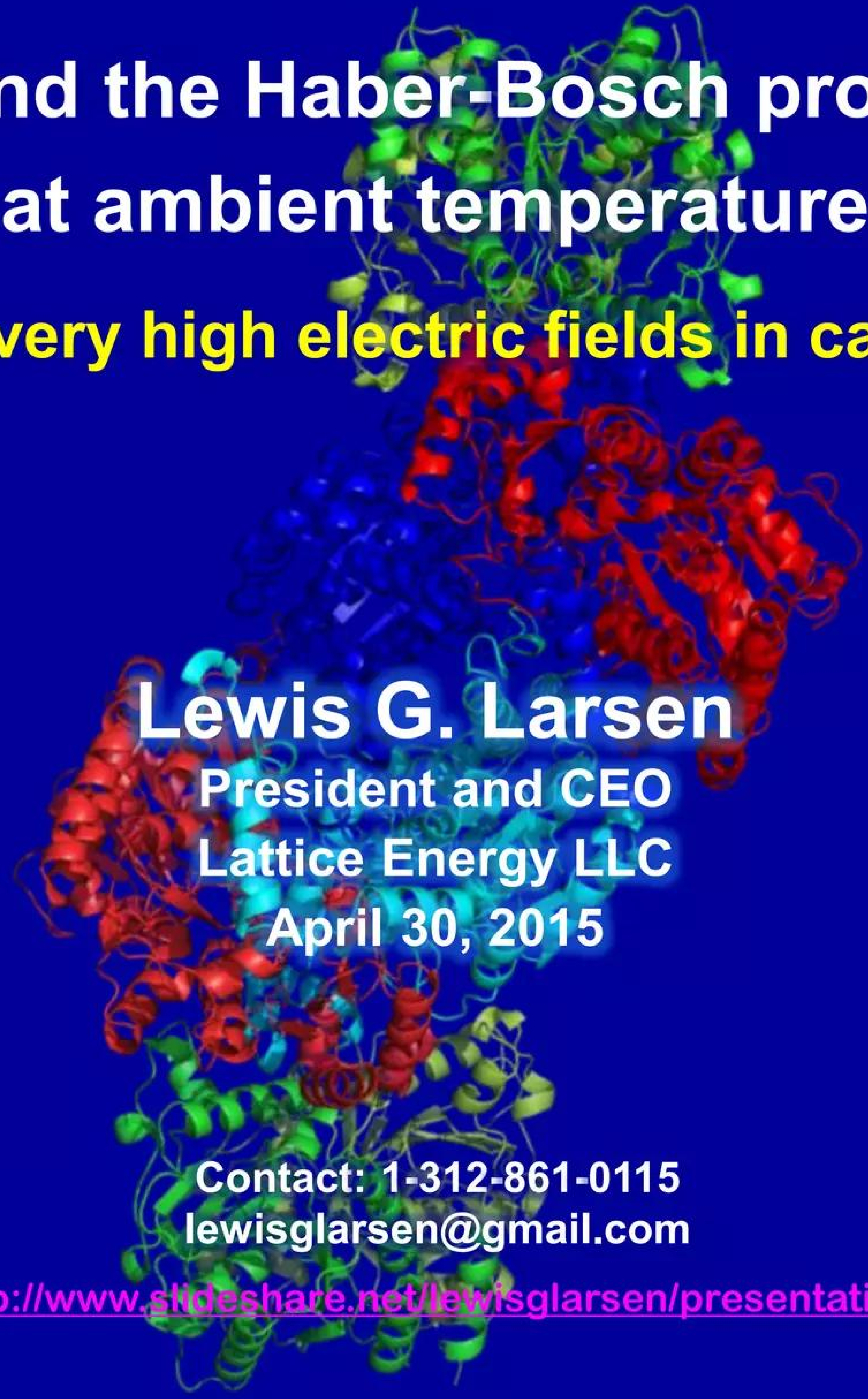
Lattice Energy LLC

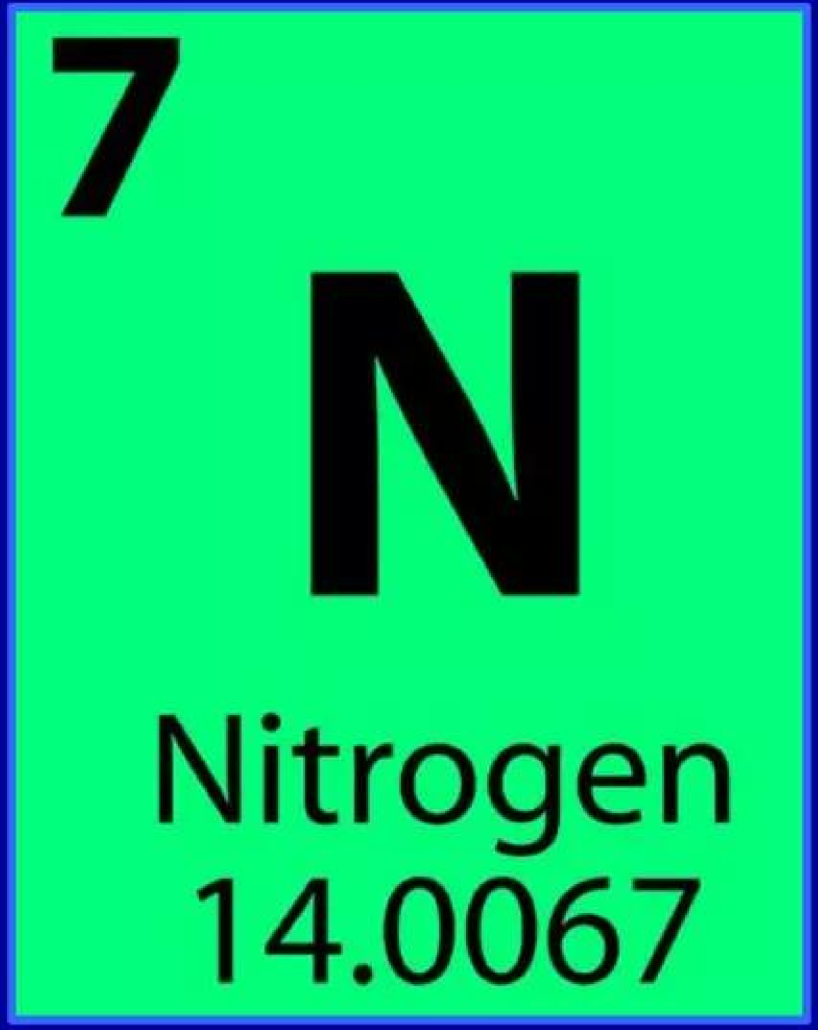
Commercializing a next-generation source of green nuclear energy

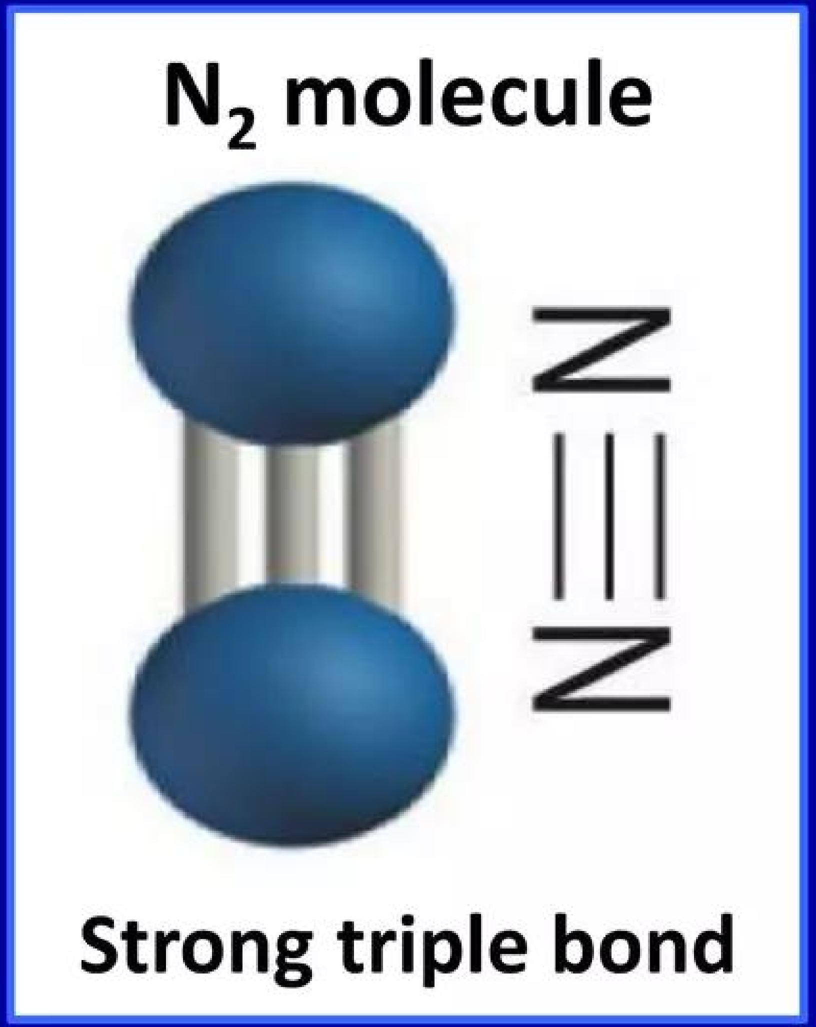
Beyond the Haber-Bosch process: Fixing Nitrogen at ambient temperatures and pressures

Create and modulate very high electric fields in catalytically active sites



"Nitrogenase" by Jsjjsjjs - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons





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April 30, 2015

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http://www.slideshare.net/lewisglarsen/presentations

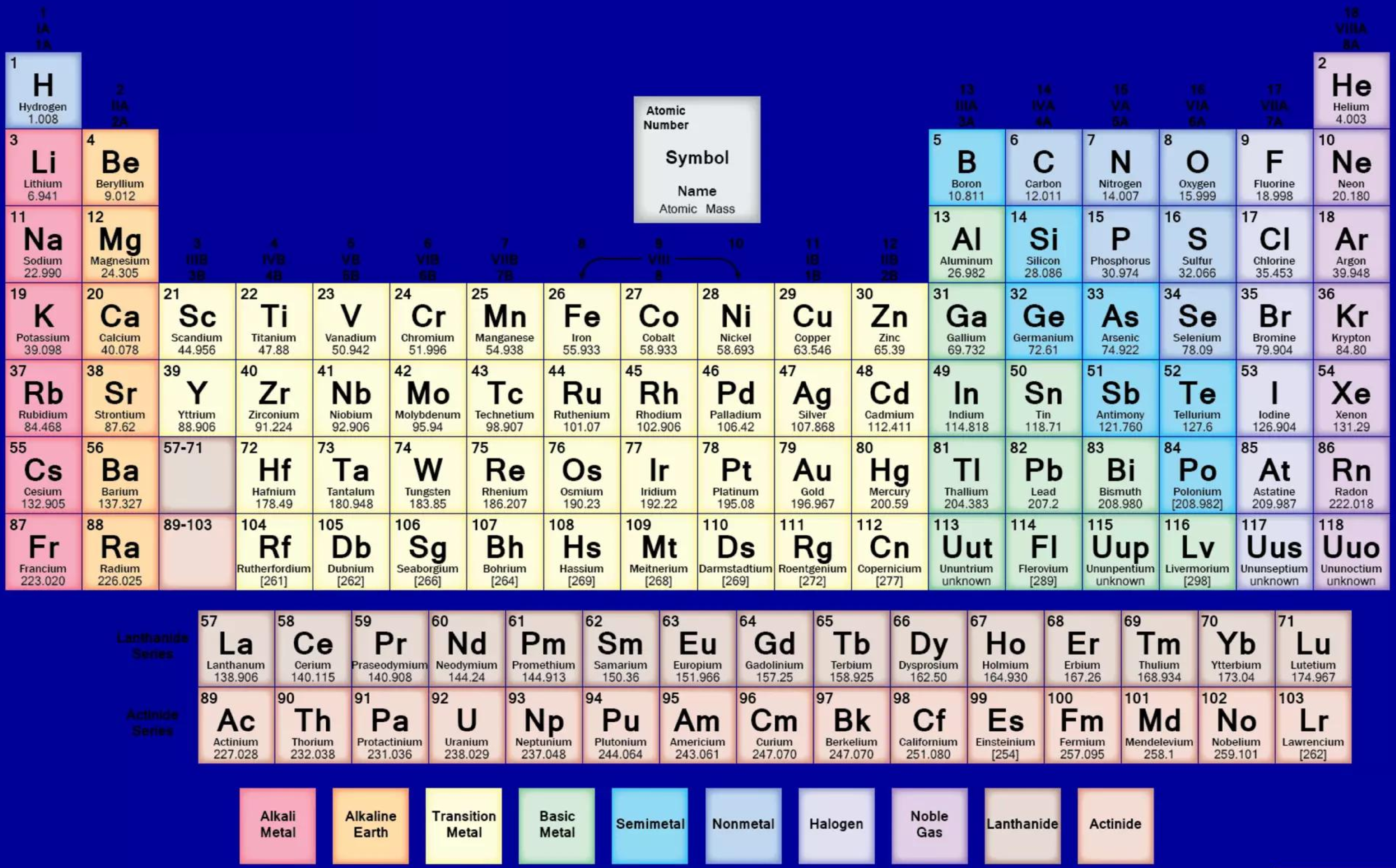
Summary

Opportunity: distributed small-scale production of low cost ammonia

- ✓ High-temp, high-pressure Haber-Bosch process has dominated commercial production of anhydrous ammonia for over 100 years; its cost is closely tied to economics of available supplies of input natural gas that are slowly dwindling
- ✓ Haber-Bosch is arguably single most important industrial chemical process on Earth; 40% of world's people are alive today thanks to reasonable cost and wide availability of ammonia-based fertilizers. Plants have become quite large
- ✓ Recent advances in advanced materials science, nanotechnology, chemistry, enzymology, and many-body collective condensed matter physics have just created a new opportunity to develop commercial Nitrogen fixation processes that can operate at near-ambient temperatures and pressures and utilize natural gas, or alternatively water, as a source of Hydrogen to react with N
- ✓ Based on its LENR work, Lattice has developed a unique body of valuable proprietary insights into catalysis that directly applies to this opportunity
- ✓ Successful development of new lower-cost Nitrogen fixation technologies that go far beyond the 1909 Haber-Bosch process could: sever the present almost obligatory linkage between natural gas supplies and ammonia production; further reduce manufacturing costs (high temps and pressures unnecessary); and enable development of new types of smaller, lower-CAPEX commercial ammonia plants that are cost-effective for worldwide distributed production

Contents

Periodic Table of the elements



Atomic Number
Symbol
Name
Atomic Mass

1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.933	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.732	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.09	35 Br Bromine 79.904	36 Kr Krypton 84.80
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown

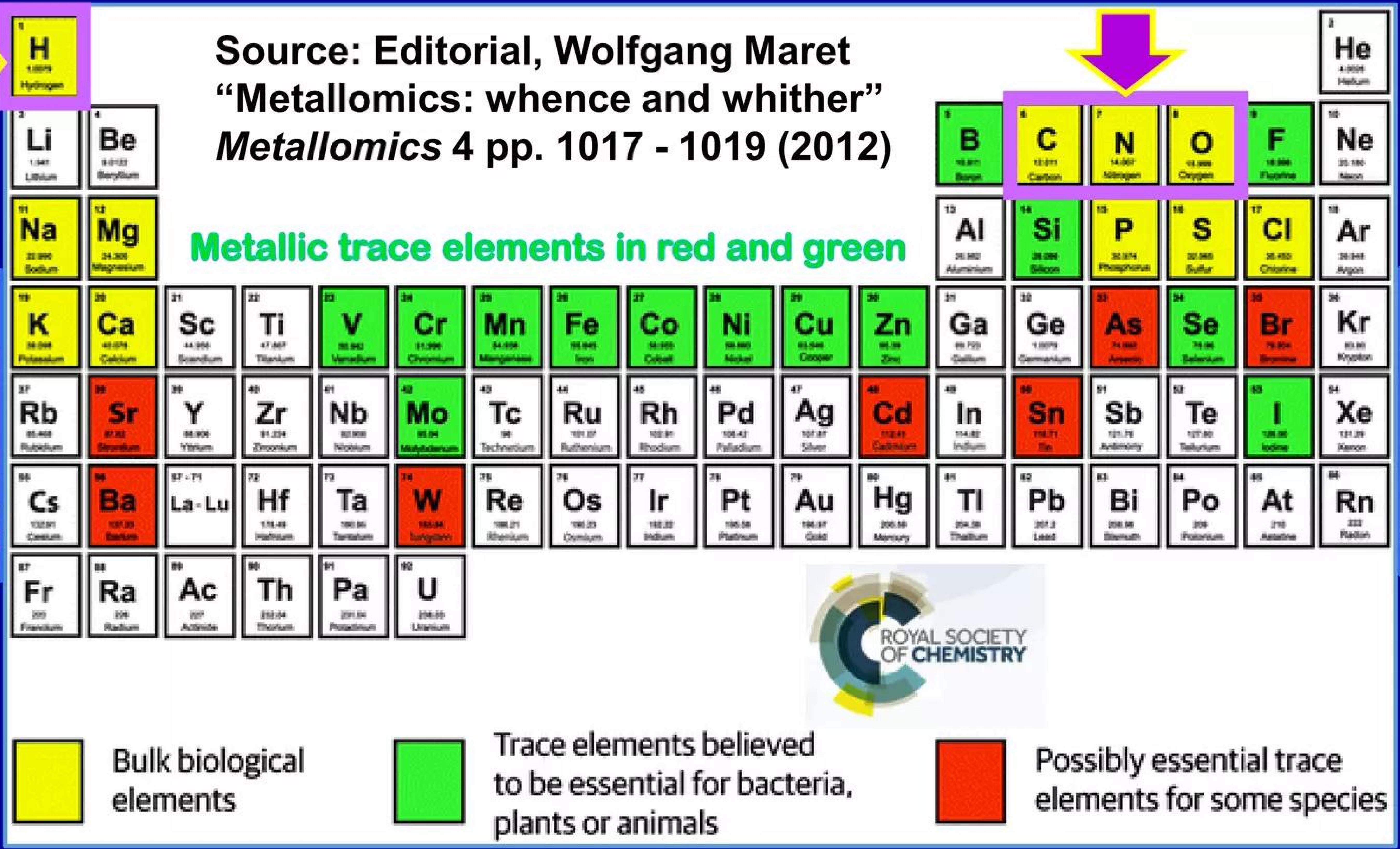
Lanthanide Series	57 La Lanthanum 138.906	58 Ce Cerium 140.115	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.966	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.26	69 Tm Thulium 168.934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
Actinide Series	89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

