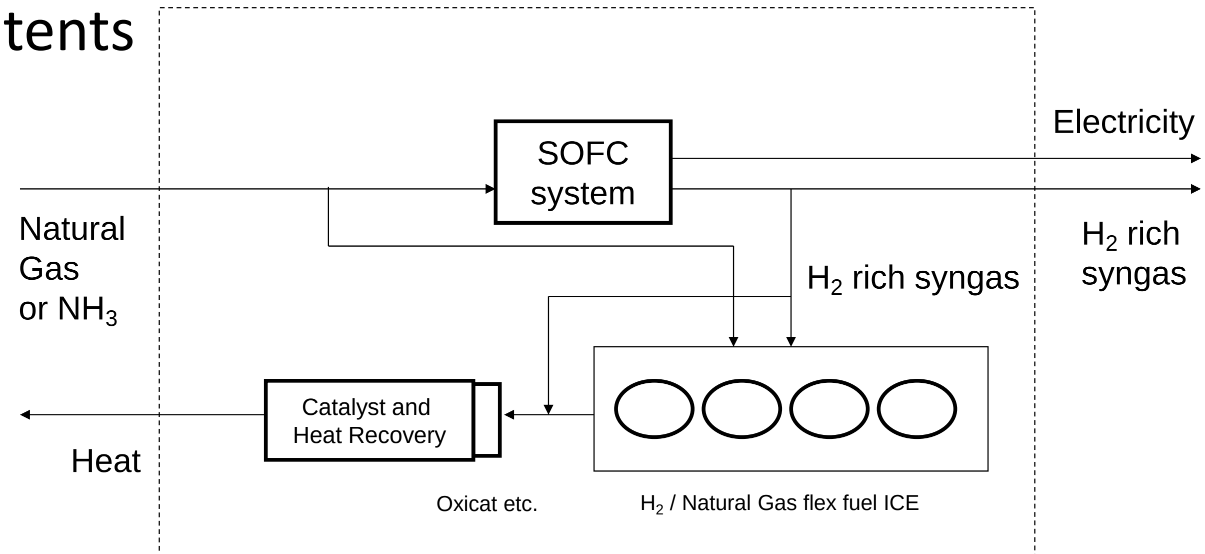
Downstream Technologies

Product Development for which AHEAD or partners seek funding

(3) SOFC/ICE Hybrid Distributed Generation System

- Possible DOE project (with PNNL and other partners)
- NH3 or biomethane SOFC runs all the time (making electricity + by-product heat and H2)
- ICE runs during peaks (co-fueled with H2 for high efficiency and low emissions) [8]

- FUNDING BEING EVALUATED
- licensing of Delphi patents
- application for SOFC



[8] http://am.delphi.com/pdf/techpapers/2003-01-1356.pdf

AHEAD ENERGY

Downstream Technologies

Product Development for which AHEAD or partners seek funding

(4) Bi-Fuel LPG/NH3 Internal Combustion Engine (ICE) Combined Cooling Heat and Power (CCHP) System [4]

- European CHP system, optimized for alternative fuels
- Merrill Rusling, LLC project (with partners)
- Coupling commercial ICE CHP product with desiccant based Air Conditioning System

- FUNDING BEING EVALUATED
- Possible application for Isothermal Desiccant Wheel technology

[4] related Toyota paper, showing high efficiency and high power density of NH3 engine: http://www.whec2012.com/wp-content/uploads/2012/06/ASR15-HirhoshiMiyagawa-3.pdf

AHEAD ENERGY 501(C)(3)

AHEAD Energy 501(c)(3)

PREMISE: ACCESS to energy is a key factor in economic development

- 1988 Not-for-profit formed at the University of Rochester

PHASE 1 Help Mozambique develop local natural gas infrastructure.

