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NanoScience Exchange

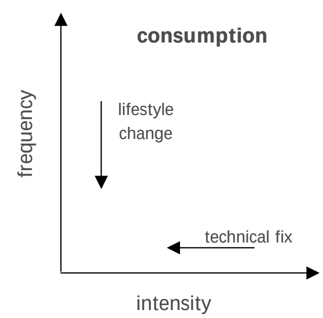
Energy Technologies to Reduce Dependence on Foreign Oil

October 11, 2004

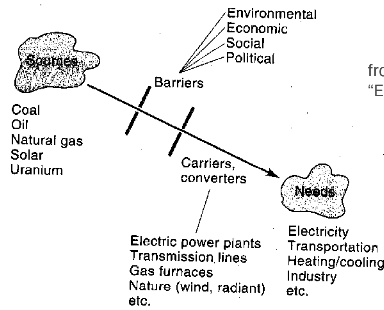
making fuel cells viable

Energy

- Two parts of the overall energy landscape
  - Generation
    - driven by available resources & technology
  - Consumption
    - driven by available technology & societal needs
    - energy delivery, end usage
    - end usage = energy intensity * frequency



- Pathways to energy independence:
  - Fuel independence
  - Increased generating efficiency
  - Lower consumption



from Hinrichs & Kleinbach
"Energy – Its Use and the
Environment" 2002

Energy Efficiencies

- Improvements in consumption can make a large difference

Table 3.5 ENERGY CONVERSION EFFICIENCIES

Efficiency for a process is the product of the efficiencies for the individual steps.
Example of lighting:

Process	Efficiency of Step	Overall Efficiency
Production of coal	96%	96%
Transportation of coal	97%	93%
Generation of electricity	33%	31%
Transmission of electricity	85%	26%
Lighting		
Incandescent bulb	5%	1.3%
Fluorescent bulb	20%	5.2%

from Hinrichs & Kleinbach "Energy – Its Use and the Environment" 2002

Energy Generation

- In addition to technical & market challenges, financial barriers face new approaches to energy generation.
- Mature
  - Fossil fuel fired steam plant
  - Low technical risk
    - High debt/equity ratio possible. Low cost of debt.
  - Economies of scale reduce capital cost
  - Low labor cost during operation
  - High fuel cost
    - typically subsidized (direct, indirect)
- Immature
  - PV, Wind, fuel cell, other solar
  - High technical risk
    - Low debt/equity ratio is reality. Much higher cost of equity, higher cost of debt.
  - High capital cost
  - Higher labor cost during operation
  - Low or no fuel cost

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Fuel Independence & The Environment

Table 14.6 ANNUAL ENVIRONMENTAL IMPACTS ASSOCIATED WITH A 1000-MWe POWER PLANT*

Impact	Coal	Nuclear (LWR)
Land use (acres)	17,000	1900
Water discharges (tons)	40,000	21,000
CO_2 emissions (tons)	6×10^6	0
Air emissions (tons)	380,000	6200
Radioactive emissions (curies)	1	28,000
Occupational Health		
Deaths	0.5–5	0.1–1
Injuries	50	9
Total fatalities (public and worker)	2–100	0.1–1

*Includes extraction, processing, transportation, and conversion. Strip-mined coal. (WASH-1250 and *Ann. Nuclear Energy*, 13, 173, 1986)

- Three barriers to wide-spread nuclear energy generation
  - Nuclear waste (transport to waste storage vs. storage method)
  - High construction cost
  - Not viable for distributed generation

Distributed Generation

- Large, central generation is present method
  - Large capacity (100 MW+)
  - Capital cost recuperation only when begin generating
    - Accurate forecasting is critical
    - "Negawatts" can be viable
- Distributed generation is generating power on-site
  - Home
  - Office, hospital
  - Plant
  - Campus
- Advantages
  - Increased efficiency
  - Pay as you go, CHP, etc.
  - Homeland security
    - Fuel network is more redundant & robust than electrical grid
- Requires low cost (< $1000/kW installed), efficient, and clean (NIMBY issue) generating technologies