Alkali Metal
Alkaline Earth
Transition Metal
Basic Metal
Semimetal
Nonmetal
Halogen
Noble Gas
Lanthanide
Actinide

Living systems use subset of elements in Periodic Table

O (~65%), C (~19%), H (~10), N (~3%) comprise ~97% of total biomass

Metallic trace elements commonly serve as cofactors in active sites of enzymes



Source: Editorial, Wolfgang Maret
“Metallomics: whence and whither”
Metallomics 4 pp. 1017 - 1019 (2012)

Metallic trace elements in red and green

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
🟨 H																	He
Li	Be											🟩 B	🟨 C	🟨 N	🟨 O	🟩 F	Ne
🟨 Na	🟨 Mg											Al	🟩 Si	🟨 P	🟨 S	🟨 Cl	Ar
🟨 K	🟨 Ca	Sc	Ti	🟩 V	🟩 Cr	🟩 Mn	🟩 Fe	🟩 Co	🟩 Ni	🟩 Cu	🟩 Zn	Ga	Ge	🟥 As	🟩 Se	🟥 Br	Kr
Rb	🟥 Sr	Y	Zr	Nb	🟩 Mo	Tc	Ru	Rh	Pd	Ag	🟥 Cd	In	🟥 Sn	Sb	Te	🟩 I	Xe
Cs	🟥 Ba	La - Lu	Hf	Ta	🟥 W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Th	Pa	U												

🟨 Bulk biological elements

🟩 Trace elements believed to be essential for bacteria, plants or animals

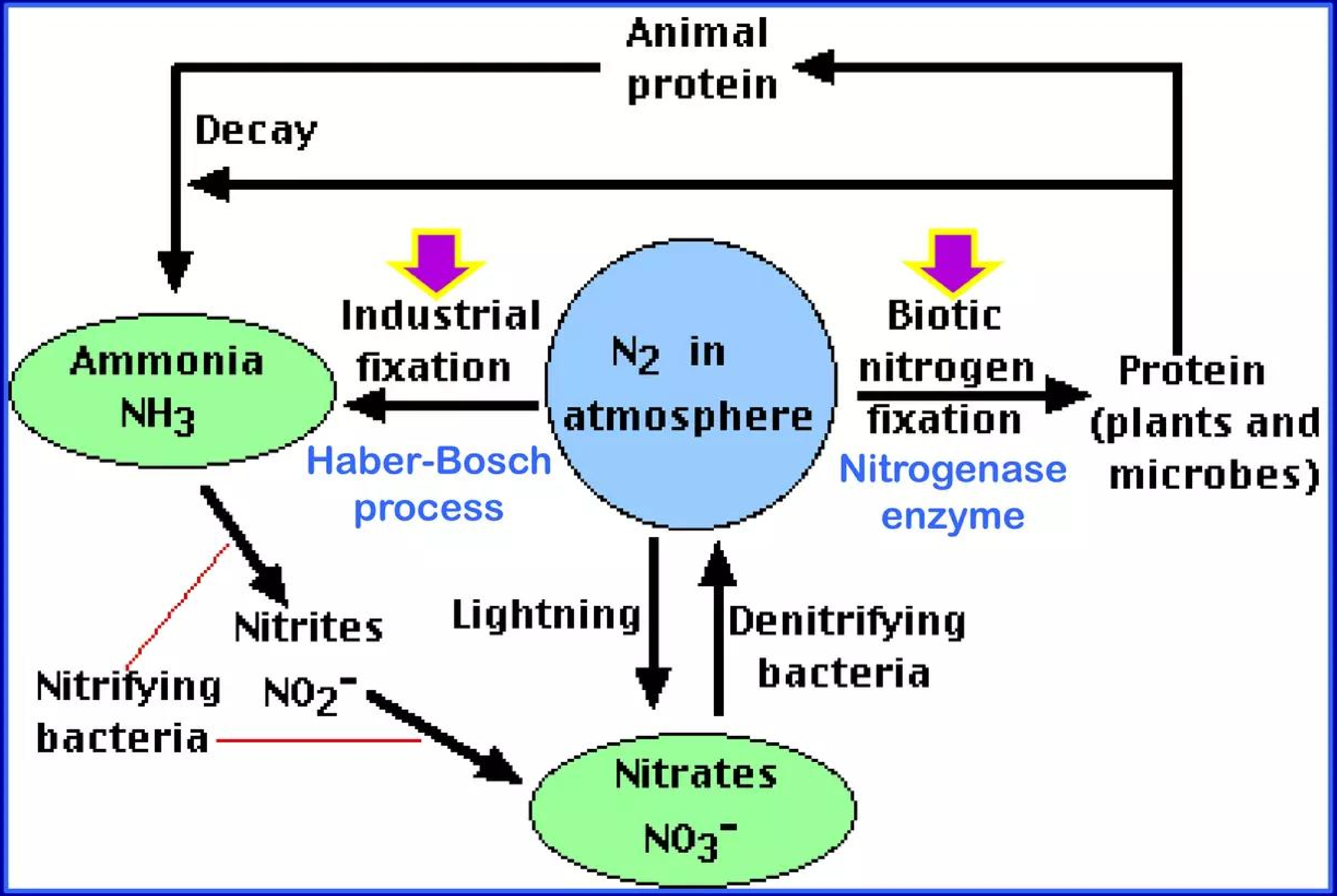
🟥 Possibly essential trace elements for some species

http://pubs.rsc.org/en/content/articlelanding/2012/mt/c2mt90041f/unauth#!divAbstract

Global elemental Nitrogen cycles between various reservoirs

Gaseous atmospheric Nitrogen (N_2) molecule has strong triple bond

Triple bond must be broken (fixed) to make Nitrogen chemically reactive



Adapted from source: http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/N/NitrogenCycle.html

Haber-Bosch process preeminently used to fix Nitrogen

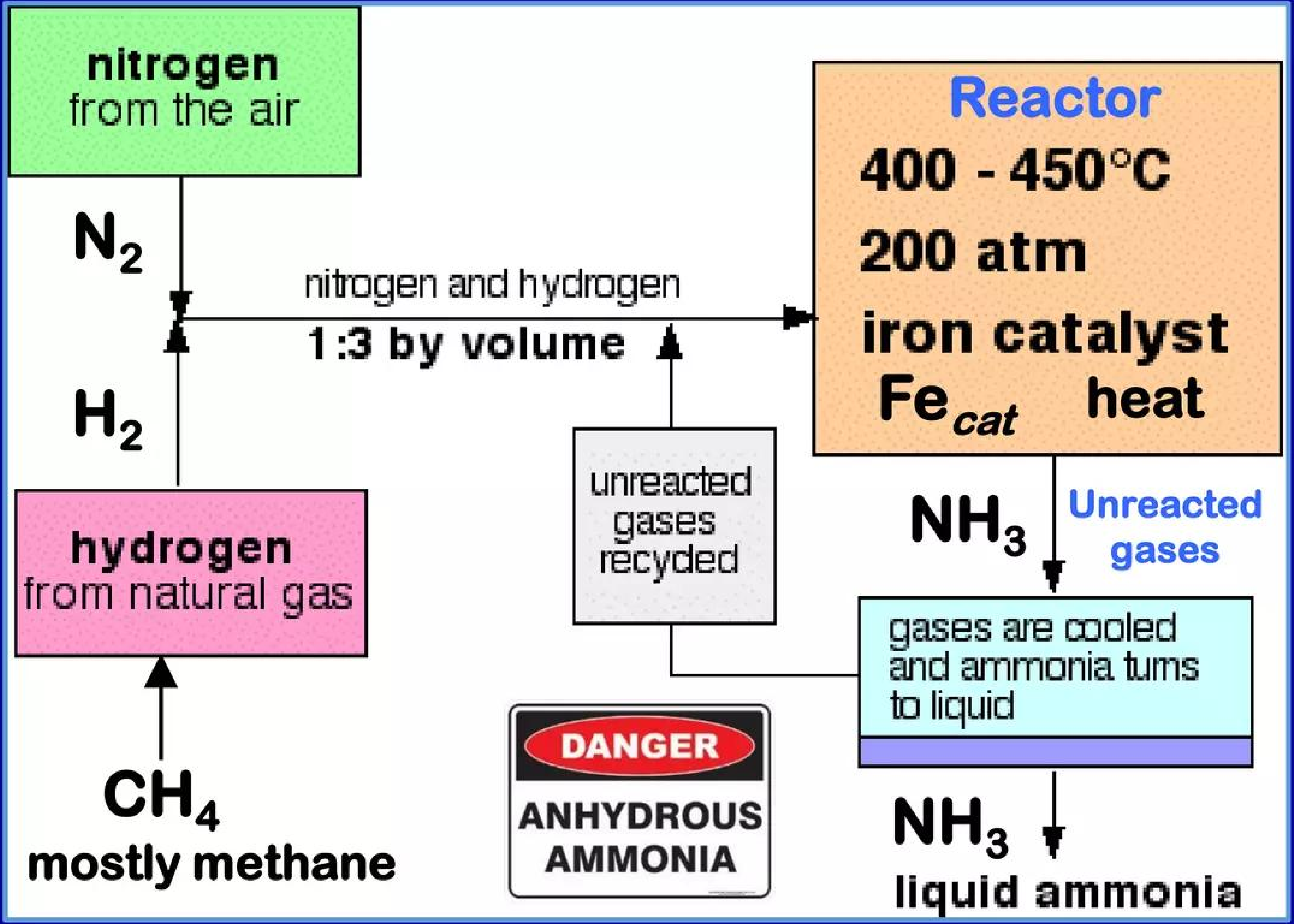
Invented in Germany in 1909 and dominated global market ever since

Nitrogen and Hydrogen are reacted with a Fe catalyst to make usable ammonia

Chemical reaction

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)} \quad \Delta H = -92\ \mathrm{kJ\ mol^{-1}}$$

Fritz Haber



nitrogen
from the air

N_2

nitrogen and hydrogen
1:3 by volume

H_2

hydrogen
from natural gas

CH_4
mostly methane

Reactor
400 - 450°C
200 atm
iron catalyst
Fe_{cat} heat

unreacted gases recycled

NH_3

Unreacted gases

gases are cooled and ammonia turns to liquid

DANGER
ANHYDROUS AMMONIA

NH_3
liquid ammonia

Carl Bosch

Adapted from source: http://www.chemguide.co.uk/physical/equilibria/haber.html

Largest Haber-Bosch ammonia-urea plant in the world

"Enven" facility owned by Engro Corp. and located in Daharki, Pakistan

Cost = US$ 1.1 billion; commissioned in 2010

Production capacity = 1.3 million metric tons/yr. or ~ 3,500 mt/day

Plant's inputs are Hydrogen (from natural gas), Nitrogen (extracted from air), and lots of energy

Nitrogenase is the only enzyme in Nature that can fix N_2

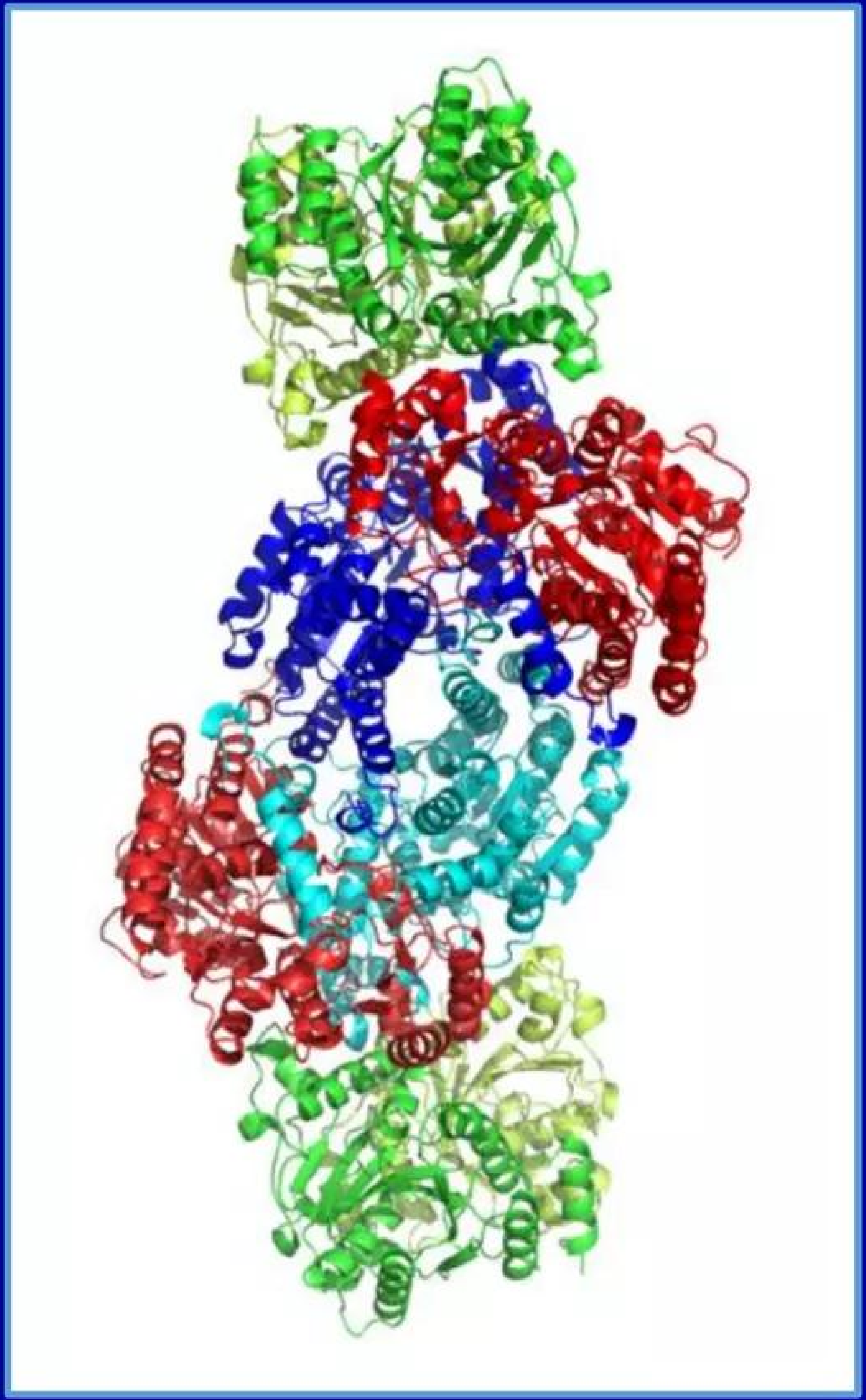
Converts triple bonded Nitrogen molecule into chemically usable NH_3

Biological version of the Haber-Bosch process operates at low temps/pressures

$$\mathrm{N_2 + 8\,H^+ + 8\,e^- + 16\,ATP \longrightarrow 2\,NH_3 + H_2 + 16\,ADP + 16\,P_i}$$

- ✓ Only family of enzymes in Nature able to break (fix) strong N_2 triple bond to make usable ammonia (NH_3)
- ✓ Higher organisms can't do this; this enzyme found only in green sulfur bacteria, azotobacteria, and symbiotic diazotrophs that --- among other things --- live in association with roots and nodules in plants (soybeans for example); diverse diazotroph group includes Rhizobia, Frankias, and cyanobacteria
- ✓ Molybdenum (Mo) cation in active site is critical to catalysis; less proficient variants of this enzyme substitute Vanadium (V) or Iron (Fe) for Mo in site
- ✓ General consensus amongst researchers that key details of catalytic process in enzyme's active site are still poorly understood; FeMo cofactor is crucial