PHASE 2 Recent projects in Uganda, Mozambique, Kenya - renewable schools, orphanages, clinics:

- Photovoltaic
- Wind Turbine
- Bio-digester
- Small-Scale Hydroelectric

PHASE 3 (current):

Promote CLEAN FOSSIL TECHNOLOGIES:

- ***Consulting with governments, banks, energy companies, product developers***
- ***Third party testing and evaluation of new products***
- ***Participate in R&D projects with innovators, assist in demonstration/deployment***
- ***Assist clients in underserved areas with education, training and tech exchange***

Synergies between **CLEAN FOSSIL** and **RENEWABLES** in underserved areas

- **PREMISES:**
  - Renewable energy capacity should be deployed **where capacity is needed**.
  - In absence of a robust grid, back-up support must be **distributed generation**.
- **SOLUTION FOR OFF-GRID AREAS IN AFRICA:**
  - Modest use of **RENEWABLES**: WIND, SOLAR and BIOGAS, where it makes sense.
  - Mass deployment of **CLEAN FOSSIL fuels** and mass-produced **small engine generators**, **gas turbines** and **fuel cell systems**.
  - Mass deployment of **STORAGE** (advanced batteries and electronics, derived from automotive hybrids)
- **BENEFITS of the AHEAD ENERGY SOLUTION:**
  - AVOIDS Large Investments in Grid, Power Plants and Energy Storage
  - LEVERAGES Small Generators as a Virtual Power Plant supporting local needs of a SMART MICROGRID by filling the gaps in renewable supply.
  - HYBRID SOLUTION is low-cost, flexible, environmentally sound and sustainable!

Next Steps, for AHEAD

1. ***Identify academic and business nominees to expand AHEAD Energy's board***

2. ***Participate in government contracts, student projects and internships in related areas***

3. ***Website upgrades, webinars, presentations to governments, foundations, oil industry to promote AHEAD's Agenda***

4. ***Possible reconstitution of AHEAD as a for-profit company (with Outreach work folding into a private foundation)***

Summary

Fuel-based power systems will remain the dominant part of the global energy system for decades. AHEAD Energy seeks pragmatic, affordable solutions to climate change based on a CLEAN FOSSIL approach.

Renewables have a minor, complementary role. But renewables can't keep up with the accelerating global demand for grid based electricity.

Integration of CO2/EOR and the production of carbon-free ELECTRICITY, HYDROGEN and AMMONIA is a green and profitable way of using coal and stranded gas. This is viable AT SCALE today without subsidy in some locales. The business case will accelerate with any introduction of carbon taxes.

Internal Combustion Engines, Fuel Cells and Batteries are important (as enablers of high end-use efficiency and distributed generation).

AHEAD Energy seeks to work with local universities and innovative companies to put the required technologies into practice.

AHEAD ENERGY

QUESTIONS? COMMENTS?

AHEAD Energy's CLEAN FOSSIL Agenda
for Economic and Climate-Friendly
Energy Systems for the Next 50 years

http://www.aheadenergy.org

part-time office:
252 Alexander St., Rochester, NY 14607 USA
tel: +1 888-563-4432 fax: +1 585-461-5313

Thank you for your time and attention.

James Grieve, Chairman

mjgrieve@aheadenergy.org

QUESTIONS AND ANSWERS

AT RIT SEMINAR 2014-02-26

Q. How is Ammonia created, HABER BOSCH?

A. Yes, HABER BOSCH reacts nitrogen and hydrogen over a catalyst. It is a relatively efficient process, done worldwide at gigantic scale. Other methods are being researched, but HABER BOSCH is clearly the mature and well-known process. Nitrogen comes from air and is not a significant input cost.

Q. Availability of Ammonia, around the world?

A. Ammonia is already a global chemical, used as a fertilizer, industrial refrigerant and as a reagent in chemical processes. So it is already available worldwide. In some locations it is already cheaper than hydrocarbon-based fuels on an energy equivalent basis. This economic advantage likely improves further with scale.

Q. Is Ammonia a pollutant or environmental hazard?

A. Ammonia is lighter than air and small leaks will dissipate readily. It does form NOx (slowly) in the atmosphere but the storage infrastructure is hermetic, and releases to the environment will be extremely low. Ammonia is an inhalation hazard so any large leaks are locally dangerous. But the strong odor of low concentrations of ammonia makes it self alerting. Fire and explosion risks are much less than conventional fuels. Ammonia is likely the safest of alternative fuels with the lowest (near zero) pollution impact and risk.