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Fuel Cells

- Direct conversion of chemical energy to electrical energy
- Very modular – high efficiencies at sub-kW level through MW
- Fuel cells are not dependent on the Hydrogen Economy
  - "fuel cell" ≠ PEMFC
  - PEMFC require very pure H2 feed stream
    - Low electrical efficiency
- High temperature fuel cells can run off fossil fuels
  - MCFC and SOFC
  - Direct or indirect reforming to H2 & CO containing feed streams
  - High electrical efficiency
  - Very high cogeneration efficiency
  - Most viable pathway to fuel cell commercialization
    - For present, utilize existing fuel infrastructure with higher efficiency
    - In future, use hydrogen infrastructure with higher efficiency
      - remember, H_2 is a greenhouse gas
- Current barriers to SOFC commercialization are high cost and low durability

Kainos Energy
At A Glance

The Company:
- **Kainos Energy Corporation** is a subsidiary of NanoGram Corporation.

History:

NanoGram Corporation

NeoPhotonics — Raised > $42M, March 2004

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NanoGram Devices Corp. — Founded Jan 2003. Purchased by WGB Tech. $45M (cash), March 2004

Technology Status:
- Over **6 years** development of core process and equipment
- Over **$65 Million** invested

IP & License:
- Kainos has access to NanoGram's large and growing patent portfolio
  - greater than 100 patent applications
  - currently 33 allowed or issued, protected globally
- KEC has exclusive Field of Use Rights for fuel cell commercialization.

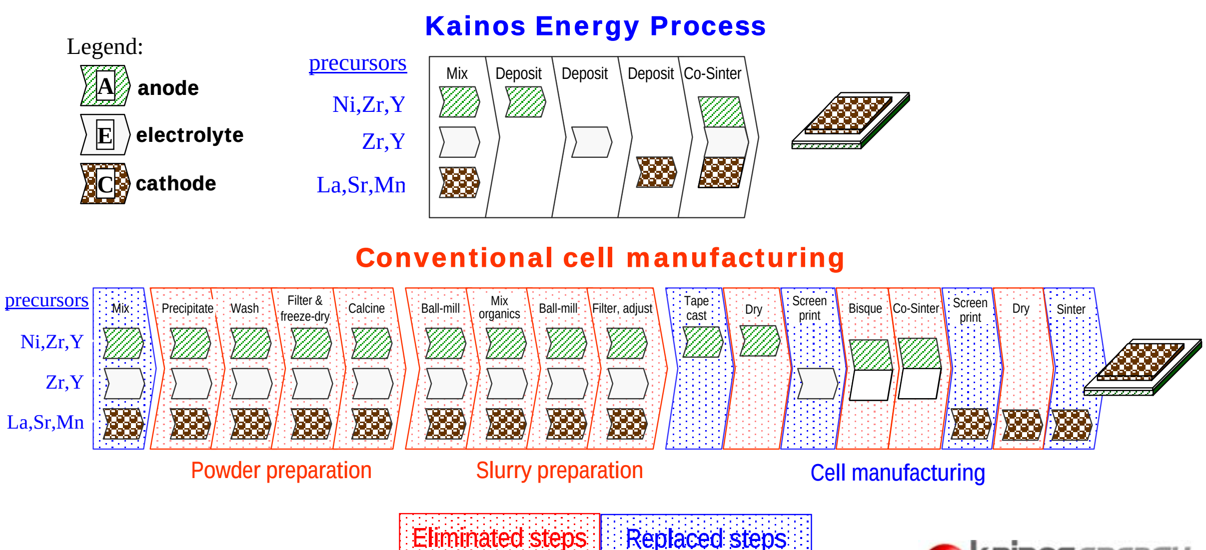
Kainos Energy
At A Glance

Ownership/ Investors:
- NanoGram and Kainos Energy are privately held. Investors include:

Staff & Facilities:
- Experienced core team, plus incubation support from NanoGram Corp.