Nitrogenase structure



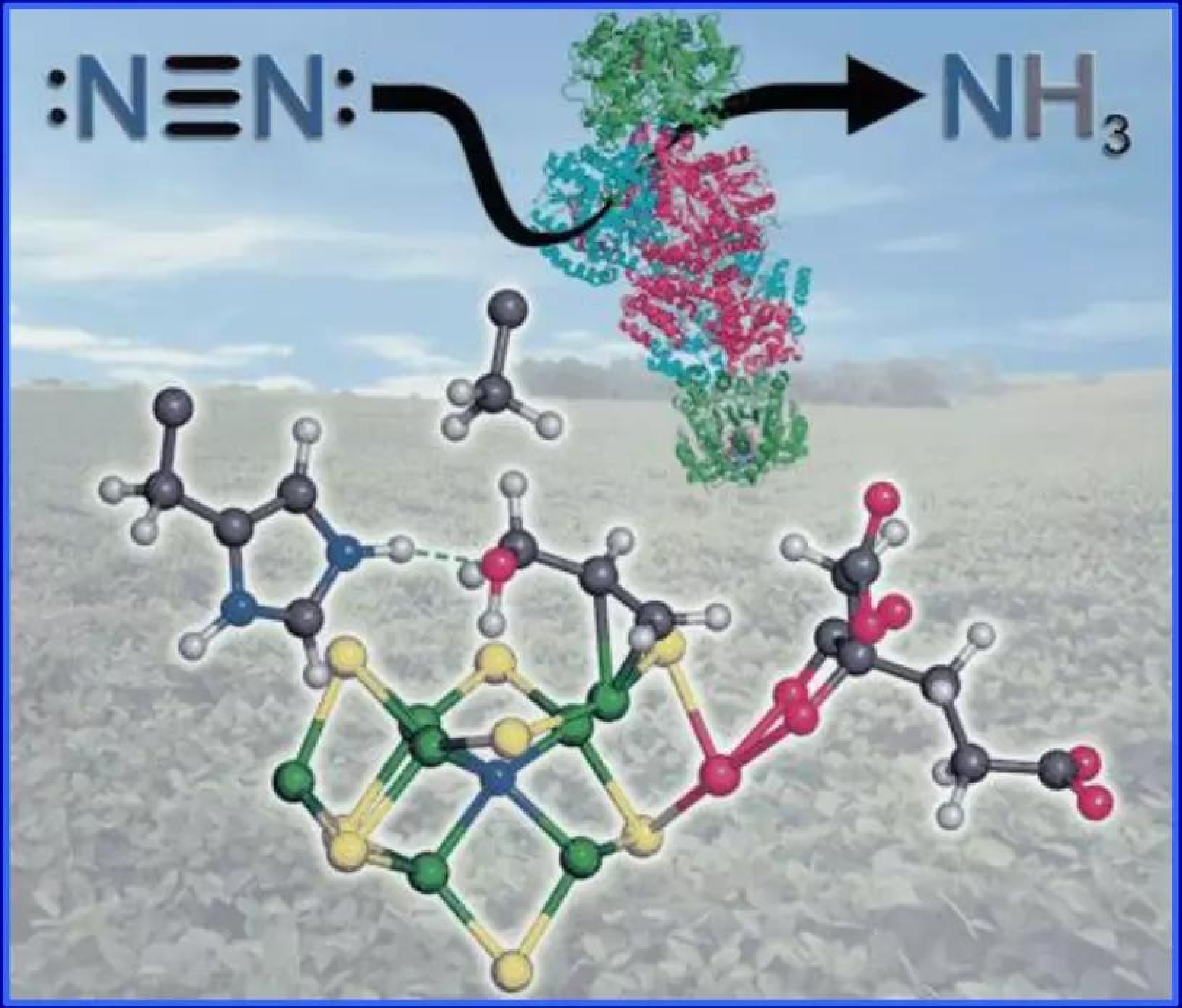
Nitrogenase enzyme has complex molecular structure

Most common form of enzyme in Nature has Molybdenum in active site

Mo-nitrogenase version exhibits highest rates of catalytic activity and proficiency

jbc THE JOURNAL OF BIOLOGICAL CHEMISTRY

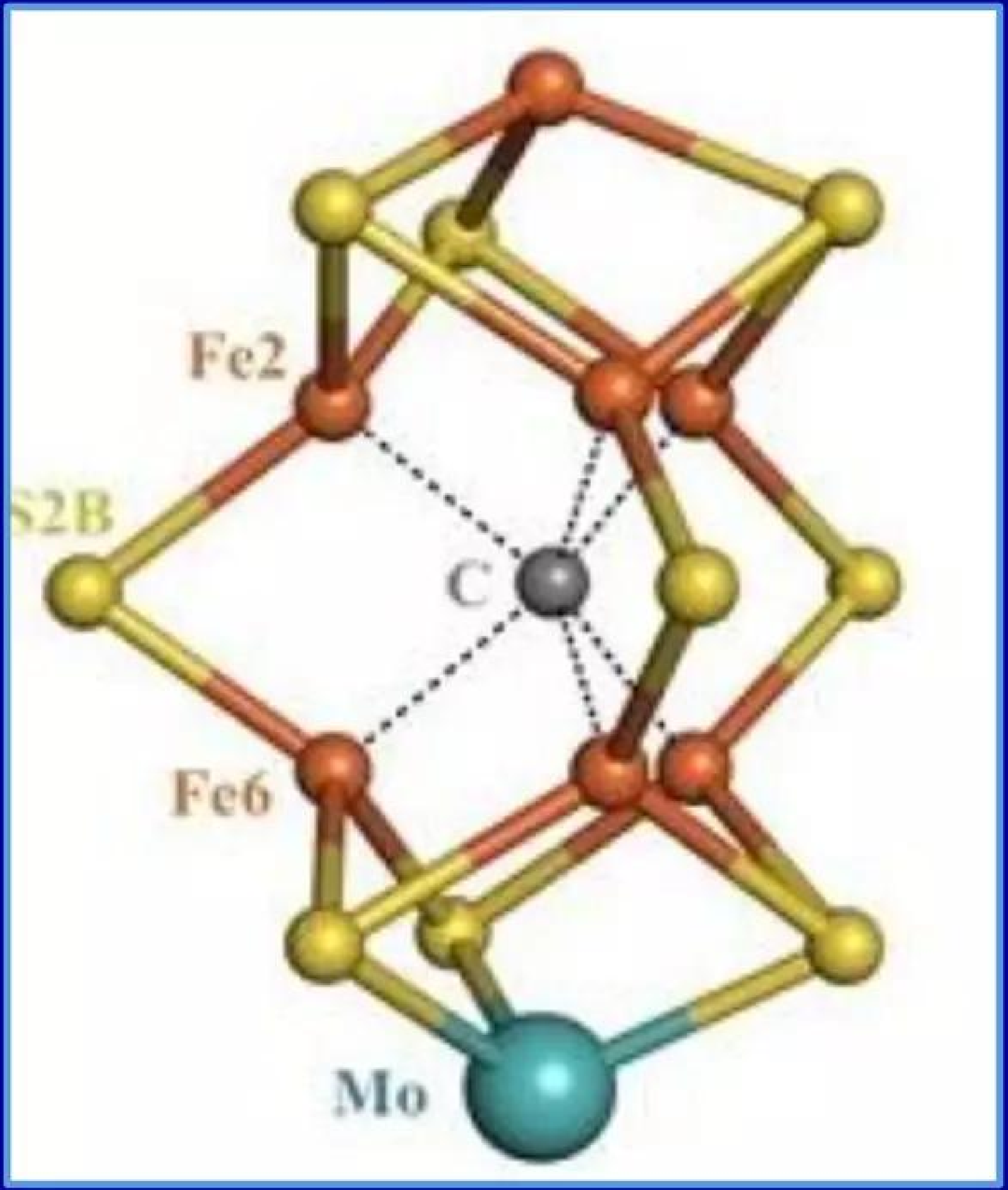
Active site structure as known in 2004



Source: *Journal of Biological Chemistry* (2004)

SLAC NATIONAL ACCELERATOR LABORATORY

Active site structure in 2015



Source: SLAC (2015)

Widom-Larsen theory of low energy neutron reactions

Explain the absence of deadly energetic neutron and gamma radiation

Many-body collective effects enable electroweak catalysis in condensed matter

"Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces" Rigorously explains *e* + *p* reaction in condensed matter
A. Widom and L. Larsen
European Physical Journal C - Particles and Fields 46 pp. 107 - 112 (2006)

http://www.slideshare.net/lewisglarsen/widom-and-larsen-ulm-neutron-catalyzed-lenrs-on-metallic-hydride-surfacesepjc-march-2006

"Theoretical Standard Model rates of proton to neutron conversions near metallic hydride surfaces" Reaction rate calculations agree with experiments
A. Widom and L. Larsen
Cornell physics preprint arXiv:nucl-th/0608059v2 12 pages (2007)

http://arxiv.org/pdf/nucl-th/0608059v2.pdf

"A primer for electro-weak induced low energy nuclear reactions"
Y. Srivastava, A. Widom, and L. Larsen Summary of W-L theory to date
Pramana - Journal of Physics 75 pp. 617 - 637 (2010)

http://www.ias.ac.in/pramana/v75/p617/fulltext.pdf

W-L theory posits that LENRs are a multi-step process

Summary of key steps that occur in electroweak catalysis of neutrons

Five-step hard-radiation-free process occurs in 200 - 400 nanoseconds or less

1. Collectively oscillating, quantum mechanically entangled, many-body patches of hydrogen (protons or deuterons) form spontaneously on metallic surfaces

2. Born-Oppenheimer approximation spontaneously breaks down, allows E-M coupling between local surface plasmon electrons and patch protons; enables application of input energy to create nuclear-strength local electric fields > 2.5 x 10^{11} V/m - increases effective masses of sites' surface plasmon electrons

3. Heavy-mass surface plasmon electrons formed in many-body active sites can react directly with electromagnetically interacting protons; process creates neutrons and benign neutrinos via a collective electroweak $e + p$ reaction

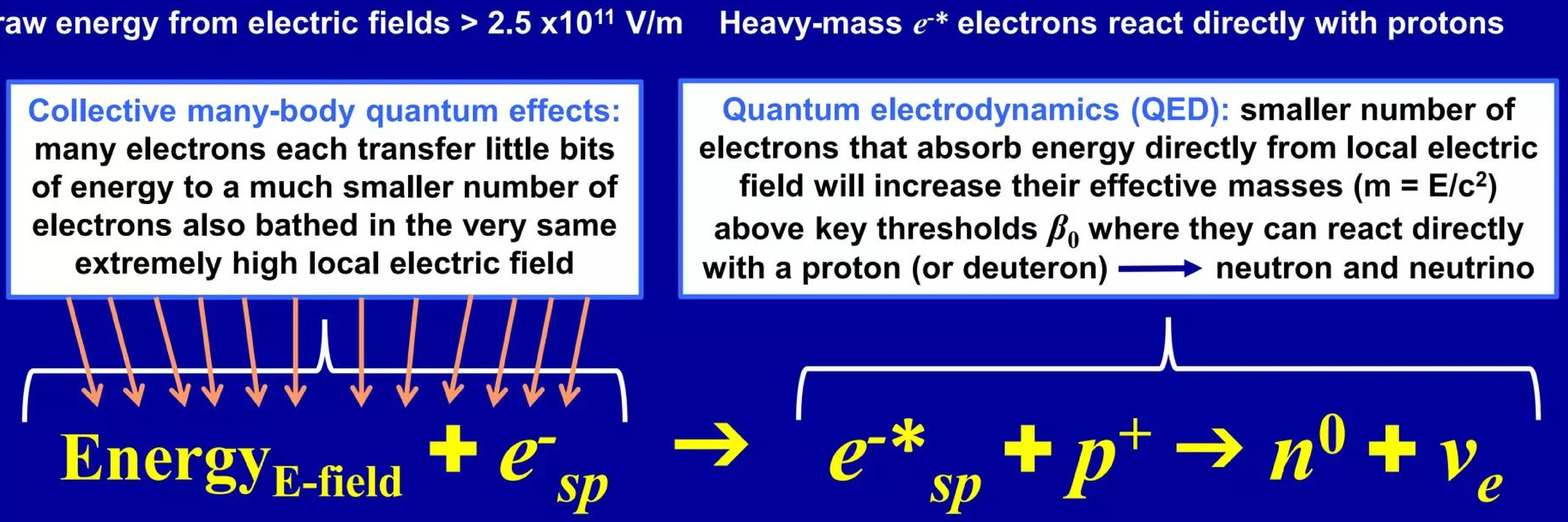
4. Neutrons collectively created in sites have ultra-low kinetic energies; almost all absorbed by nearby atoms - few neutrons escape into environment; locally produced or ambient gammas converted directly into infrared photons by unreacted heavy electrons (US# 7,893,414 B2) - no deadly gamma emissions

5. Transmutation of atoms of locally present elements is induced at active sites

Electroweak reaction in Widom-Larsen theory is simple

Protons or deuterons react directly with electrons to make neutrons

W-L explains how e + p reactions occur at substantial rates in condensed matter



Draw energy from electric fields > 2.5 x10^{11} V/m

Collective many-body quantum effects: many electrons each transfer little bits of energy to a much smaller number of electrons also bathed in the very same extremely high local electric field

Heavy-mass $e^{-}*$ electrons react directly with protons

Quantum electrodynamics (QED): smaller number of electrons that absorb energy directly from local electric field will increase their effective masses ($m = E/c^2$) above key thresholds β_0 where they can react directly with a proton (or deuteron) → neutron and neutrino

$$\text{Energy}_{\text{E-field}} + e^{-}_{sp} \rightarrow e^{-*}_{sp} + p^{+} \rightarrow n^{0} + v_{e}$$

v_e neutrinos: ghostly unreactive photons that fly-off into space; n^0 neutrons capture on nearby atoms

$$\text{Neutrons + atomic nuclei} \xrightarrow{\text{Induce transmutation}} \text{heavier elements + decay products}$$

Radiation-free green transmutations in mild conditions

Electrons react directly with protons to make neutrons and neutrinos

Reactions are ‘green’: no deadly emissions of energetic neutrons and gammas

Non-stellar neutron production in condensed matter under mild conditions:

Collective many-body processes require external input energy

$$e^{-*} + p^{+} \rightarrow n + \nu_e$$

Electric fields dominate

$$e^{-} + p^{+} \rightarrow lepton + X$$

Magnetic fields dominate

Electroweak nuclear reactions produce neutrons (n) and neutrinos (ν_e)

Transmutation of elements and star-like nucleosynthesis in labs and Nature:

Neutron capture-driven transmutation in Earthly environs

$$n + (Z, A) \rightarrow (Z, A+1)$$

Neutron capture

$$(Z, A+1) \rightarrow (Z + 1, A+1) + e_{\beta}^{-} + \bar{\nu}_e$$

Beta decay

Unstable neutron-rich products of neutron captures will undergo beta$^-$ decay

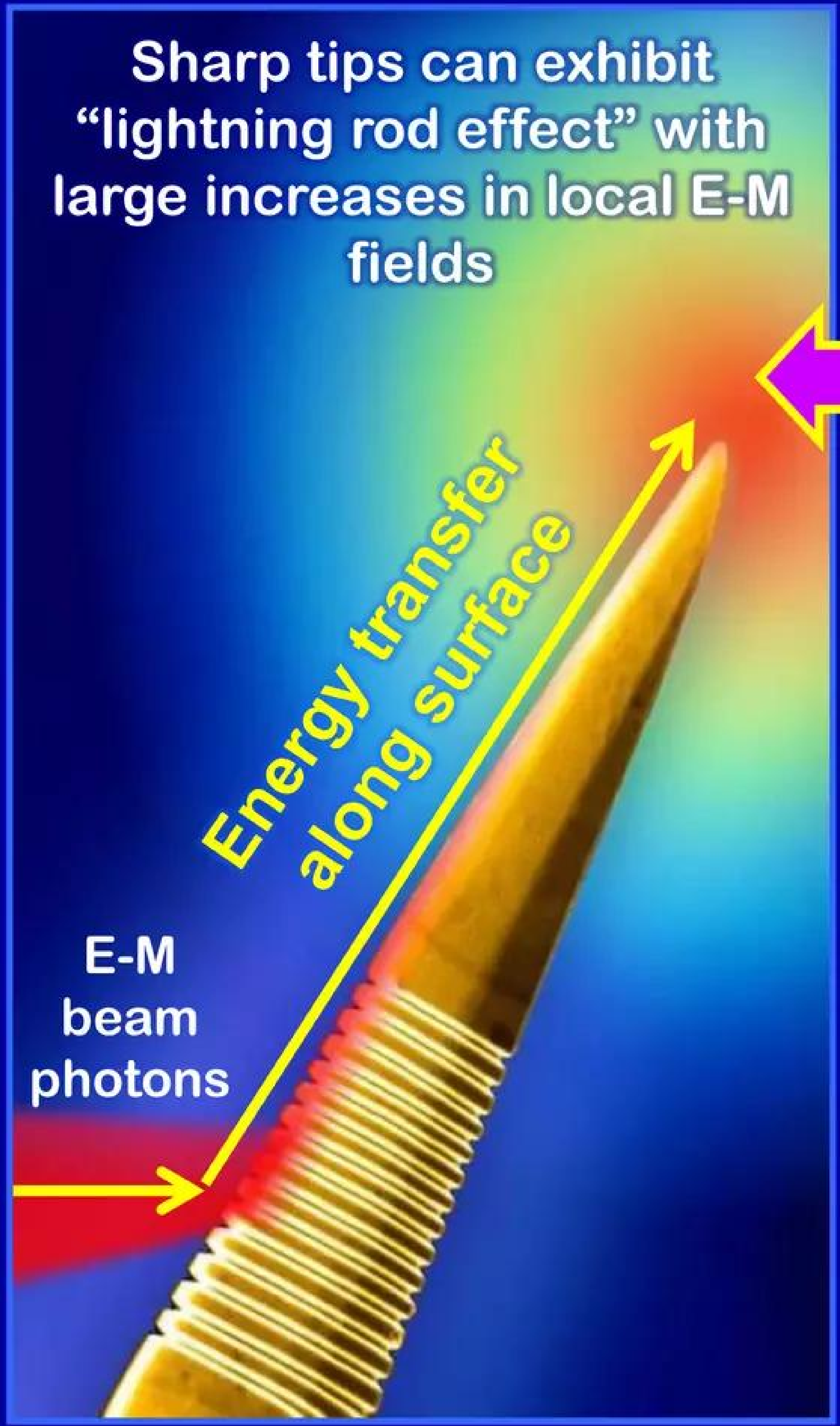
Can create heavier stable isotopes/elements along rows of Periodic Table