Q. What are the combustion by-products of ammonia? Doesn't it form NOx?

A. NOx can be controlled to near zero levels. In an SOFC, NH3 is fully converted to N2. In an Internal Combustion Engine some NOx is produced, but actually not in very high concentrations – about the same as with gasoline combustion. Known techniques can be used to convert essentially all of this NOx to N2 in an exhaust catalyst. In a Gas Turbine, a special staged combustor is likely needed. Any NOx formed can also be controlled in an SCR catalyst. So emissions will be very low, essentially zero in all cases with known technology.

Q. What is the efficiency of making ammonia? Has life cycle assessment of production, transportation and usage been completed?

A. There are losses in producing ammonia, but, as described in Toyota Central R&D Lab's presentation, there are large advantages in making, shipping, storing and using ammonia compared to hydrogen. The fact that all of the process CO2 can be captured and that the value of the CO2 essentially fully offsets the cost of the input coal or stranded gas makes the approach very attractive economically. Ammonia is much easier to ship and store than natural gas, for example a given pipeline diameter can transport about 2X the energy as ammonia than as natural gas and the energy consumed will be marked less. So the delivered cost of energy from remote sources of natural gas (Alaska's North Slope) to distant markets (Japan, California etc.) is likely to be lower than natural gas, especially LNG. That said, life cycle analysis has not been done by AHEAD (or by others to our knowledge). It would be very useful, especially in identifying and verifying the benefits of specific projects for early adopters of ammonia as a fuel.

Q. What's the advantage of biofuels or other fuels (as indicated in some of AHEAD's proposed projects)?

A. Bio-methane also has a very low carbon intensiveness (and can sometimes be carbon negative). California's Low Carbon Fuel Standard process shows that biomethane is a particularly clean fuel source. Its limitation is that the supply is relatively limited. Like other bio-fuels it might be in the range of a 2% solution. But for an off-grid area in Africa for example on a farm, a biodigester is a way of dealing with waste water better and to make safe, organic fertilizer. So using in a biomethane/ammonia dual fuel hybrid system makes sense.

Q. Barriers to ammonia? Comparison of business case for ammonia vs. wind and solar?

A. There are no obvious barriers. Ammonia can be price competitive with diesel, propane and LNG as a fuel for electric power generation anywhere these fuels are used today. And it can be zero carbon. But the status quo is still the status quo and someone has to be motivated to invest to scale up the CLEAN FOSSIL solution. Because of the large extra costs associated with storage and back-up generation, it is hard to see how wind and solar are viable in mature markets with conventional electric grids. As Boone Pickens said, in many cases, "you can't make the numbers work". But certainly in remote/off-grid areas renewables are the best approach and the hybrid system, with some renewables, some storage and CLEAN FOSSIL back-up distributed generation using ICE or SOFC seems like the most flexible and cost effective approach.

Q. What are the production costs of making ammonia, compared other approaches to mitigate carbon emissions?

A. Using low cost coal or natural gas and CO2/EOR it appears that ammonia can be made at a very large scale at \$150/tonne (net of credits for the by-product CO2). This corresponds to about \$8/GJ. This is comparable with LNG when considering that the shipping and handling costs will be lower. Asian LNG is currently in the range of \$12 - \$15/GJ delivered. Propane is about \$15/GJ and diesel \$22/GJ at recent Gulf of Mexico prices.

The YARA link is useful in calculating the bulk cost of ammonia. The spot price is much higher than this currently, because of where ammonia is in its commodity cycle. But lots of new supply is coming to market in the next few years (and much more again in our CLEAN FOSSIL scenario)…

Conventional approaches to CO2 sequestration, where power plants are retrofitted to capture CO2 from the dilute exhaust and then the CO2 is purified, compressed and pipelined a long distance seem fundamentally more expensive than doing this at the wellhead.

Q. Compare costs per kW-h for ammonia based generation.

A. This will vary depending on logistics. As indicated above, it appears that ammonia is fully competitive with LNG, Propane and Diesel TODAY– so markets where these are used as power generation fuels are the obvious early adopters. Once there is a price on carbon, and once CO2/EOR is much more extensively used (providing a large and stable market for CO2), ammonia can gain share in larger power generation markets that use pipeline natural gas or coal as fuels. Using an off-grid example for Africa. Assuming a delivered cost of distributed ammonia at \$300/tonne (which corresponds to \$16.10 / GJ) and assuming 50% average efficiency in an SOFC/ICE hybrid distributed power system, the fuel cost of electricity for a remote area would be \$0.116/kW-h. This of course would be fully dispatchable and would hybridize well with wind/solar and batteries to supply reliable power for less than \$0.20/kW-h at a village scale. Looking further into the future, with CO2 tax of \$50/tonne natural gas powered utility power plants would incur an additional cost of about \$0.02/kW-h. Assuming \$200/tonne for bulk ammonia delivered, the fuel cost for a utility would be about \$0.077/kW-h. This would be about on par with LNG at \$8/GJ delivered.