LRD™-based SOFC Manufacturing

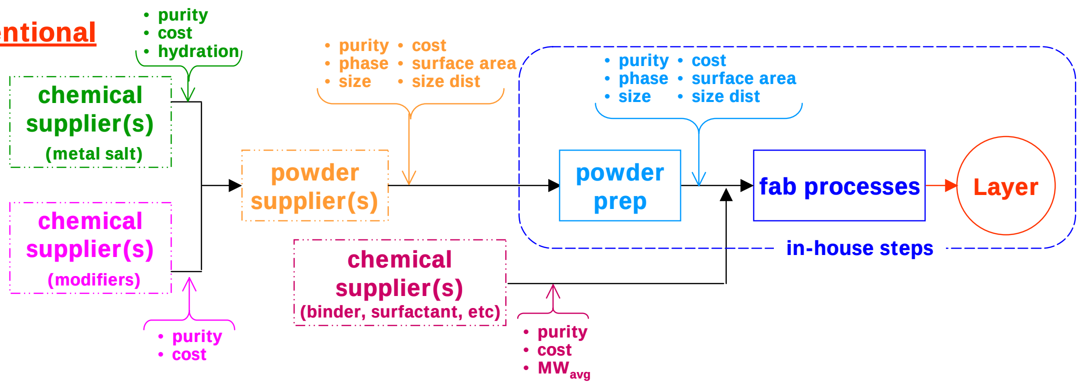
- Direct Conversion™ technology simplifies cell development and manufacturing
  - Eliminates 66% of the unit operations and 50% of the equipment
  - Dramatically lower cycle time, improved scalability
- Extendable to interconnects, seals



LRD™ Technology Simplifies SOFC Mfg

- Ability of LRD™ to directly convert chemical precursors to fuel cell structures simplifies supply chain & reduces process input variables.

Conventional



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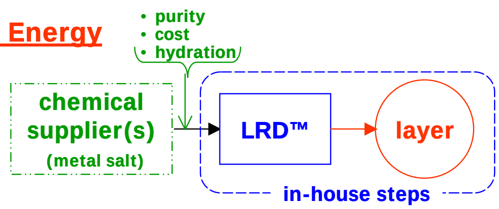

- eliminates 75% of supply chain
- eliminates 80% of process input variables
  - drastically simplifies QC
- composition agnostic
  - more easily accommodates new materials
- **facilitates transition from development to manufacturing**

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Nanoscale Material Benefits to SOFC

- Nanomaterials can have two major effects on SOFCs
  - higher performance (W/cm^2, fuel utilization)
  - lower processing temperatures
- Higher performance
  - Source: Increased reaction area
  - Impact(s):
    - Lower system cost
    - Higher reliability
    - Lower operating cost
- Lower processing temperature
  - Source: Nano-effect on sinterability
  - Impact(s):
    - Lower manufacturing cost
    - Higher reliability
    - Lower operating cost
    - Faster start-up

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Nano Enhanced Performance

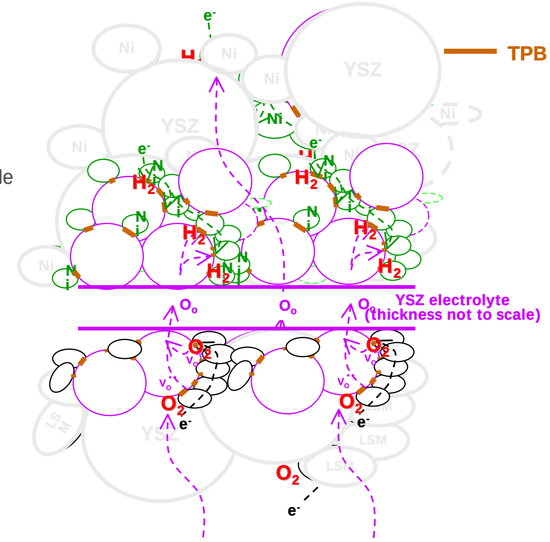
- SOFC Reactions take place at electrode's triple-phase boundary (TPB)
  - Reaction at SOFC anode:
    - $H_{2(g)} + O_{O,YSZ} \Leftrightarrow H_2O_{(g)} + V^{\bullet\bullet}_{O,YSZ} + 2e^-_{Ni}$
    - TPB is intersection of pore, YSZ particle, & Ni particle
  - Reaction at SOFC cathode:
    - $O_{2(g)} + 4e^-_{LSM} + 2V^{\bullet\bullet}_{O,YSZ} \Leftrightarrow 2O_{O,YSZ}$
    - TPB is intersection of pore, YSZ particle, & LSM particle
- Greater TPB area translates to higher electrode performance
- Nano enables higher performance electrodes