Nanostructures can be antennas that absorb E-M energy

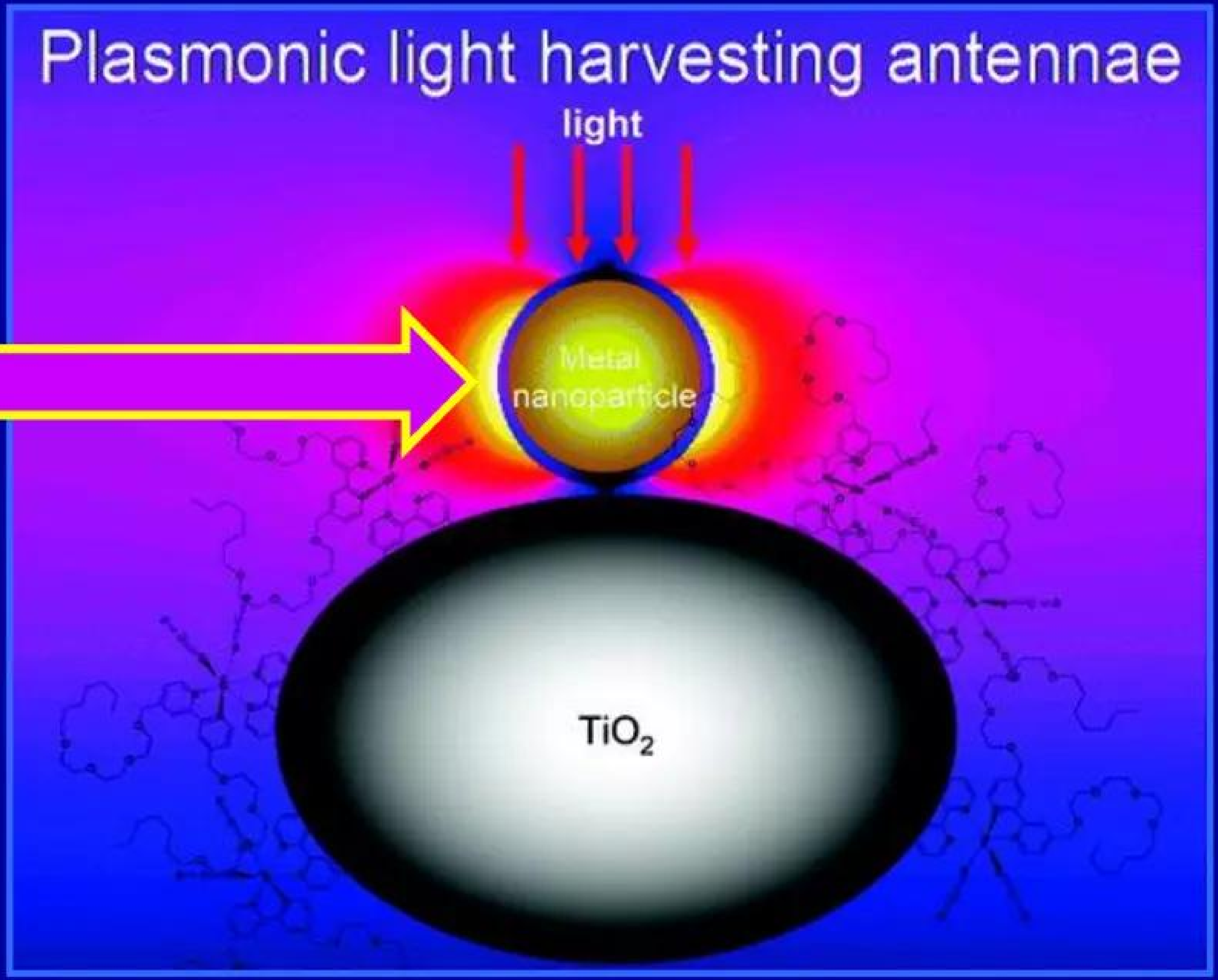
SP electrons on nanoparticles can greatly intensify local electric fields

Nanostructures can be designed to briefly create pulsed E-fields > 2.5 x 10^{11} V/m

Graphics show capture of E-M photons and energy transfer by SP electrons


Sharp tips can exhibit "lightning rod effect" with large increases in local E-M fields

Region of enhanced electric fields


Plasmonic light harvesting antennae

http://people.ccmr.cornell.edu/~uli/res_optics.htm

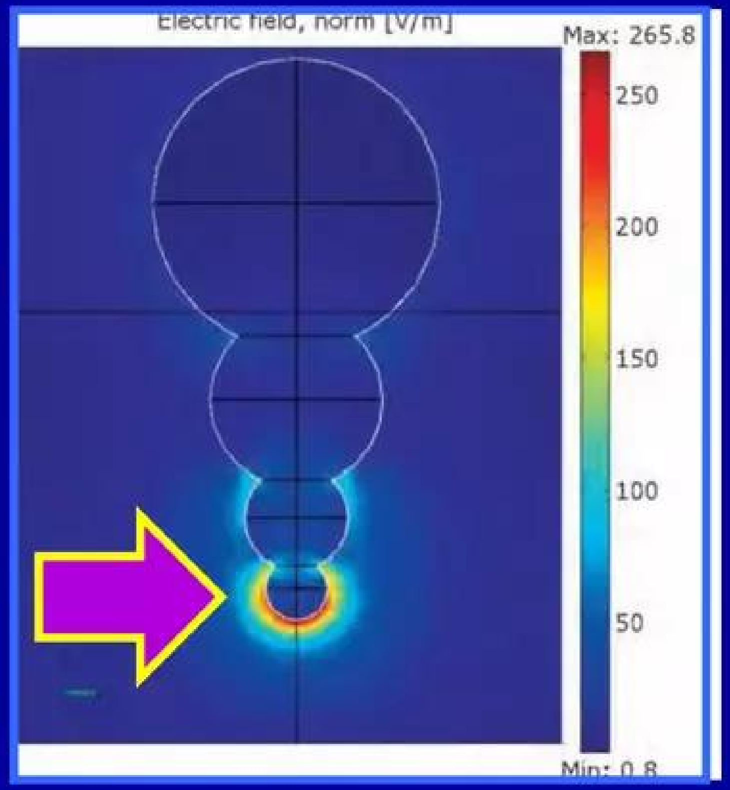
Source of above image is Wiesner Group at Cornell University:

"Plasmonic dye-sensitized solar cells using core-shell metal-insulator nanoparticles" M. Brown *et al.*, *Nano Letters* 11 pp. 438 - 445 (2011) http://pubs.acs.org/doi/abs/10.1021/nl1031106

Huge increase in local E-field strengths on nanoscale

Nanostructures of right shapes/compositions amplify electric fields

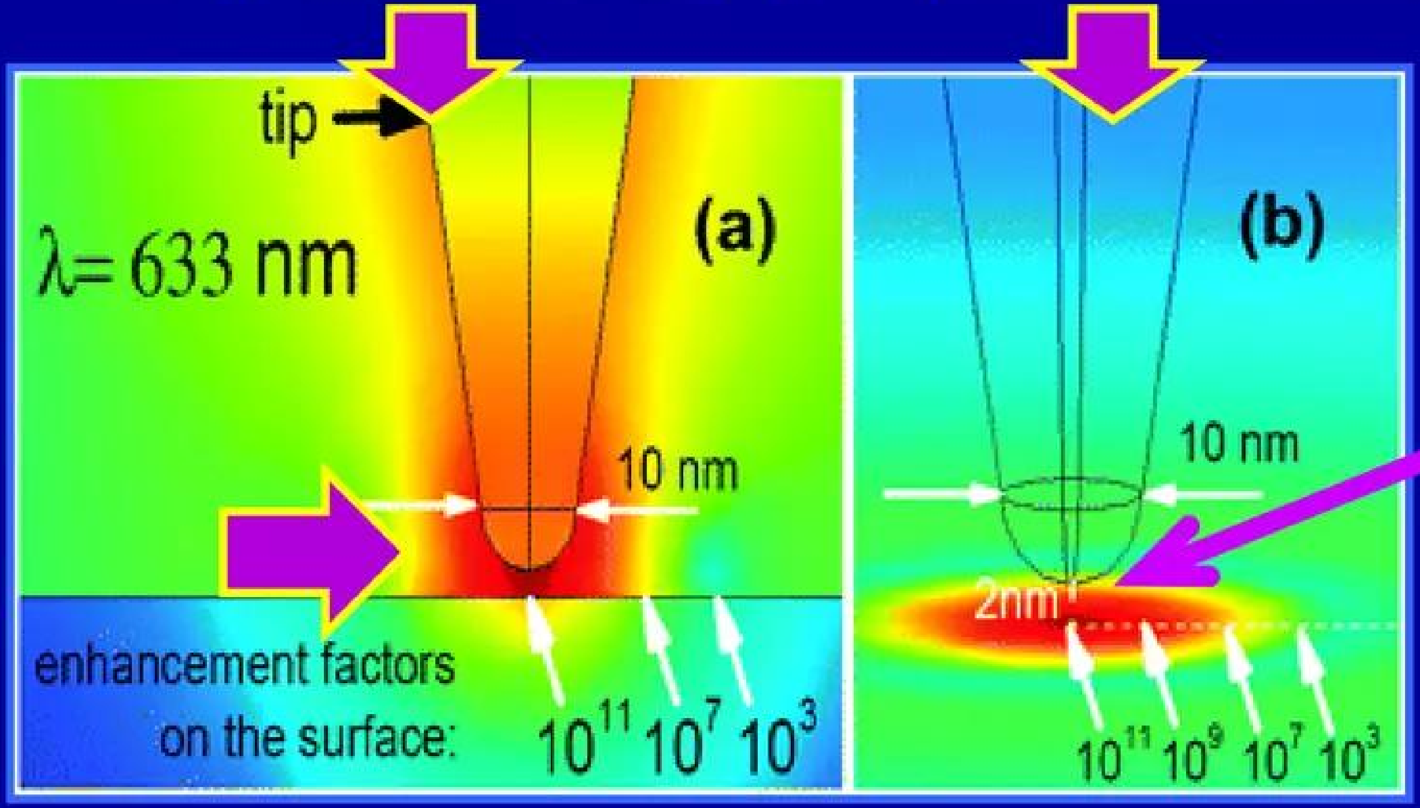
Details of nanoparticulate features on *nm* to *µ* length-scales very key to LENRs



Electric field enhancement at nano-antenna tip: R. Kappeler *et al*. (2007)

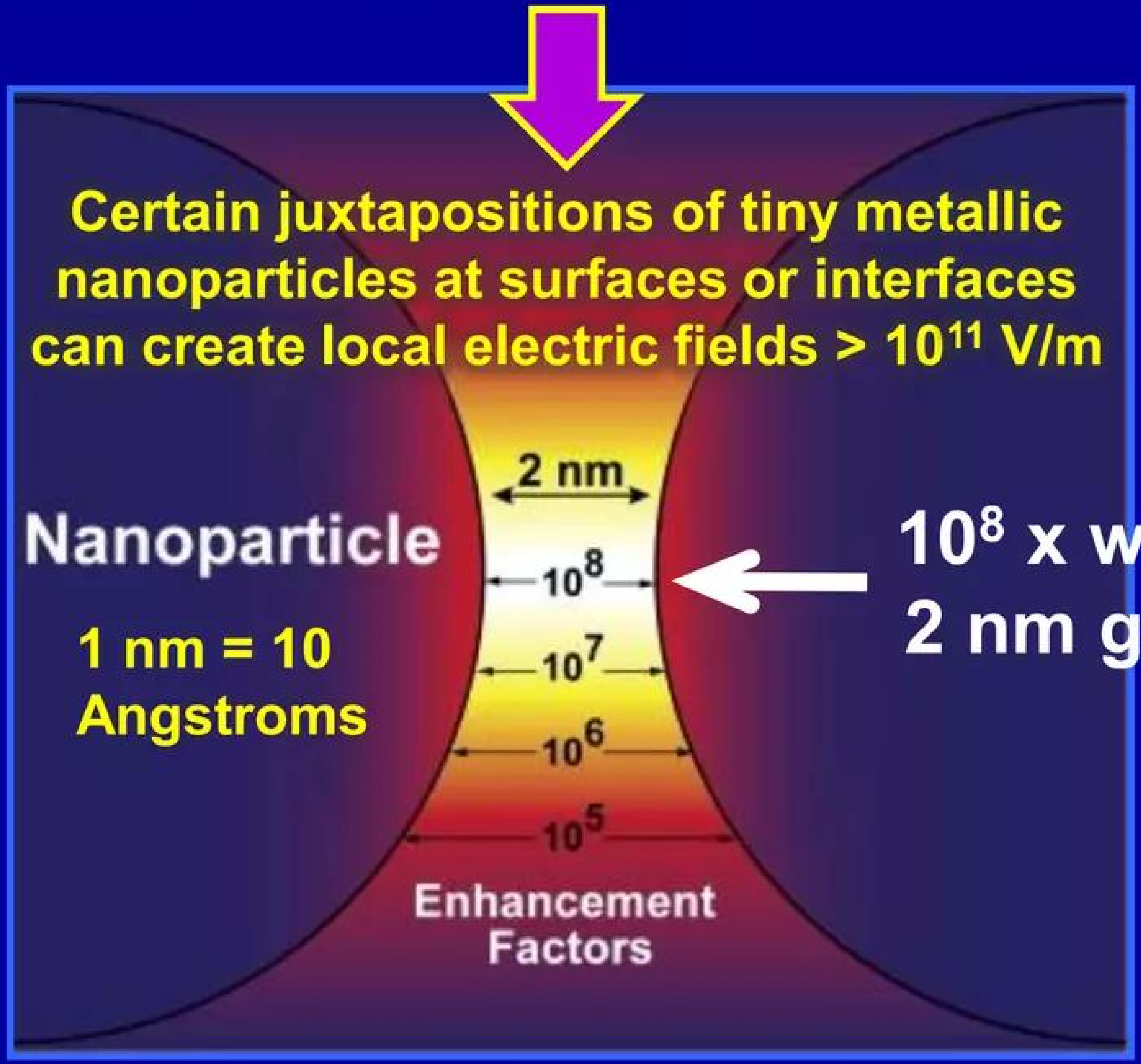
Sharp tips exhibit so-called "lightning rod effect" by creating enormous local enhancement in electric field strengths

Electric fields at tips of atomic force microscopes (AFM) often reach 10^{11} V/m



10^{11} x increase

Shows E-M field strength enhancement as a function of interparticle spacing



Certain juxtapositions of tiny metallic nanoparticles at surfaces or interfaces can create local electric fields > 10^{11} V/m

1 nm = 10 Angstroms

10^{8} x with 2 nm gap

Nanoparticle shapes/positioning redistribute E-fields

Fang & Huang's Figs. 1 and 3 show how electric fields are redistributed

Nonuniformity can be predicted, modeled, and used to design LENR active sites

Figure 1.

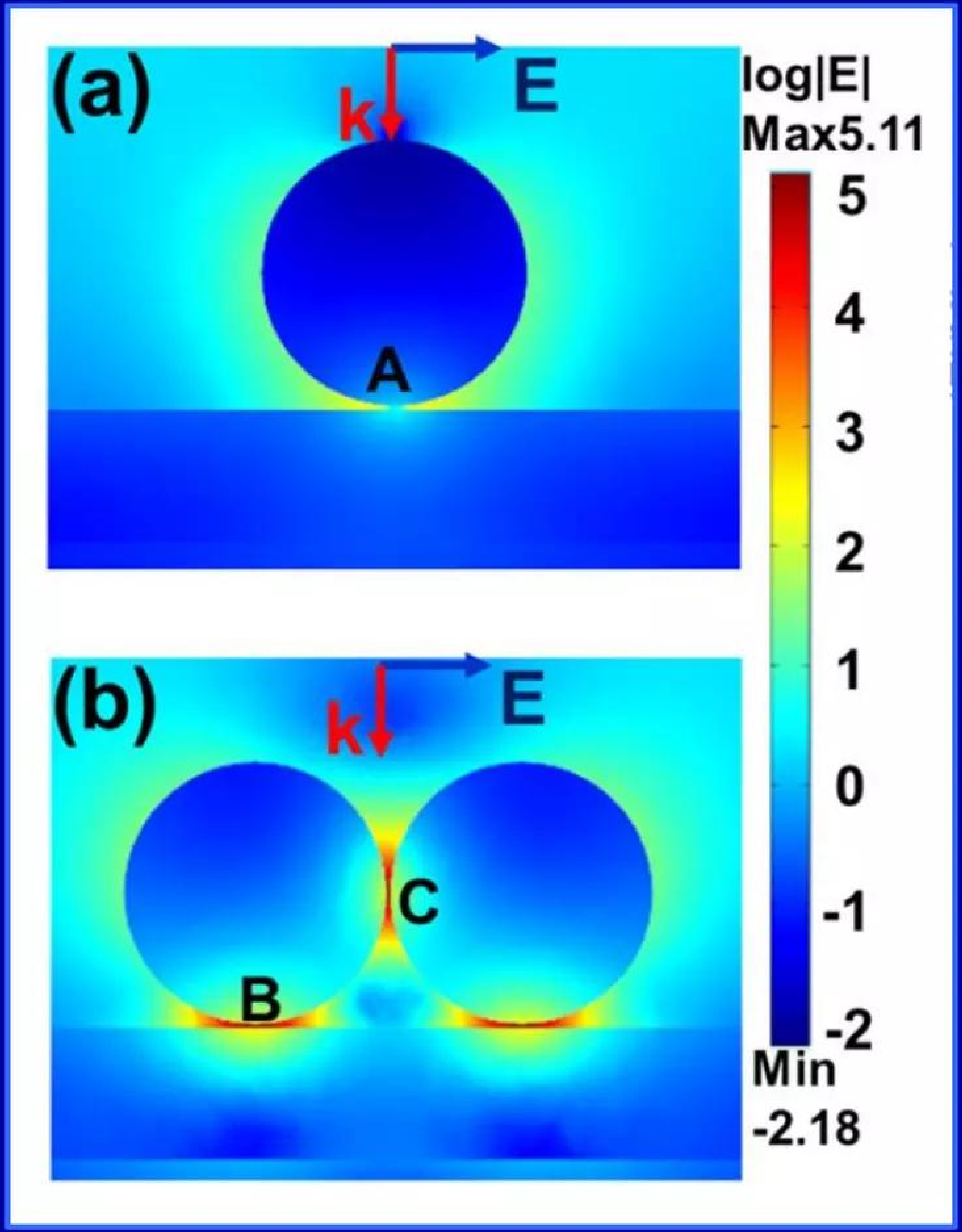
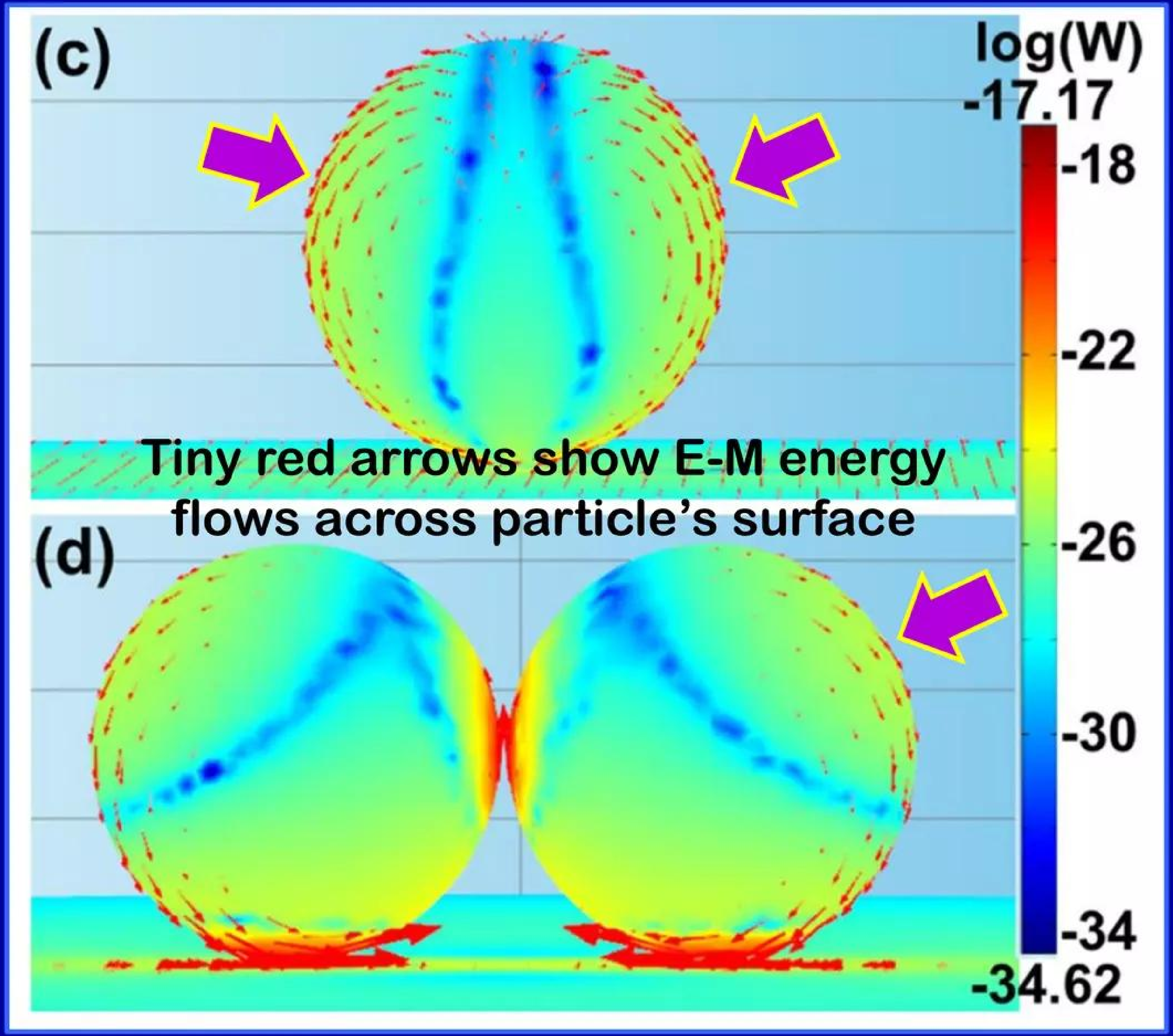