Q. Aren't ammonia prices volatile?

A. The ammonia price is normally tightly correlated with natural gas. With high natural gas prices in the early 2000s in the USA, many ammonia plants were shut down and sold for scrap because it was cheaper to buy imported ammonia (from Trinidad, Canada, Eastern Europe and Russia). Recently, with much cheaper natural gas prices in the USA and with limited local capacity and high demand, the price has been abnormally high. This imbalance is likely to end soon, as many large scale ammonia plants are being built here. When ammonia is scaled up and available as a fuel, the price should be much more stable. Utilities will be able to switch to LNG or propane if those fuels are cheaper from time to time. In the CLEAN FOSSIL scenario, ammonia prices will be linked to COAL and STRANDED GAS. Coal is clearly going to be the cheapest fossil fuel input . One recent example of this is the HYDROGEN ENERGY CALIFORNIA project, which proposes to use coal and oxygen as inputs to make H2 and CO2. The H2 would be used to power a co-located power plant, to power PEM fuel cell cars, or as an input to a co-located ammonia plant. The CO2 would be used by Occidental Petroleum in their CO2/EOR operations. Thus the electricity, hydrogen and ammonia are essentially carbon free. This is all in Bakersfield (111 miles north of Los Angeles) and offers the prospect of dispatchable carbon-free electricity at a small fraction of the full cost of renewables and at parity with conventional power plants.

Q. For the proposed SOFC/ICE hybrid system, what is the ratio of the power capacity of the fuel cell vs. the engine?

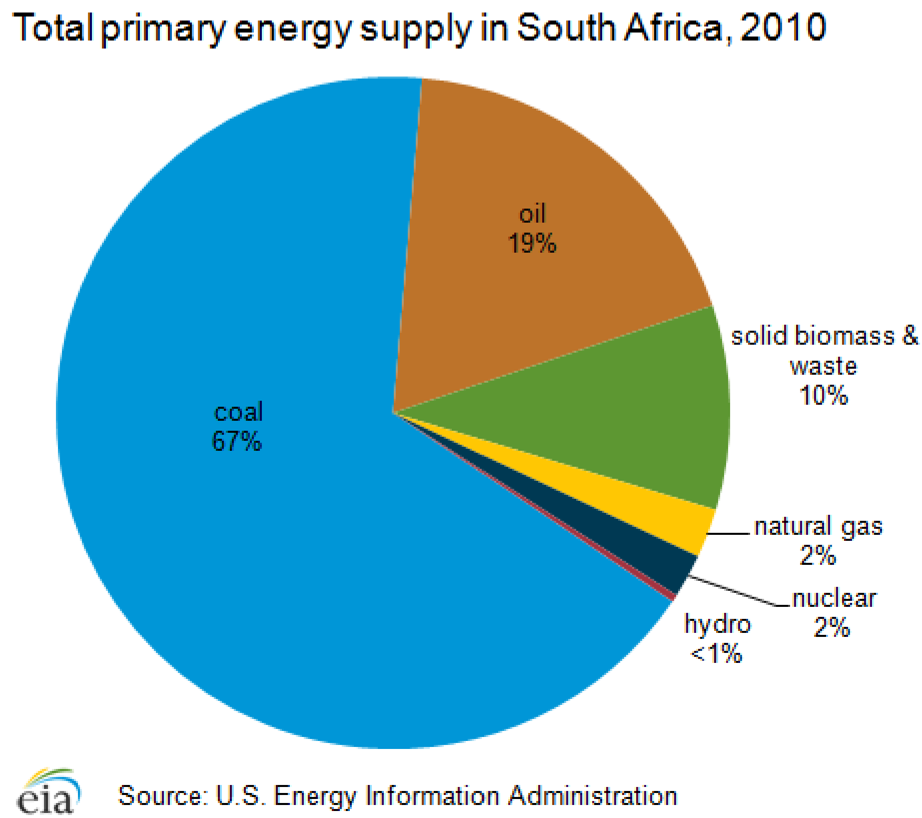
A. A range of ratios is possible. Typically the SOFC would be quite small, for example 5 kW with a 100 kW ICE. That's enough to provide the enhanced combustion and aftertreatment function to the ICE. With a larger SOFC, the peak and average efficiency gets higher, but the system costs more. So it's a trade-off.