  $\Downarrow$ particle size $\Rightarrow$ $\Uparrow$ surface area

  $\Uparrow$ surface area $\Rightarrow$ $\Uparrow$ interfacial area

  $\Uparrow$ interfacial area $\Rightarrow$ $\Uparrow$ TPB

  $\Uparrow$ TPB $\Rightarrow$ $\Uparrow$ voltage efficiency
- Current barriers to nanoscale SOFC materials
  - stability at high operating temperatures (650 to 800^{o}C)
  - difficult to incorporate into tape-based processes
  - high added cost of powder and cell processing



Technology Benefits and Impact

KEC technology

Low Development and Manufacturing Cost

nano-enabled benefits:
- lower processing temperatures

nano-independent benefits:
- shorter development cycles
- direct scale-up
- drastically reduced mfg. steps
- "green" manufacturing

High Performance Components

nano-enhanced benefits:
- high efficiency cells
- increased electrode functionality
- improved durability

nano-independent benefits:
- high utilization cells

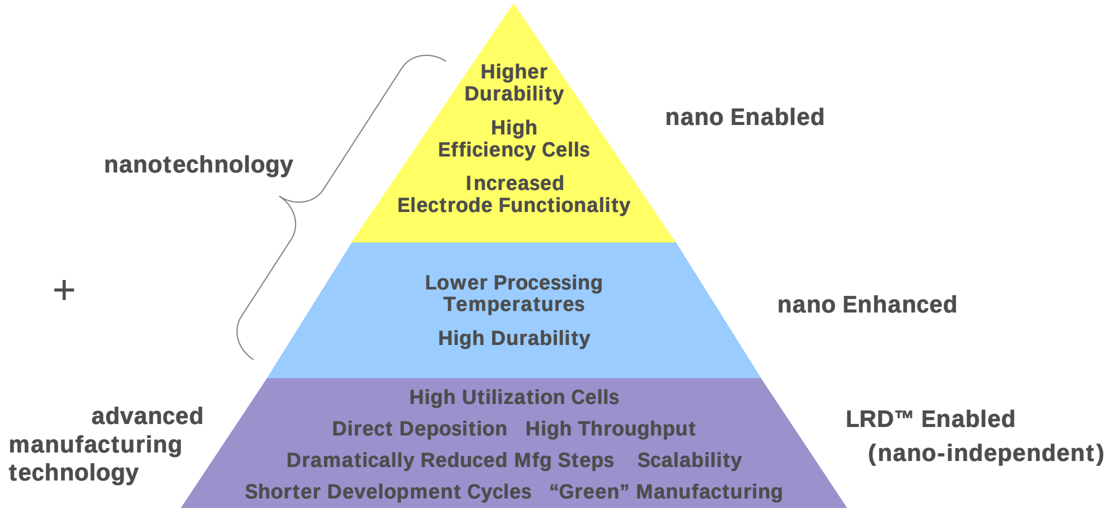
Lower Stack Cost
- reduced component mfg cost
- higher power density

Lower BOP Cost, Higher System Durability
- simplified system (eliminate/reduce de-S & reformer)
- reduced operating temp (smaller recuperator & blower)

Mass commercialization of low cost, high performance fuel cell components and stacks

KEC Technology's Unique and Comprehensive Benefits

...combine to provide low cost and high performance stacks.



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