Figure 3.



Tiny red arrows show E-M energy flows across particle's surface

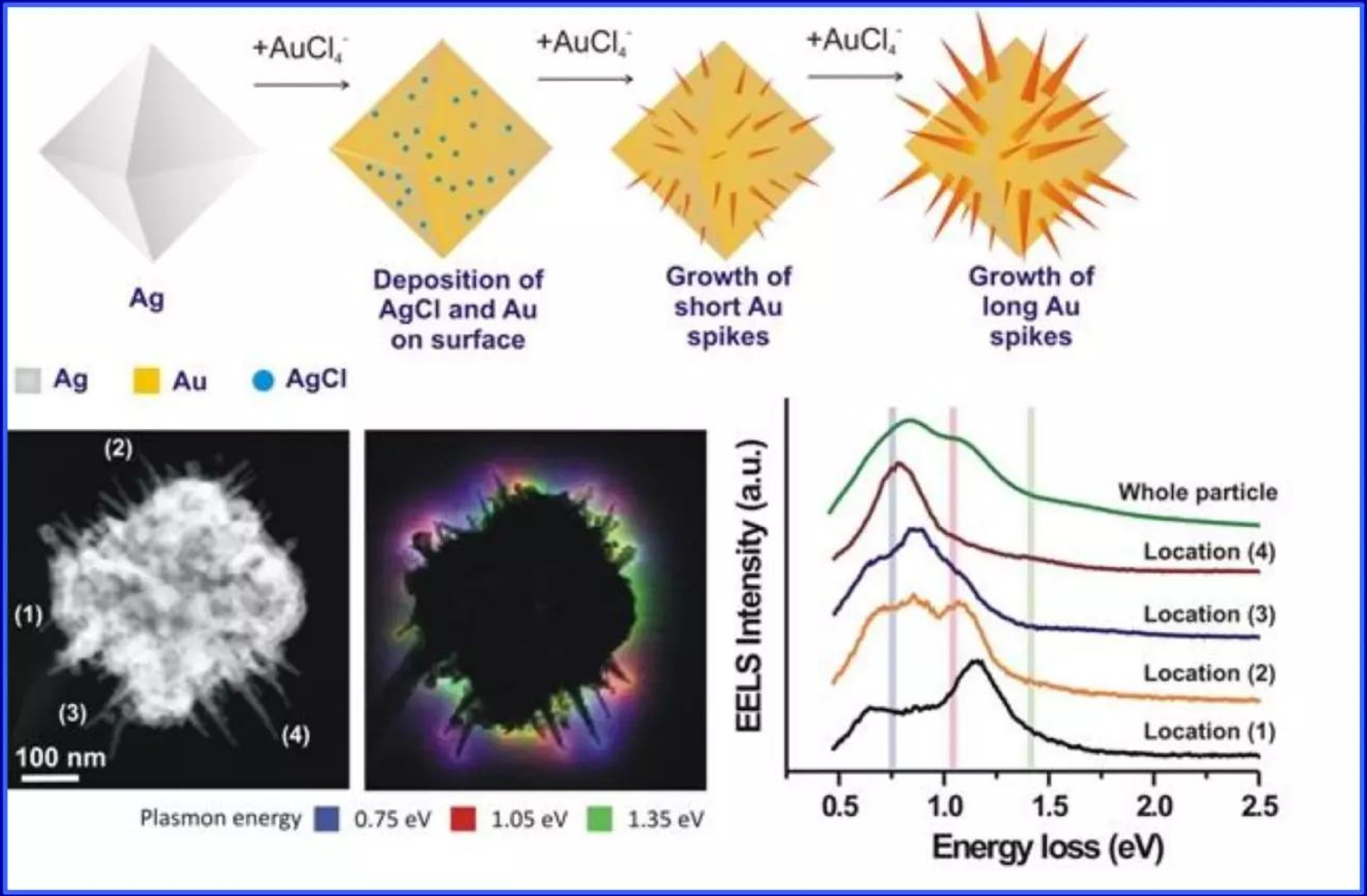
http://publications.lib.chalmers.se/records/fulltext/178593/local_178593.pdf

Nanoparticle shapes locally intensify electric fields

Grow in Nature and are readily fabricated in nanotech laboratories

Surface plasmons are present on surfaces of metallic NPs embedded in oxides

"Synthesis of spiky Ag-Au octahedral nanoparticles and their tunable optical properties" S. Pedireddy *et al*., *J. Phys. Chem. C* 117 pp. 16640 - 16649 (2013)
http://pubs.acs.org/doi/abs/10.1021/jp4063077



LENRs occur in microscopic active sites found on surfaces

Many-body collections of protons and electrons form spontaneously

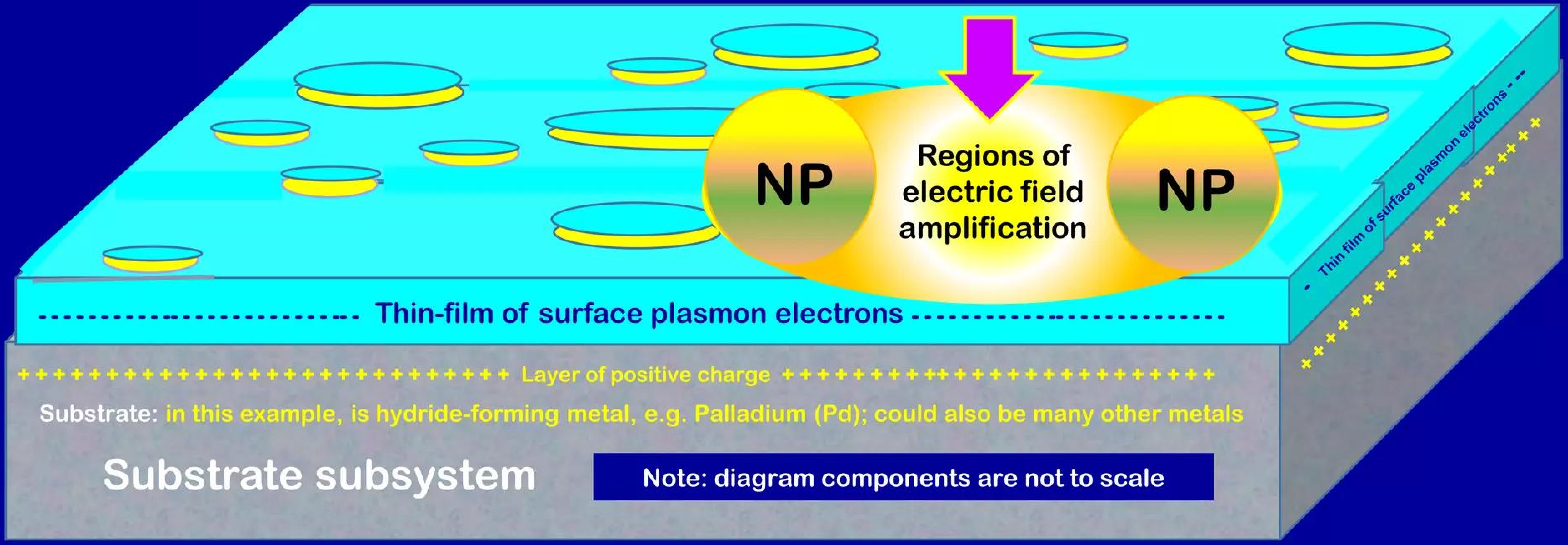
Ultralow energy neutrons produced & captured close to LENR active sites

After being produced, neutrons will capture on nearby atoms:

$n + (Z, A) \rightarrow (Z, A+1)$ [local atoms compete to capture neutrons]

$(Z, A+1) \rightarrow (Z + 1, A+1) + e_{\beta}^{-} + \nu_{e}$ [beta^{-} decay]

Captures often followed by β^{-} decays of neutron-rich intermediate LENR products



Substrate: in this example, is hydride-forming metal, e.g. Palladium (Pd); could also be many other metals

Note: diagram components are not to scale

Chemical and nuclear realms interoperate on surfaces

LENRs: complex interplay between E-M/chemical/nuclear processes

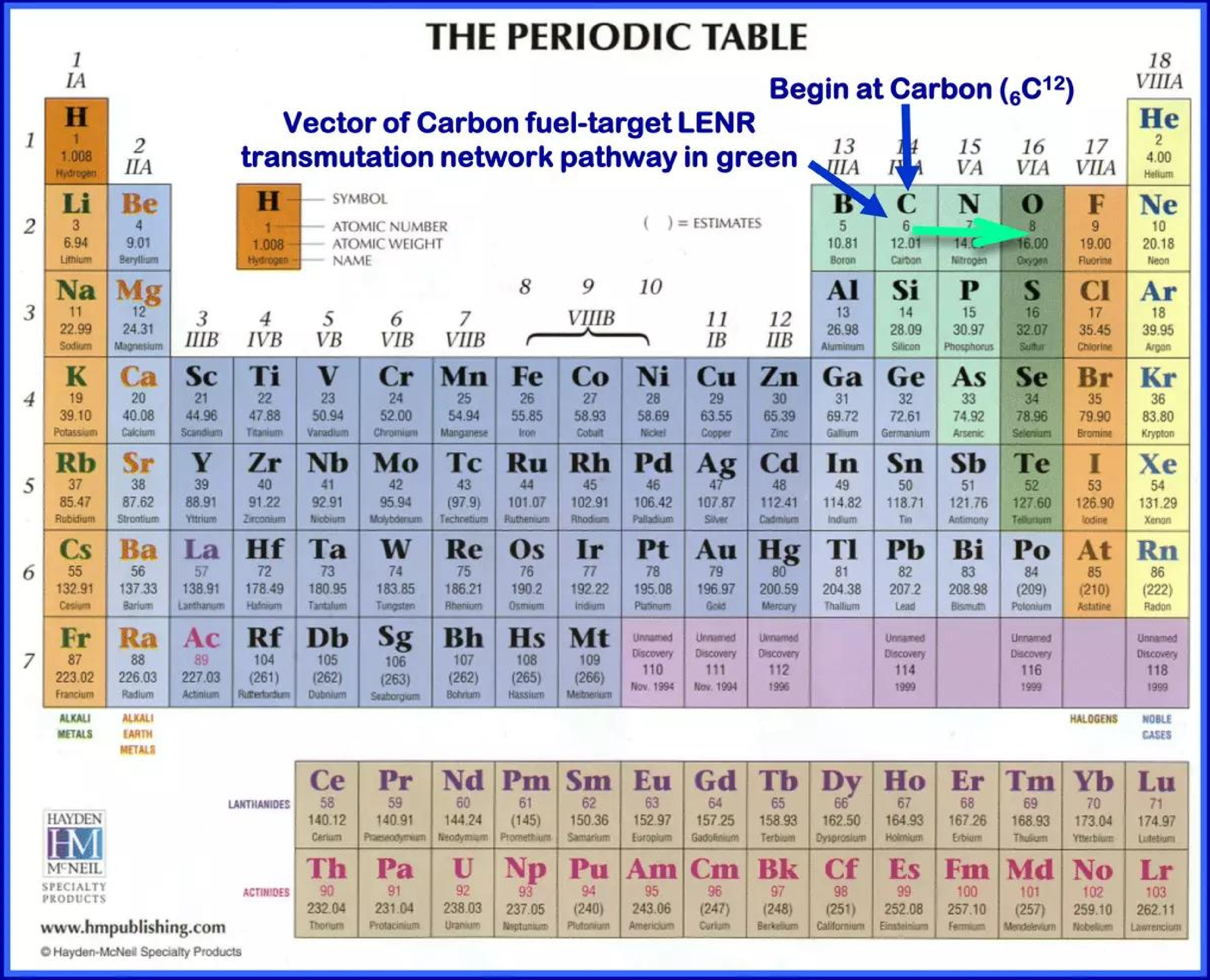
Resonant E-M cavities can transfer energy directly to LENR active surface sites

- ✓ It is well-known that metallic surface nanostructures and SP electrons can have configurations that can absorb electromagnetic (E-M) energy over a wide area, transport and concentrate it, and --- in conjunction with contiguous surface patches of collectively oscillating protons --- create nuclear-strength local electric fields that are required to produce neutrons in LENR active sites
- ✓ For substrate surfaces on which LENR active sites have formed, there are a myriad of different complex, nanometer-to micron-scale electromagnetic, chemical, and nuclear processes operating simultaneously. LENR active sites involve extremely complex interplays between surface plasmon electrons, E-M fields, and many different types of nanostructures with various geometries, surface locations relative to each other, different-strength local E-M fields, and varied chemical or isotopic compositions. Key: electromagnetic, chemical, and nuclear processes can coexist and interact on small length-scales at surfaces
- ✓ To varying degrees, many of these complex, time-varying surface interactions are electromagnetically coupled on many different physical length-scales. Thus, mutual E-M resonances can be very important in such systems. In addition to optical frequencies, SP and π electrons in condensed matter often also have strong absorption and emission bands in both infrared (IR) and UV portions of E-M spectrum; this can lead to formation of resonant E-M cavities

LENR transmutation processes can convert C → N → O

Similar to stars but radiation-free and occurs under earthly conditions

Series of neutron captures and decays create elements along same row of Table



Begin at Carbon ($_6C^{12}$)