Q. Summarize why you see ammonia as a better choice than LNG?

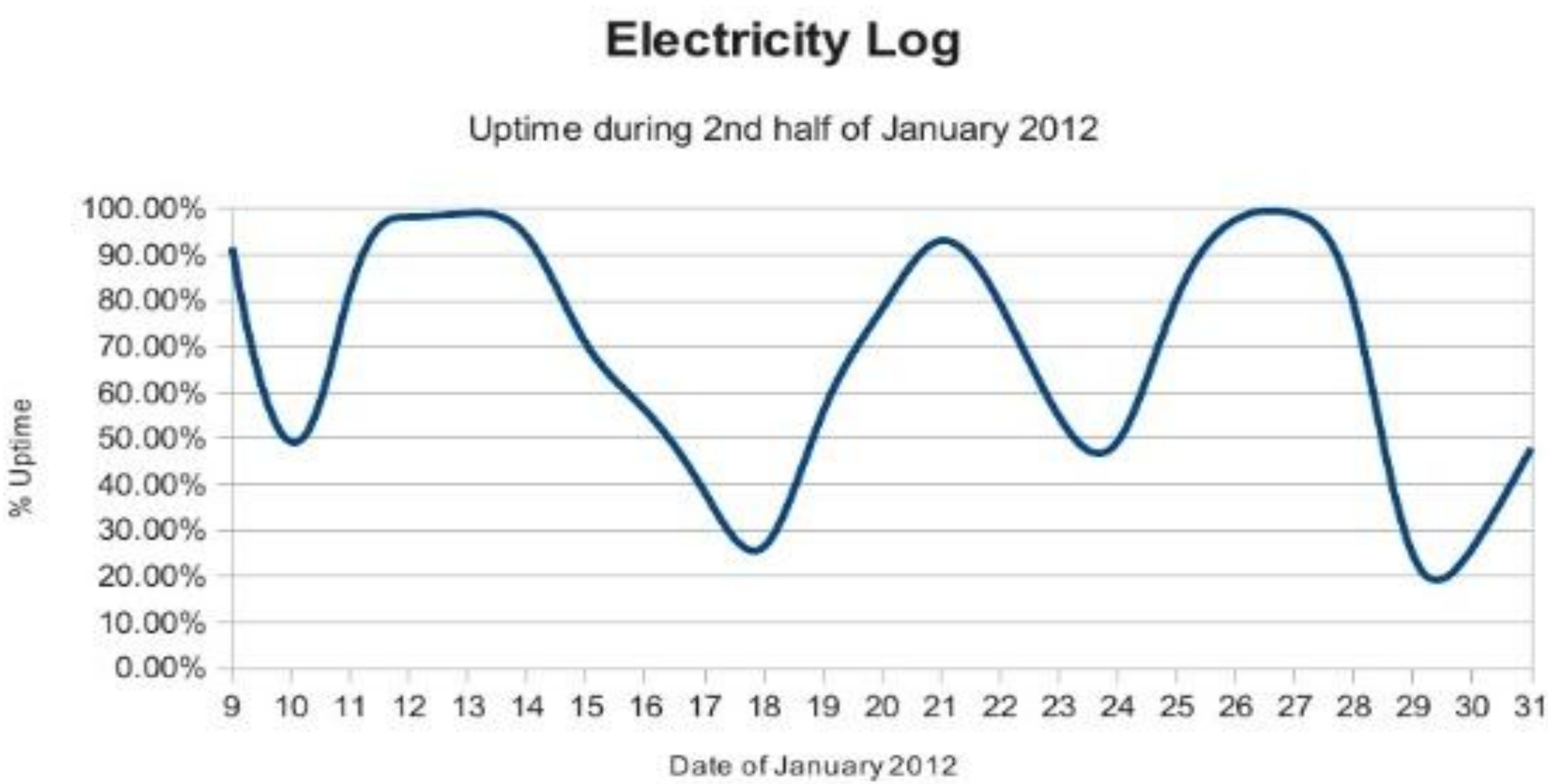
LNG	*Ammonia*
(1) CO2 intensive (similar W2W CO2 emissions as diesel fuel)	*CO2-free (using CO2/EOR, nuclear, spilled wind etc.)*
(2) fundamentally expensive (based on infrastructure)	*sustainably low cost (linked to coal or stranded gas)*
(3) potentially very UNSAFE	*VERY SAFE if handled with care (no catastrophic risk)*