Vector of Carbon fuel-target LENR transmutation network pathway in green

THE PERIODIC TABLE

H — SYMBOL
1 — ATOMIC NUMBER
1.008 — ATOMIC WEIGHT
Hydrogen — NAME

( ) = ESTIMATES

	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	H 1 1.008 Hydrogen																	He 2 4.00 Helium
2	Li 3 6.94 Lithium	Be 4 9.01 Beryllium											B 5 10.81 Boron	C 6 12.01 Carbon	N 7 14.0 Nitrogen	O 8 16.00 Oxygen	F 9 19.00 Fluorine	Ne 10 20.18 Neon
3	Na 11 22.99 Sodium	Mg 12 24.31 Magnesium											Al 13 26.98 Aluminum	Si 14 28.09 Silicon	P 15 30.97 Phosphorus	S 16 32.07 Sulfur	Cl 17 35.45 Chlorine	Ar 18 39.95 Argon
4	K 19 39.10 Potassium	Ca 20 40.08 Calcium	Sc 21 44.96 Scandium	Ti 22 47.88 Titanium	V 23 50.94 Vanadium	Cr 24 52.00 Chromium	Mn 25 54.94 Manganese	Fe 26 55.85 Iron	Co 27 58.93 Cobalt	Ni 28 58.69 Nickel	Cu 29 63.55 Copper	Zn 30 65.39 Zinc	Ga 31 69.72 Gallium	Ge 32 72.61 Germanium	As 33 74.92 Arsenic	Se 34 78.96 Selenium	Br 35 79.90 Bromine	Kr 36 83.80 Krypton
5	Rb 37 85.47 Rubidium	Sr 38 87.62 Strontium	Y 39 88.91 Yttrium	Zr 40 91.22 Zirconium	Nb 41 92.91 Niobium	Mo 42 95.94 Molybdenum	Tc 43 (97.9) Technetium	Ru 44 101.07 Ruthenium	Rh 45 102.91 Rhodium	Pd 46 106.42 Palladium	Ag 47 107.87 Silver	Cd 48 112.41 Cadmium	In 49 114.82 Indium	Sn 50 118.71 Tin	Sb 51 121.76 Antimony	Te 52 127.60 Tellurium	I 53 126.90 Iodine	Xe 54 131.29 Xenon
6	Cs 55 132.91 Cesium	Ba 56 137.33 Barium	La 57 138.91 Lanthanum	Hf 72 178.49 Hafnium	Ta 73 180.95 Tantalum	W 74 183.85 Tungsten	Re 75 186.21 Rhenium	Os 76 190.2 Osmium	Ir 77 192.22 Iridium	Pt 78 195.08 Platinum	Au 79 196.97 Gold	Hg 80 200.59 Mercury	Tl 81 204.38 Thallium	Pb 82 207.2 Lead	Bi 83 208.98 Bismuth	Po 84 (209) Polonium	At 85 (210) Astatine	Rn 86 (222) Radon
7	Fr 87 223.02 Francium	Ra 88 226.03 Radium	Ac 89 227.03 Actinium	Rf 104 (261) Rutherfordium	Db 105 (262) Dubnium	Sg 106 (263) Seaborgium	Bh 107 (262) Bohrium	Hs 108 (265) Hassium	Mt 109 (266) Meitnerium	Unnamed Discovery 110 Nov. 1994	Unnamed Discovery 111 Nov. 1994	Unnamed Discovery 112 1996		Unnamed Discovery 114 1999		Unnamed Discovery 116 1999		Unnamed Discovery 118 1999
	ALKALI METALS	ALKALI EARTH METALS															HALOGENS	NOBLE GASES

LANTHANIDES	Ce 58 140.12 Cerium	Pr 59 140.91 Praseodymium	Nd 60 144.24 Neodymium	Pm 61 (145) Promethium	Sm 62 150.36 Samarium	Eu 63 152.97 Europium	Gd 64 157.25 Gadolinium	Tb 65 158.93 Terbium	Dy 66 162.50 Dysprosium	Ho 67 164.93 Holmium	Er 68 167.26 Erbium	Tm 69 168.93 Thulium	Yb 70 173.04 Ytterbium	Lu 71 174.97 Lutetium
ACTINIDES	Th 90 232.04 Thorium	Pa 91 231.04 Protactinium	U 92 238.03 Uranium	Np 93 237.05 Neptunium	Pu 94 (240) Plutonium	Am 95 243.06 Americium	Cm 96 (247) Curium	Bk 97 (248) Berkelium	Cf 98 (251) Californium	Es 99 252.08 Einsteinium	Fm 100 257.10 Fermium	Md 101 (257) Mendelevium	No 102 259.10 Nobelium	Lr 103 262.11 Lawrencium

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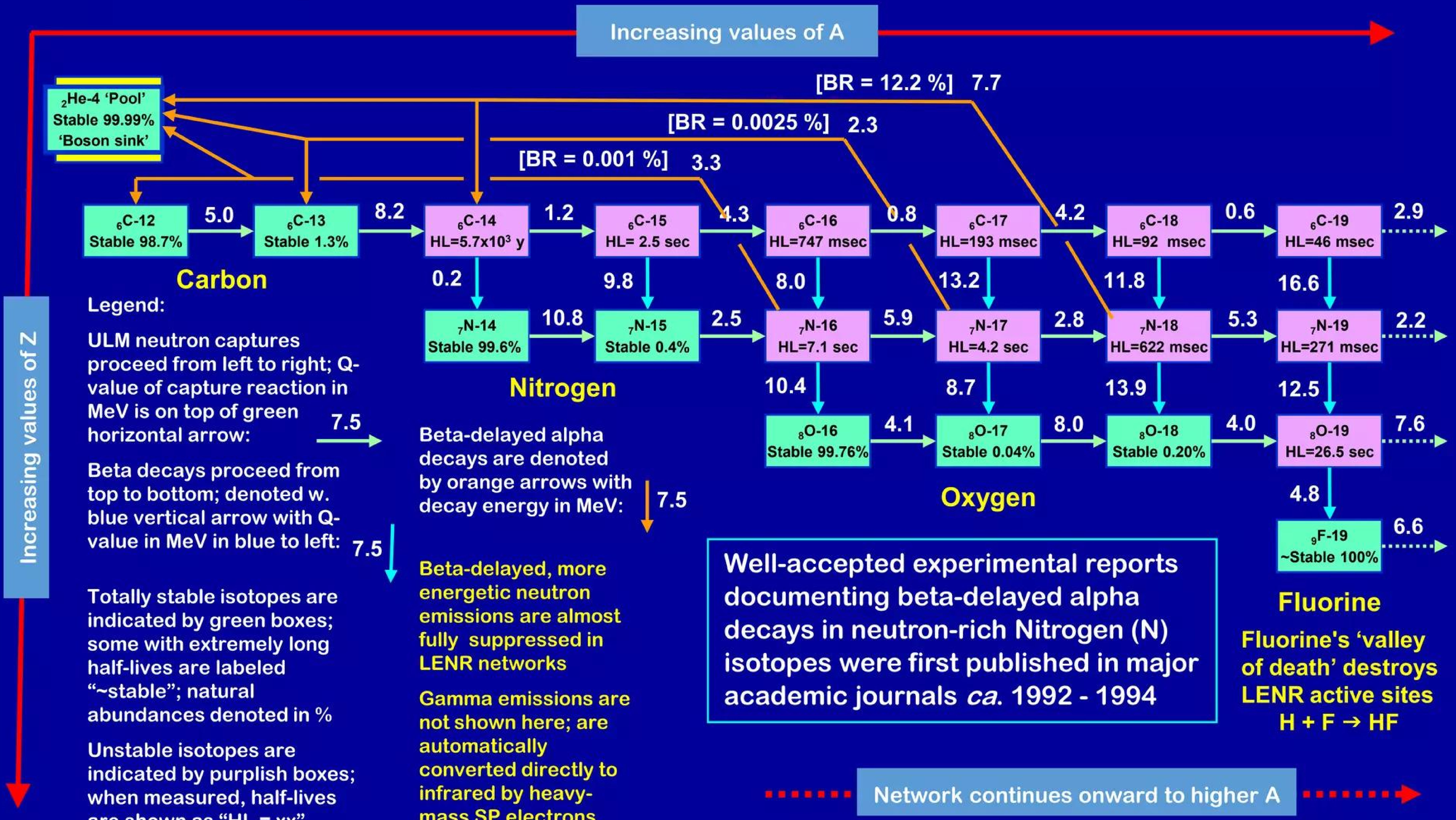
Neutron captures and decays can transform C → N → O

Theorized LENR transmutation network starting with stable Carbon-12

Network cannot get past Oxygen-18 unless neutron fluxes are > 1×10^{10} cm^2/sec



Legend:

ULM neutron captures proceed from left to right; Q-value of capture reaction in MeV is on top of green horizontal arrow: 7.5

Beta decays proceed from top to bottom; denoted w. blue vertical arrow with Q-value in MeV in blue to left: 7.5

Totally stable isotopes are indicated by green boxes; some with extremely long half-lives are labeled "~stable"; natural abundances denoted in %

Unstable isotopes are indicated by purplish boxes; when measured, half-lives are shown as "HL = xx"

Beta-delayed alpha decays are denoted by orange arrows with decay energy in MeV: 7.5

Beta-delayed, more energetic neutron emissions are almost fully suppressed in LENR networks

Gamma emissions are not shown here; are automatically converted directly to infrared by heavy-mass SP electrons

Well-accepted experimental reports documenting beta-delayed alpha decays in neutron-rich Nitrogen (N) isotopes were first published in major academic journals *ca*. 1992 - 1994

Fluorine's 'valley of death' destroys LENR active sites H + F → HF

Conceptual paradigm shift: terrestrial nucleosynthesis

W-L predicts transmutations at very low rates in planetary environs

Neutron production via *e* + *p* reaction can occur in lightning and earth's crust

- ✓ Theoretically predicted production of low-energy neutrons in lightning via the Widom-Larsen *e* + *p* mechanism was effectively confirmed by Gurevich *et al*. (*Phys. Rev. Lett*. 2012); please see following document:

"New Russian data supports Widom-Larsen theory neutron production in lightning" L. Larsen, Lattice Energy LLC, April 4, 2012 [73 slides]
http://www.slideshare.net/lewisglarsen/lattice-energy-llcnew-russian-data-supports-wlt-neutron-production-in-lightningapril-4-2012

- ✓ In recent presentation we discussed key compelling experimental data published in peer-reviewed journals suggesting W-L neutron production is occurring abiotically --- and perhaps also biologically --- in earth's crust:

"Implications of LENRs and mobile + charge carriers in Earth's crust for seismicity, terrestrial nucleosynthesis, and the Deep Biosphere: paradigm shifts in geophysics, geochemistry, and biology"
L. Larsen, Lattice Energy LLC, December 22, 2014 [102 slides]
http://www.slideshare.net/lewisglarsen/lattice-energy-llc-lenrs-pholes-crustal-nucleosynthesis-seismicity-and-deep-biosphere-dec-22-2014

Terrestrial nucleosynthesis is heretical but plausible

W-L theory posits chemical & nuclear processes overlap on nanoscale

LENR transmutations occur in parallel with more common chemical fractionation

Before proceeding further, please note that we are:

- ✓ Not asserting that the existing chemical fractionation paradigm fails to adequately explain most reported isotope anomalies with respect to statistically significant deviations from natural abundances --- indeed, it may well effectively and accurately explain the vast majority of them
- ✓ Claiming that the presently available published literature contains a significant subset comprising many examples in which a chemical fractionation paradigm must be pushed very hard (which includes use of various *ad hoc* constructs) to explain certain isotope anomalies, i.e. it is being overly stretched to be able to accommodate certain data
- ✓ Suggesting that in such instances it may be fruitful for researchers to reexamine isotopic measurements through conceptual lens of a W-L LENR paradigm to determine whether Widom-Larsen theory can help lead to a better understanding of such anomalous experimental data

Definition of chemical fractionation of isotopes

Isotope fractionation: "… is the physical phenomenon which causes changes in the relative abundance of isotopes due to their differences in mass … are two categories of isotope effects: equilibrium and kinetic."

"An equilibrium isotope effect will cause one isotope to concentrate in one component of a reversible system that is in equilibrium. If it is the heavier isotope that concentrates in the component of interest, then that component is commonly referred to as enriched or heavy. If it is the light isotope that concentrates then the component is referred to as depleted or light. In most circumstances the heavy isotope concentrates in the component in which the element is bound more strongly and thus equilibrium isotope effects usually reflect relative differences in the bond strengths of the isotopes in the various components of the system. A kinetic isotope effect occurs when one isotope reacts more rapidly than the other in an irreversible system or a system in which the products are swept away from the reactants before they have an opportunity to come to equilibrium [typical in biological processes]. Normally, the lighter isotope will react more rapidly than … heavy isotope and thus … product will be lighter than the reactant."

"It should be noted that isotope fractionation will only occur in systems in which there is both an isotope effect and a reaction that does not proceed to completion. Thus, even in the presence of an isotope effect, there will be no isotope fractionation if all the reactant goes to a single product because all the atoms have reacted and thus the ratio of the heavy to light isotope must be the same in the product as it was in the reactant. The magnitude of an isotope effect is expressed as a fractionation factor. This is defined as the ratio of the heavy to light isotope in the product divided by the ratio of the heavy to light isotope in the reactant. Stated mathematically:"

$$f = \frac{(heavy / light)\mathrm{product}}{(heavy / light)\mathrm{reactant}}$$

"When f is greater than 1 … product is heavy or enriched. When … less than 1 … product is light or depleted. Most fractionation factors lie between 0.9 and 1.1 … fractionation factor of 1.050 is … referred to as a 5% isotope effect."

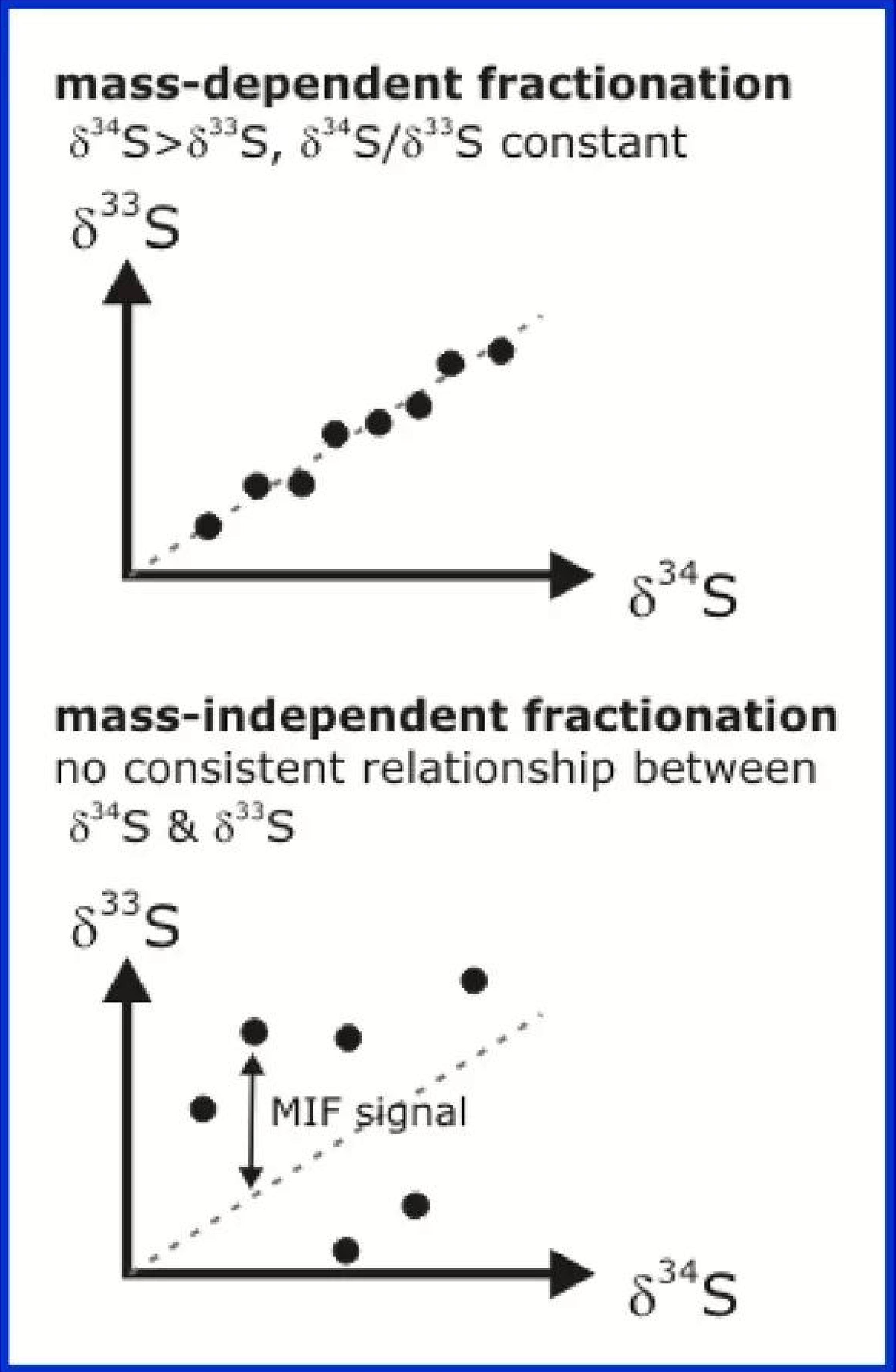
Source: D. Schoeller and A. Coward at http://www.unu.unupress/food2/uid05e/uid05e0e.htm

LENR isotopic effects can mimic chemical fractionation

Neutrons can potentially be captured by any element in Periodic Table

LENRs are definitely occurring in Earth's environs: terrestrial C → N → O cycle?