SUPPLEMENTAL SLIDES

AHEAD Energy:
Why Green Energy for Africa?



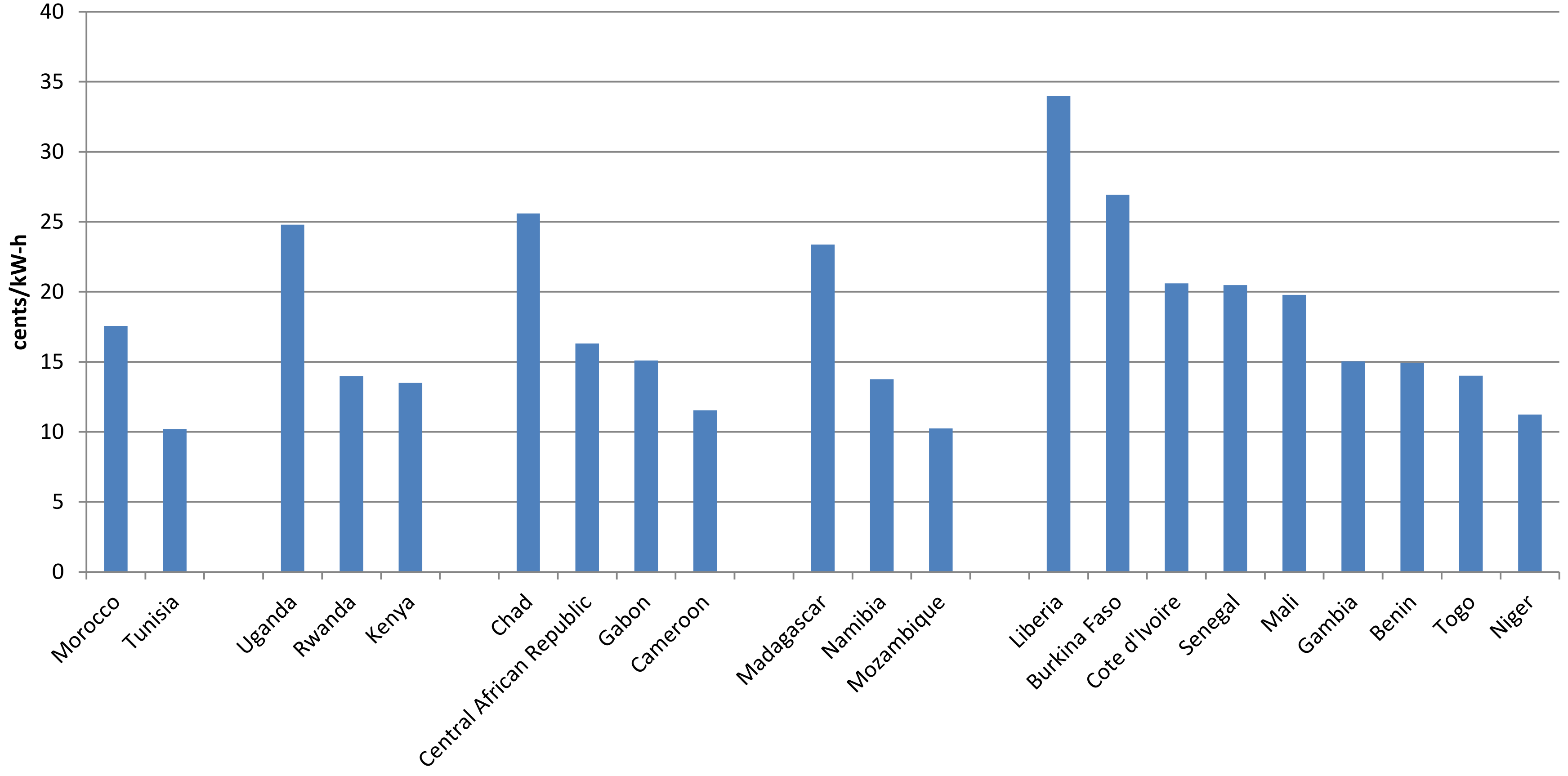
AHEAD Energy:
Why Green Energy for Africa?