- ✓ For ~ 60 years, a body of theory has been developed and articulated to explain progressively increasing numbers of stable isotope anomalies observed in a vast array of mass spectroscopic data obtained from many different types of natural and experimental, abiotic and/or biological, systems. Central ideas in chemical "fractionation" theory embody equilibrium and irreversible, mass-dependent and mass-independent, chemical processes that are claimed to separate isotopes, thus explaining the reported anomalies
- ✓ Although not explicitly acknowledged by the fractionation theorists, an intrinsic *fundamental assumption* underlying all of such theory and interpretation of data is that NO neutron-catalyzed nucleosynthetic processes are ever occurring anywhere in these systems - at any time - that are capable of altering isotope ratios or producing new mixtures of different elements over time; ergo, just chemistry explains everything
- ✓ However, if *in situ* neutron production is occurring in certain systems within which isotopic "fractionations" are observed, the fundamental assumption above is obviously erroneous



Definition: delta (δ) notation for stable isotope ratios

For some elements variability of ratio in range of 3rd - 5th decimal place

Formula expresses very tiny values in terms of per mil or parts per thousand (‰)

Stable isotope ratios of Nitrogen are commonly expressed in δ-notation:

$$\delta = \left(\frac{R_{sample} - R_{standard}}{R_{standard}} \right) \text{ x } 1000$$

Wherein by convention: $R = \text{ratio} = \left(\frac{X_{\text{measured isotope}}}{X_{\text{most abundant}}} \right)$

δ-notation for stable isotope ratios of Nitrogen:

$$\delta^{15}N(‰) = \left(\frac{\left({}^{15}N/{}^{14}N\right)_{sample} - \left({}^{15}N/{}^{14}N\right)_{standard}}{\left({}^{15}N/{}^{14}N\right)_{standard}} \right) \times 1000$$

International standards for isotope ratios shown below

Absolute ratio in Table embodies idea of "natural isotopic abundance"

In delta (δ) notation, isotopic ratio R_{sample} measured in a sample is compared to an internationally agreed-upon reference standard; this approach derived directly from notion that there exists an ~ invariant "natural isotopic abundance" for every stable element found on a planet, e.g., earth. A measured δ value will be positive if a sample contains *more* of the measured isotope vs. a standard; a δ value will be negative if sample contains *less* of measured isotope vs. given isotopic standard

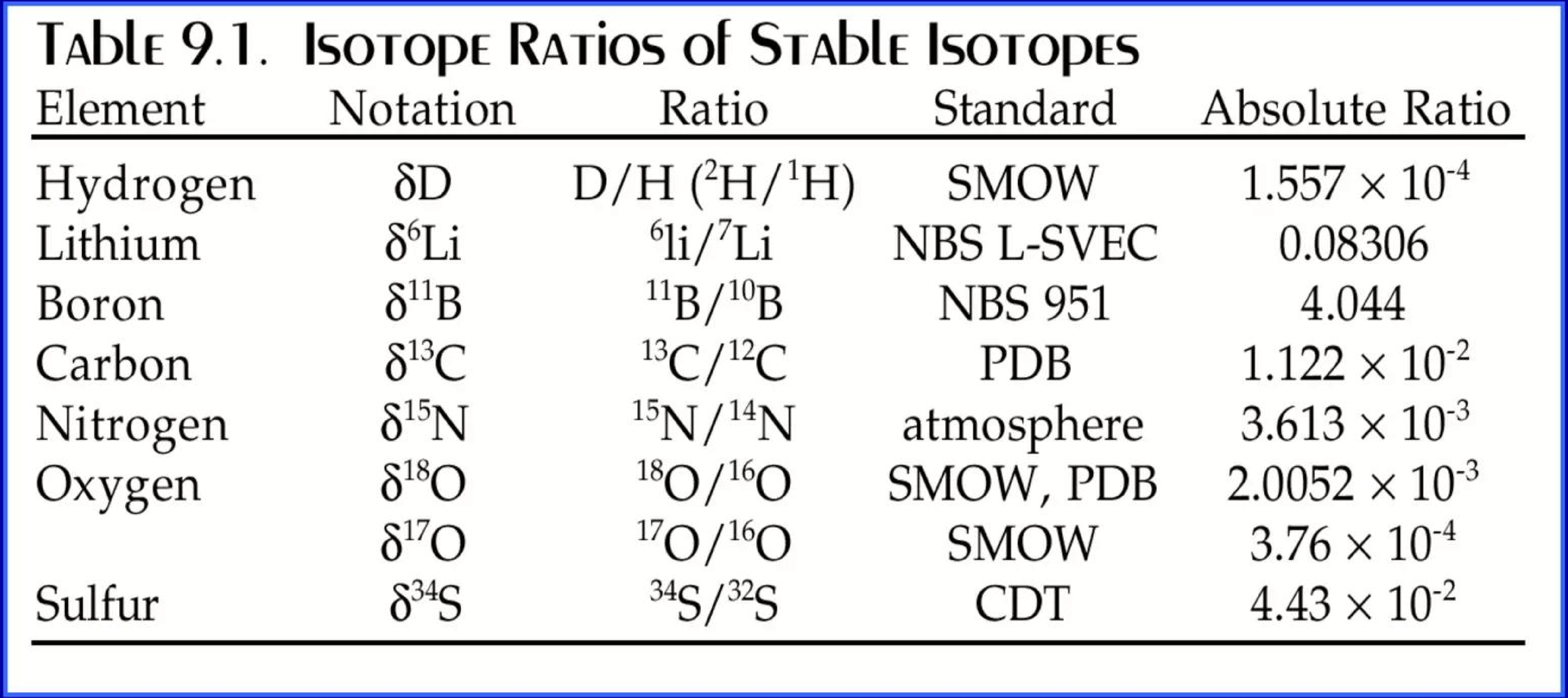


TABLE 9.1. ISOTOPE RATIOS OF STABLE ISOTOPES

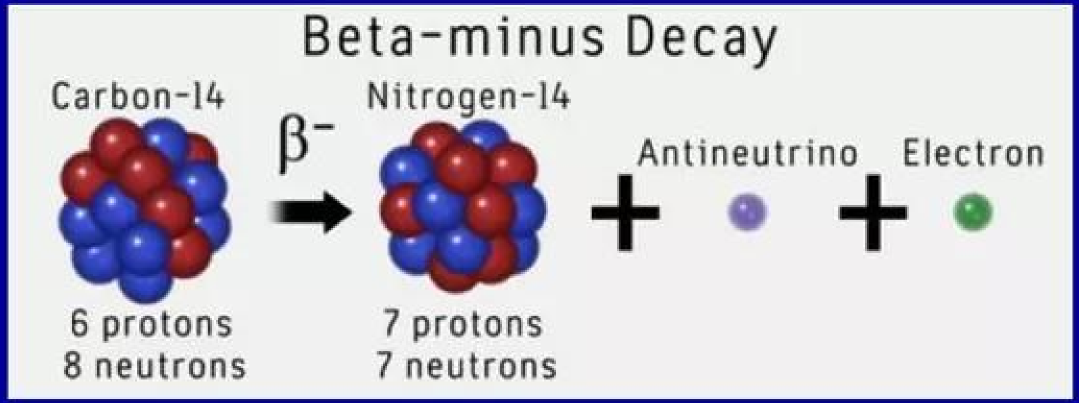
Element	Notation	Ratio	Standard	Absolute Ratio
Hydrogen	δD	D/H ($^{2}H/^{1}H$)	SMOW	1.557×10^{-4}
Lithium	$\delta^{6}Li$	$^{6}li/^{7}Li$	NBS L-SVEC	0.08306
Boron	$\delta^{11}B$	$^{11}B/^{10}B$	NBS 951	4.044
Carbon	$\delta^{13}C$	$^{13}C/^{12}C$	PDB	1.122×10^{-2}
Nitrogen	$\delta^{15}N$	$^{15}N/^{14}N$	atmosphere	3.613×10^{-3}
Oxygen	$\delta^{18}O$	$^{18}O/^{16}O$	SMOW, PDB	2.0052×10^{-3}
	$\delta^{17}O$	$^{17}O/^{16}O$	SMOW	3.76×10^{-4}
Sulfur	$\delta^{34}S$	$^{34}S/^{32}S$	CDT	4.43×10^{-2}

Source: Prof. Paul Asimow, Caltech, slide from a Geology lecture in 2006

Neutron capture causes complex changes in isotope ratios

LENR transmutations either enrich or deplete different Nitrogen isotopes

$$\delta^{15}N(‰) = \left(\frac{\left({}^{15}N / {}^{14}N \right)_{sample} - \left({}^{15}N / {}^{14}N \right)_{standard}}{\left({}^{15}N / {}^{14}N \right)_{standard}} \right) \times 1000 \tag{1}$$



Natural abundances (two stable isotopes): ^{14}N = ~99.636%; ^{15}N = ~0.364%
Thermal neutron capture cross-section (barns): ^{14}N = 0.080 ; ^{15}N = 0.04 mb

- ✓ If ^{14}N were somehow exposed to fluxes of ultra-low-energy neutrons, it could readily be transmuted to ^{15}N with the capture of a single neutron. Therefore, the abundance of ^{15}N can be enriched by neutron-catalyzed LENR processes; i.e., δ^{15}N would *increase* versus the standard which happens to be the isotopic ratio of Nitrogen in Earth's atmosphere
- ✓ Interestingly if not perversely, when stable Carbon-13 (^{13}C natural abundance = ~1.3%) captures one neutron, it creates unstable Carbon-14 (^{14}C with half-life = 5,730 years - varying trace amounts always present in living matter), which beta decays to Nitrogen-14 (^{14}N) thus *decreasing* δ^{15}N (increases value of $^{14}N_{sample}$ in equation's denominator)
- ✓ If ^{15}N captures a neutron, it would be transmuted to ^{16}N which happens to be unstable (half-life = 7.1 seconds); ^{16}N beta decays to stable Oxygen (^{16}O – natural abundance 99.76%). In this case, ^{15}N will be depleted and ^{16}O enriched; in addition, mass-balance of Nitrogen may show a deficit; will be "missing Nitrogen" that seemingly 'disappears'
- ✓ Depending greatly on initial conditions, exposure of Nitrogen atoms to LENR neutrons would undoubtedly alter whatever isotopic ratios may have existed prior to exposure

Enzyme active sites create very high electric fields

Quasi-static E-fields ~ 1.5 x 10^{10} V/m were measured in WT isomerase

Still unable to measure fast transients that represent even higher field strengths

"Extreme electric fields power catalysis in the active site of ketosteroid isomerase"
S. Fried *et al.*, *Science* 346 pp. 1510 - 1514 (2014)
http://web.stanford.edu/group/boxer/papers/paper303.pdf

- ✓ Also see Lattice PowerPoint dated March 20, 2015 referenced later herein
- ✓ Using Stark Effect, measured quasi-static, near-equilibrium, time averaged electric fields of ~ 1.5 x 10^{10} V/m in Wild Type (WT) ketosteroid isomerase's active site; admitted that fast-transient, way-higher spikes in active sites' local electric field-strength could occur under dynamic non-equilibrium conditions but they can't presently be measured (S. Boxer, private communication)
- ✓ Observed linear relationship between E-field strength and effect on C=O bond
- ✓ Concluded that electric field strength in enzyme's active site responsible for: "70% of KSI's catalytic speedup relative to an uncatalyzed reference reaction"
- ✓ To create neutrons via W-L $e + p$ reaction, need E-field strengths > 2.5 x 10^{11} V/m for tens of attoseconds; do fast transients in active sites get high enough?

New breakthrough in room temperature Nitrogen fixation

FeMoS-chalcogels used could be mimicking active site of Nitrogenase

White light irradiation drives process but 1,000x less proficient than the enzyme

"Photochemical Nitrogen conversion to ammonia in ambient conditions with FeMoS-chalcogels"
A. Bannerjee *et al. JACS* 137 pp. 2030 - 2034 (2015)
http://pubs.acs.org/doi/abs/10.1021/ja512491v

- ✓ Molybdenum (Mo), Iron (Fe), and Sulfur (S) present in chalcogel (see Figure on next slide) somewhat resemble the active site of Nitrogenase enzyme
- ✓ Chalcogels are very porous, dark materials with extremely high surface areas
- ✓ Experiments: insoluble FeMoS-chalcogels were placed in aqueous H_2O solutions with additional chemicals and irradiated with white light from Xenon lamp (light replaces ATP as energy source for fixation); ammonia is then produced in reactor at ambient room temperature and atmospheric pressure
- ✓ While Banerjee *et al.* can produce ammonia under remarkably mild conditions compared to the Haber-Bosch process, it is 1,000x less proficient vs. enzyme
- ✓ Commercial challenge is to increase the catalytic proficiency of their process

Abiotic enzyme-like room temperature fixation of N_2

Requires more energy to break N≡N bond compared to C=O bond

Reasonable to speculate that higher electric field strength needed to cleave N≡N

- ✓ Experimental bond dissociation enthalpies of selected bonds at 298 K:

  N ≡ N 941 kJ/mole
  C = O 799 kJ/mole

- ✓ Nitrogen triple bond is ~18% stronger than C = O double bond
- ✓ If electric field strengths are crucial in catalysis, and if causal relationship between effects on chemical bonds and E-field strengths are ~linear per Fried *et al.*, then it is likely that electric fields in active site of Nitrogenase are somewhat higher vs. ketosteroid isomerase at 1.5×10^{10} V/m
- ✓ Follows that FeMoS-chalcogels should have measured E-fields > 1.5×10^{10} V/m in μ or smaller regions somewhere on surfaces
- ✓ Surface plasmons occur on chalcogenides

Structure of Bannerjee *et al.* chalcogel

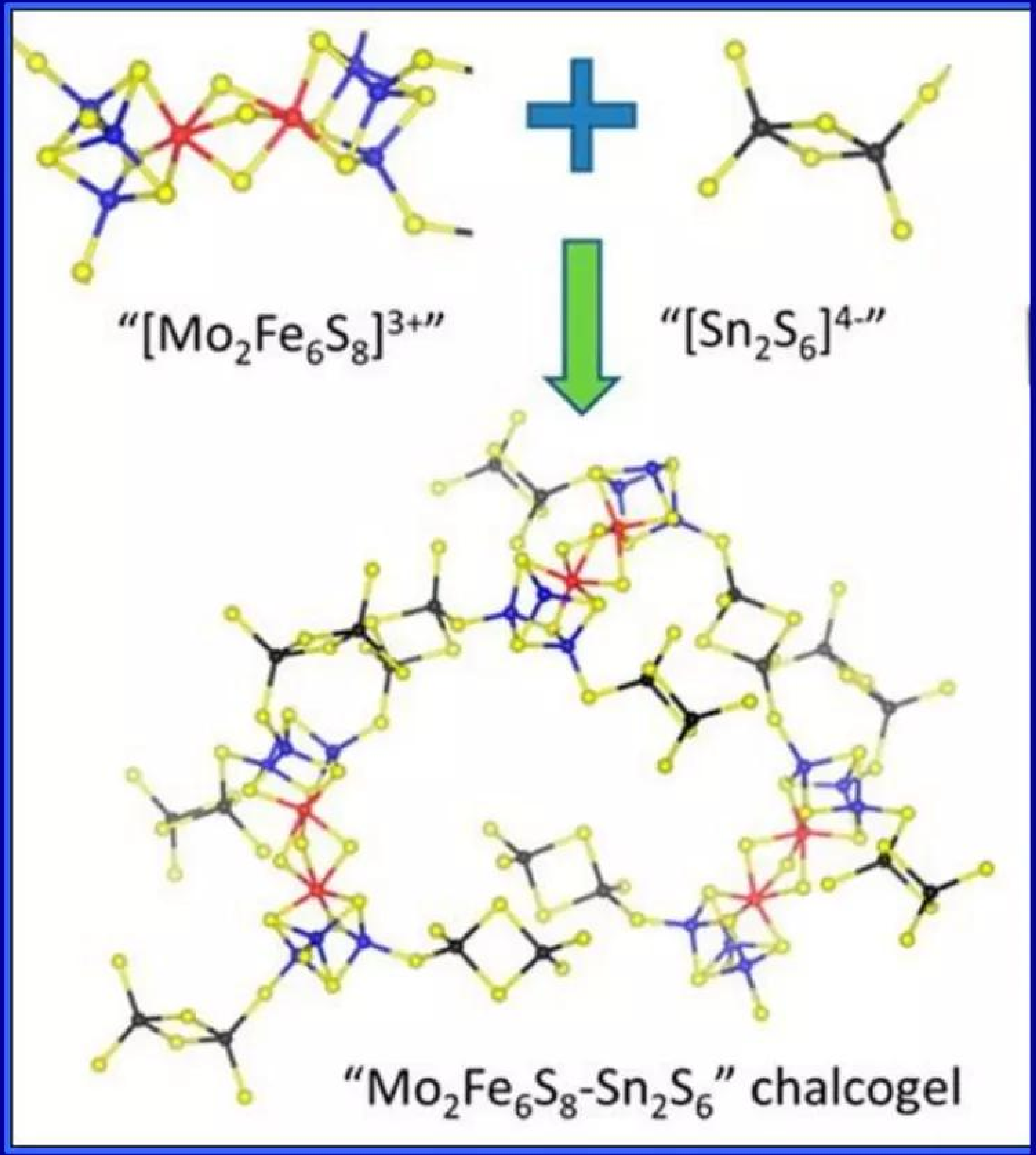


Figure source: Banerjee *et al.* *JACS* (2015)

How do we know if Nitrogenase E-fields >1.5 x 10^{10} V/m?

If fields >2.5 x 10^{11} V/m W-L predict occasional production of neutrons

‘Accidental’ events occur because Q-M entangled protons/electrons are present

- ✓ If local electric field-strengths in an active site exceed 2.5 x 10^{11} V/m for just a few tens of attoseconds, it is possible to occasionally produce neutrons via Widom-Larsen $e + p$ electroweak reaction. Such ‘accidents’ can happen because mutually quantum-entangled protons and electrons (including π electrons on aromatic rings) are innately present in active sites, along with Carbon and metal atoms, all of which will compete to capture any ultralow energy neutrons. Note than an active site would likely produce neutrons only one or two at a time and that local unreacted mass-enhanced electrons will automatically convert any locally produced gammas into infrared photons
- ✓ Per Widom-Larsen theory, physical dimensions of LENR neutron’s DeBroglie wavelength at the instant of creation should ~ match size of the many-body collective ‘patch’ of mutually entangled protons (Hydrogens) and electrons that cooperatively produced it; implies that neutron wavelengths will likely approximate the spatial dimensions of active sites’ entangled components
- ✓ If ultralow energy LENR neutrons are being produced one would expect to observe “fractionation” of isotopes of elements situated in vicinity of the active site which in this case would minimally include H, Mo, C, N, Fe, and S

Neutron production in active sites is probably accidental

Quantum fluctuations may occasionally push E-fields > 2.5 x 10^{11} V/m

Some nonzero percentage of isotopic “fractionation” could instead be LENRs

- ✓ Evolutionary pressures would select for active sites that get the job done chemically but modulate strength of local electric fields so as to keep them below thresholds required for electroweak neutron production. Even so, quantum fluctuations could sometimes push E-fields > 2.5 x 10^{11} V/m, thus causing accidental production of neutrons that are captured by local atoms
- ✓ Competition for neutron capture amongst many atoms found in or near an enzyme active site would be a many-body collective scattering process that would be very complex and exceedingly capricious in terms of outcomes --- capture products could vary enormously from one active site to another
- ✓ It is not clear that a neutron production and capture event would inevitably damage or destroy an enzyme’s active site; in some cases it might, and in others it would not --- the outcome would likely depend on exactly which element/isotope underwent neutron capture. Note that neutron production in active sites could potentially reduce the average half-life of Nitrogenase
- ✓ We will now present two selected examples of published experimental results in which isotopic “fractionation” that is attributed to purely chemical processes could plausibly have also been caused by LENRs, at least in part

Data in which LENRs may be accompanying fractionation

- ✓ "Molybdenum isotope fractionation by cyanobacterial assimilation during nitrate utilization and N_2 fixation"
  A. Zerkle *et al.* *Geobiology* 9 pp. 94 - 106 (2011)
  http://onlinelibrary.wiley.com/doi/10.1111/j.1472-4669.2010.00262.x/pdf

  "Instead, the pattern in δ^{98}Mo fractionations we observe suggests a more complex mechanism or mechanisms for fractionation … We have demonstrated that cyanobacterial assimilation of Mo can produce large fractionations in δ^{98}Mo ($\varepsilon_{\text{cells-media}}$ as large as -1‰)"

- ✓ "Fixation and fate of C and N in the cyanobacterium *Trichodesmium* using nanometer-scale secondary ion mass spectrometry"
  J. Finzi-Hart *et al.* *PNAS* 106 pp. 6345 - 6350 (2009)
  http://www.pnas.org/content/106/15/6345.full.pdf

  "NanoSIMS analysis showed substantial subcellular spatial variability in ^{15}N and ^{13}C enrichment along *Trichodesmium* trichomes and with depth through individual cells … ^{13}C/^{12}C and ^{15}N/^{14}N ratio images generated from sectioned trichomes, along with correlated TEM maps, provide direct evidence of subcellular uptake localization within cells ~8 h, and the redistribution of that enrichment after 24-h incubation … In both sectioned and whole cells, we observed discrete hotspots enriched in ^{15}N and ^{13}C at 4 h, with increased density at 8 h."