Power disruption curve in Tanzania, East Africa 2012.

AHEAD Energy:
Why Green Energy for Africa?

- **Retail cost of electricity is PROHIBITIVE in many parts of AFRICA [8]**



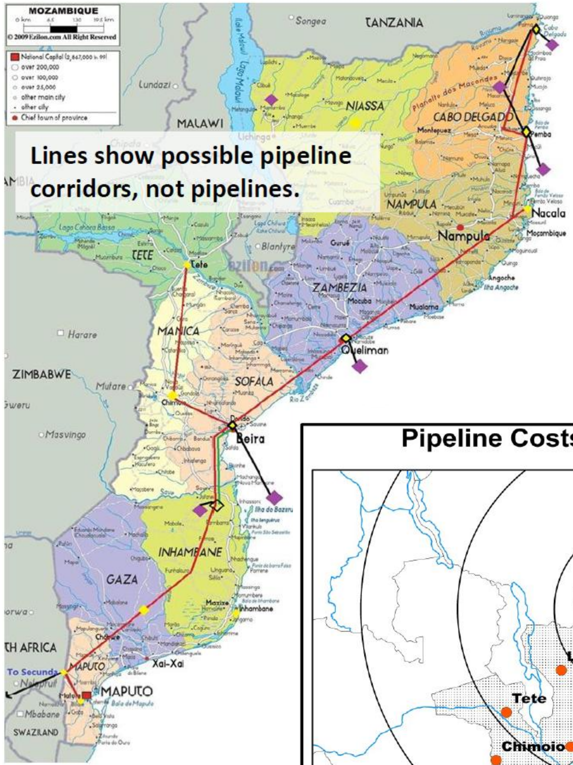
[8] Source: UPDEA, Comparative Study of Electricity Tariffs Used in Africa, Residential rates, 4 kW single phase, December 2009

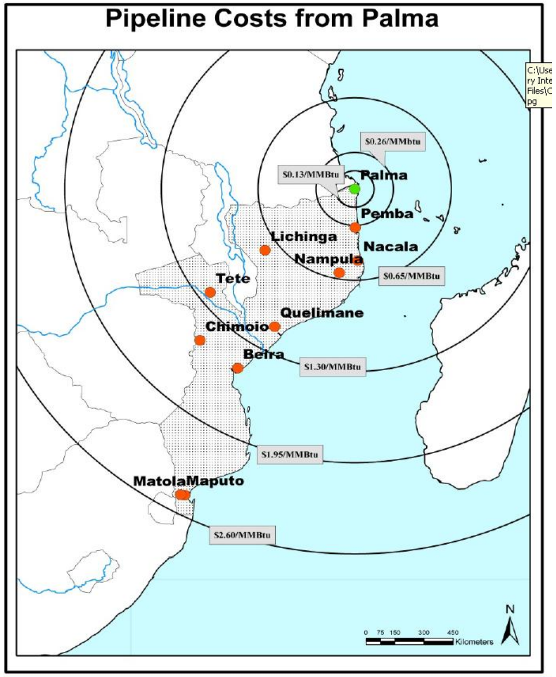
Underserved Example: Mozambique

- POTENTIAL: Natural Gas and Coal bonanza, plus wind, solar, hydroelectric.
- EXPLORATION: Major off-shore gas discovery in Palma, in far north
- COMMERCE: Capital (Maputo) and local export market (South Africa), in far south
- ENERGY: Limited Electric Grid, very limited natural gas distribution.

- Roads and Port Facilities, **CLEAN FOSSIL** production plants, and **Distributed Generation with Renewables** may be a better development plan than export LNG and domestic pipeline infrastructure.

- More than 1500 miles from Palma to Maputo





End of Presentation