Anomalies in global Nitrogen cycle noticed for 60 years

Nitrogen doesn’t mass-balance across a huge range of length-scales

Highly variable % of measured Nitrogen is ‘missing in action’ --- where did it go?

- ✓ Mystery of “missing” Nitrogen has been noted in many published studies spanning six decades; is it just measurement problems or something else?
- ✓ Prior to Widom-Larsen theory, near-universally assumed that persistently observed mass-imbalance anomaly was nothing more than researchers inability to accurately characterize and measure all the molecular moieties that contain Nitrogen … however, neutron captures can transmute N → O
- ✓ Data reported in two recent studies illustrates missing Nitrogen conundrum:

“Closing the carbon balance for fermentation by *Clostridium thermocellum*”
L. Ellis *et al*. Bioresource Technology 103 pp. 293 - 299 (2011)
http://bioenergycenter.org/besc/publications/ellis_closing_carbon.pdf

Comment: despite diligent measurement efforts, chemostat experiments could only account for ~93% of Carbon and ~92 - 96% of all elemental Nitrogen

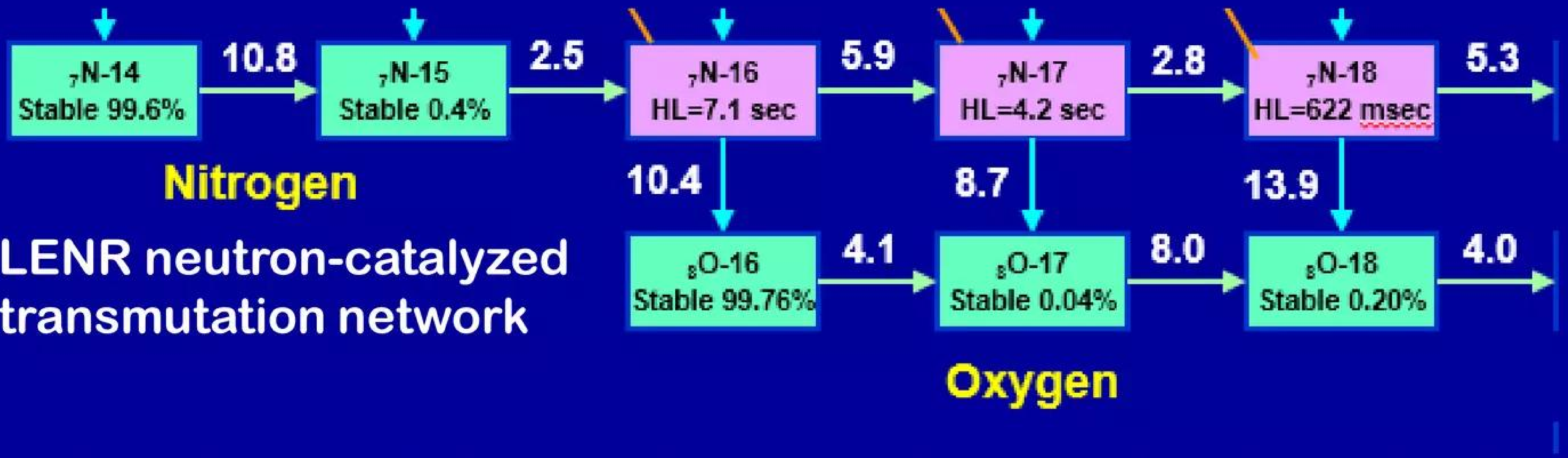
“Nitrogen control in source segregated domestic food waste anaerobic digestion using stripping technologies”
A. Serna-Maza, PhD Thesis, University of Southampton (November 2014)
http://eprints.soton.ac.uk/372768/

Comment: experiments conducted in batch laboratory-scale digesters were unable to account for all of the Nitrogen; see Chapter 4 for discussion

Speculation re cause of “missing Nitrogen” anomalies

New heresy: LENR transmutation of “missing” Nitrogen into Oxygen?

Accurate measurements of C, N, O mass-balances in closed system are needed



LENR neutron-catalyzed
transmutation network

- ✓ Today this hypothesis is informed theoretical speculation based on hard data
- ✓ Skilled experimentalists are needed to confirm or falsify this radical conjecture
- ✓ Well characterized, high-tech microbial chemostat systems might be ideal for tightly controlled experiments that are designed to test for this possibility
- ✓ Accurate, state-of-the-art mass spectroscopy analyses on before-and-after samples, including access to a nanoSIMS machine when needed, are crucial
- ✓ While LENR processes in Nature may occur at extremely low rates, their effects on isotopic ratios and abundances of elements could be very substantial over geological time horizons --- some parts of geochemistry may require revision

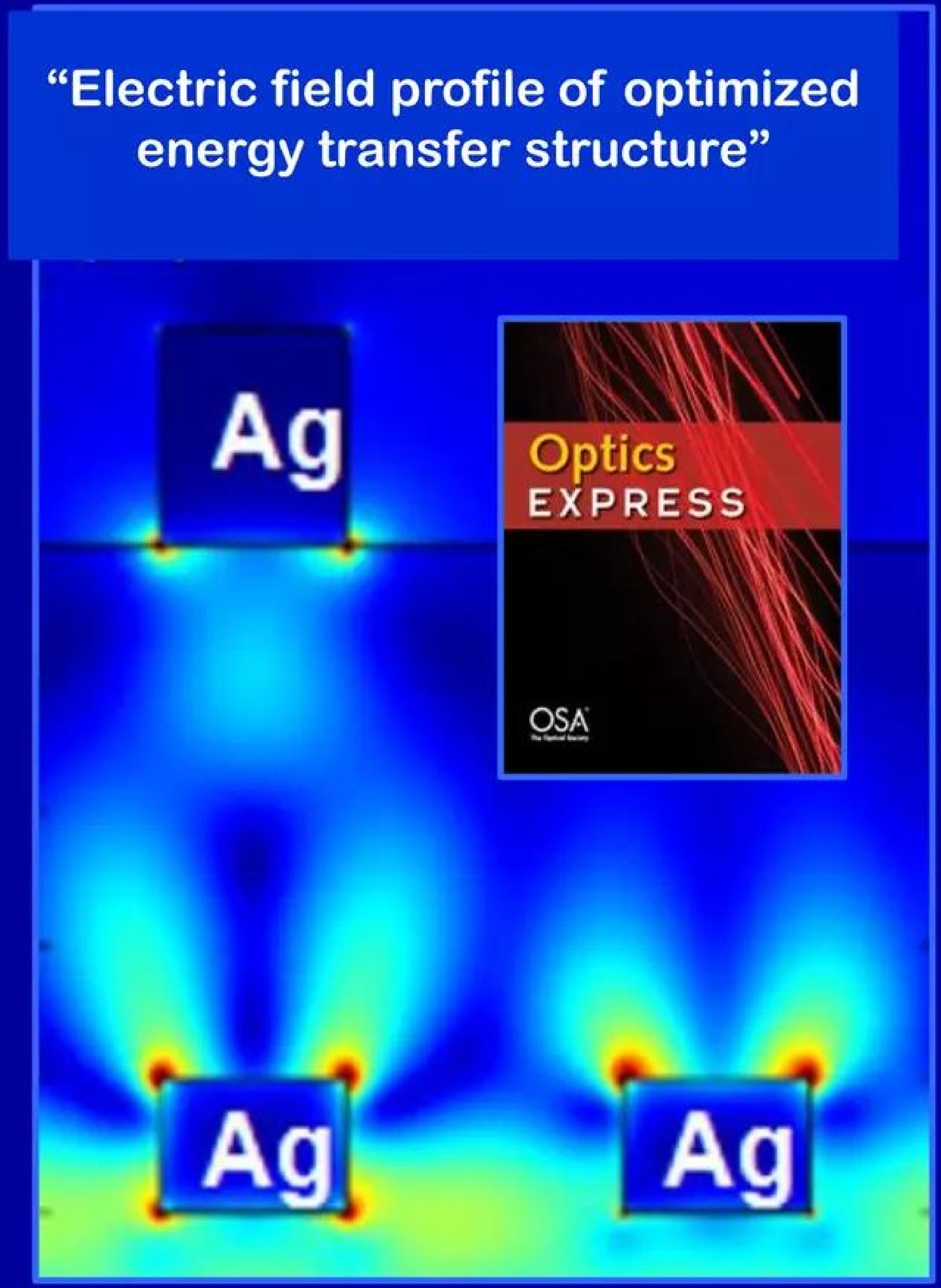
Lattice's R&D strategy for going beyond Haber-Bosch

Apply knowledge of LENR active sites and plasmonics to N_2 fixation

Boost catalytic proficiency and keep working temps & pressures near ambient

- ✓ It has become apparent that deep technical knowledge about details of abiotic LENR electroweak catalysis can provide valuable insights into the operation of both enzymatic and abiotic chemical catalysis. There is thus an opportunity to use new and unique conceptual insights to help greatly increase performance and reduce production costs for industrial abiotic, non-Haber-Bosch catalysis of Nitrogen fixation
- ✓ Chalcogens are good place to start thanks to the new discovery by Bannerjee *et al*. (*JACS* 2015); importantly, surface plasmons are well-known on chalcogenides in other nanotech applications
- ✓ Nanotechnology, plasmonics, and many-body collective quantum effects can be applied to selected FeMoS materials to purpose-design catalytically active nanoscale sites in which local electric field strengths are high enough to cleave the Nitrogen triple bond to react with Hydrogen

A. Lin *et al. Optics Express* (2013)


"Electric field profile of optimized energy transfer structure"

http://tinyurl.com/qypprkz

Additional references

✓ "The alchemy of air - a Jewish genius, a doomed tycoon, and the scientific discovery that fed the world but fueled the rise of Hitler"
T. Hager, Harmony Books - New York (2008) 316 pp.
http://www.amazon.com/The-Alchemy-Air-Scientific-Discovery/dp/0307351793

✓ "Ultrahigh local electric fields: surprising similarities between LENR active sites and enzymatic biocatalysis"
L. Larsen, Lattice Energy LLC, March 20, 2015 [101 PowerPoint slides]
http://www.slideshare.net/lewisglarsen/lattice-energy-llc-surprising-similarities-between-lenr-active-sites-and-enzymatic-catalysis-march-20-2015

✓ "Towards a generic model of catalysis"
M. Grayson and S. Janusz, IE Conference of Molecular Design (2003)
http://biochempress.com/Files/IECMD_2003/IECMD_2003_020.pdf

✓ "Nitrogenase MoFe protein from *Clostridium pasteurianum* at 1.08 Å resolution: comparison with *Azotobacter vinelandii* MoFe protein"
L-M. Zhang *et al.*, *Acta Crystallographica* D73 pp. 274 - 282 (2015)
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4321486/

✓ "Nitrogen isotope fractionation by alternative nitrogenases and past ocean anoxia" X. Zhang *et al. PNAS* 111 pp. 4782 - 4787 (2014)
http://www.pnas.org/content/111/13/4782.full.pdf

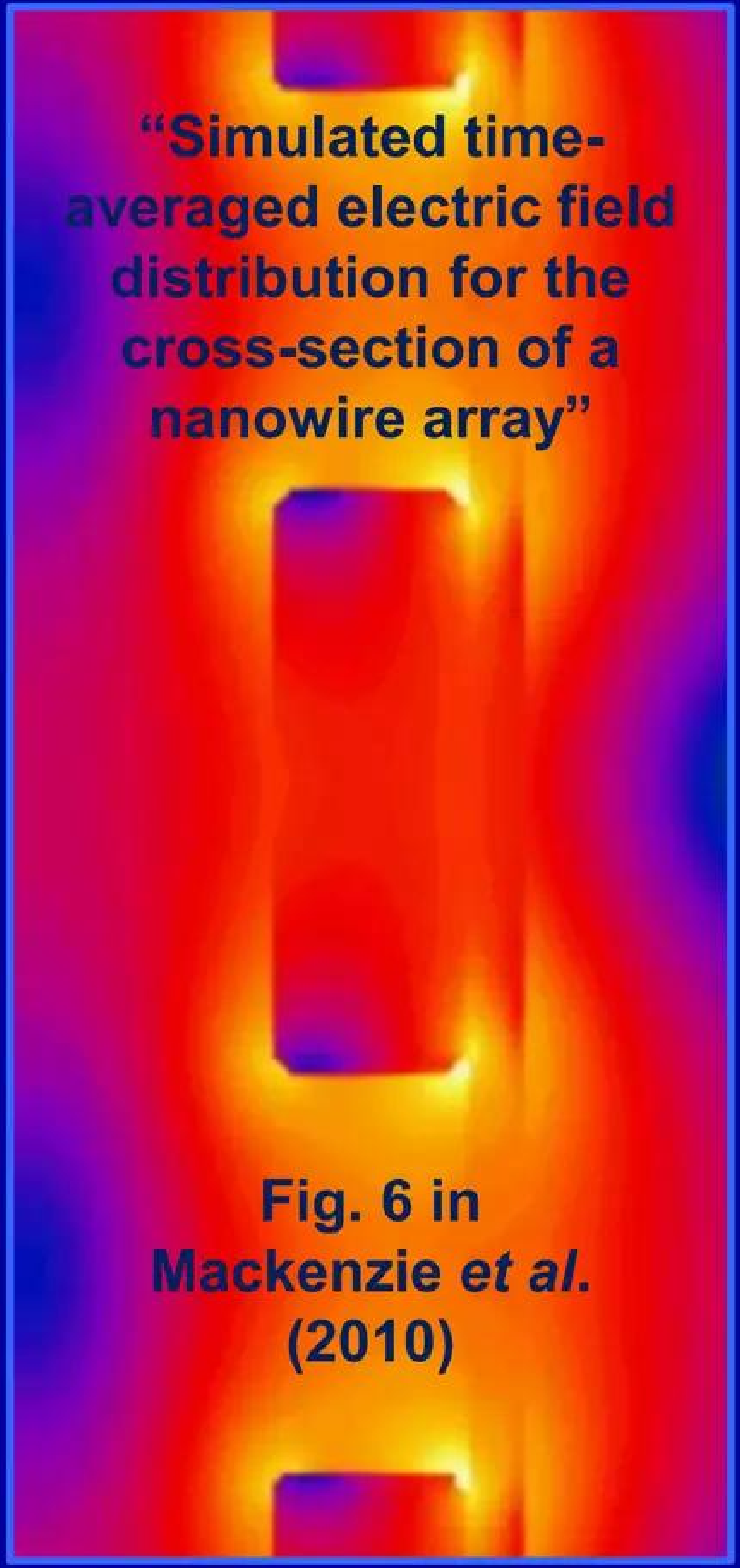
Working with Lattice

Partnering on commercialization and consulting on certain topics

Larsen cv: http://www.slideshare.net/lewisglarsen/lewis-g-larsen-cv-june-2013

1-312-861-0115 lewisglarsen@gmail.com

- Lattice welcomes inquiries from established large organizations that may have an interest in discussing the possibility of becoming a strategic capital and/or a key technology development partner with our US company
- Lewis Larsen also selectively engages in fee-based third-party consulting that does not compromise Lattice's proprietary intellectual property relating to any LENR-based power sources. Such expertise includes many areas such as optimizing industrial catalysts; LENRs as they relate to petroleum geochemistry and fracking-induced seismicity; lithium-ion battery safety; and long-term strategic implications of LENRs on high cap-ex long term investments in power generation and petroleum-related assets.



"Simulated time-averaged electric field distribution for the cross-section of a nanowire array"

Fig. 6 in Mackenzie *et al.* (2010)

http://tinyurl.com/lzvvyv9

Significance of the Haber-Bosch process today

"Today hundreds of Haber-Bosch plants are drinking in air and turning out ammonia, producing enough fertilizer not only to support a burgeoning human population but to improve average diets worldwide. All of the plants run on the same principles Haber and Bosch pioneered and are filled with the same basic catalyst that Alwin Mittasch found almost a century ago. They are however, larger and more efficient. In Carl Bosch's day, the tallest ammonia ovens were thirty feet high. Now they top one hundred feet. In 1938, it took an average of sixteen hundred workers to produce a thousand tons a day of ammonia. Today it takes 55 workers to make the same amount. In the early days it took four times as much energy to make a ton of fertilizer as it does now. Still, the demand for their products are so great that Haber-Bosch plants today consume 1 percent of all the energy on earth … This huge, almost invisible industry is feeding the world. Without these plants, somewhere between two billion and three billion people --- about 40% of the world's population … would starve to death."

Thomas Hager "The alchemy of air" (2008)

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