4th Annual Princeton SmartDrivingCars Summit

Live on Zoom 14th Episode: noon ET, Thursday, April 1

You MUST Register (only once) @: https://orfe.princeton.edu/sdc/register

If Already Registered: A recent email from *princeton.edu contains your personal link to this Live Zoom Session*

Live on Zoom @ noon Eastern (Princeton) Time

Lasting for ~1.5 hours or until Discussion with audience ends.

Ken Pyle Session Summaries of 4th Princeton SmartDrivingCar Summit:

13th Session Improving the Moving of Goods
12th Session 3/18/21 Human-centered Design of Safe and Affordable Driverless Mobility
11th Session 3/11/21 Incentivizing Through Regulation
10th Session 3/04/21 Incentivizing Through Insurance
9th Session 2/25/21 Can Level 3 be Delivered?
8th Session 2/18/21 Who Will Build, Sell and Maintain Driverless Cars?
Michael Sena's Slides, Glenn Mercer Slides
7th Session 2/11/21 Finally Doing It
6th Session 2/ 4/21 Safe Enough in the Operational Design Domain
5th Session 1/28/21 At the Tipping Point
4th Session 1/21/21 Why Customers are Buying Them
3rd Session 1/14/21 The SmartDrivingCars We Can Buy Today
2nd Session 1/ 7/21 A Look into the Future
1st Session: 12/17/20 Setting the Stage

Moderator: Michael Sena, President, Michael L. Sena Consulting AB

Michael L. Sena is an internationally recognized expert and consultant in connected vehicle services to the transport industry. Since 2013 he has written a monthly newsletter called The Dispatcher, in which he provides in-depth analyses of the trends affecting the transport industry, particularly driverless and electric vehicles. His newsletter, articles and reports can be found on his web site

Panelist: Fred Dryer, Engineering Foundation Distinguished Research Professor

Dr. Dryer (BAE'66, Rensselaer Polytechnic Institute) obtained his Ph.D. in Aerospace and Mechanical Sciences at Princeton University (1971) and was engaged in combustion research at Princeton University for more than 50 years. He served on the Professional Research Staff from 1971 – 1981, joined the tenured faculty in the Mechanical and Aerospace Engineering in 1981, and became Professor Emeritus in 2013. He also holds an honorary faculty position in Mechanical Engineering at the University of Melbourne, AU (since 2015). Dr. Dryer joined the University of South Carolina as an Educational Foundation Distinguished Research Professor in Mechanical Engineering in October 2016. His prior extensive research facilities have been relocated to the recently established Fuels, Energy Conversion, and Propulsion Technologies Research facilities within the University of South Carolina McNair Center.

Along with a number of collaborators at U of SC and elsewhere, Dr. Dryer is actively engaged in experimental and computational research involving a wide spectrum of topics on kinetic and physical fuel property effects relevant to optimizing the fuels/energy conversion interface for ground-based power generation/transportation, aircraft applications, and chemical propulsion. His fundamental research interests are focused on applications-driven needs for advancing dynamic performance, increasing energy resource (carbon) utilization efficiency, reducing air-pollutant emissions, and mitigating fire-safety-related hazards associated with gaseous and liquid flammable production and use. His research experience encompasses a wide range of fuels from hydrogen, syngas, natural gas, chemical process and low BTU gases to individual liquid hydrocarbon and oxygenated species, their mixtures, petroleum-derived real fuels (including gasolines, diesel fuels, HFO's, and crudes), and (both hydrogenated and oxygenated) alternative components derived from natural gas and bio-resources blended with petroleum fuels.

Dr. Dryer has published extensively (Scopus-1/1/20: 368 articles; H=75) and consulted for the government, industry, and the legal profession. His services on advisory committees include efforts for the National Materials Advisory Board/National Research Council (five times), NASA, DOE-BES, DOE-ARPA-E, DARPA, ARO, and NIST. He is a former associate editor and editorial board member of Combustion Science and Technology, co-editor for the Proceedings of the 26th and 27th International Symposiums on Combustion, and a former editorial board member of the International Journal of Chemical Kinetics and of Progress in Energy and Combustion Science. He is currently a Fellow (2018) of the International Combustion Institute (2000 Silver Medal, 2012 Egerton Gold Medal; 1976/1981/2014 plenary speaker), a member of the American Society of Mechanical Engineers (Fellow), the Society of Automotive Engineers (Fellow), the American Institute of Aeronautics and Astronautics (Associate Fellow; 2014 Propulsion and Combustion Medal), the American Chemical Society, and the National Fire Protection Association.

Panelist: Adam Jonas, Global Head and Managing Director, Autos and Shared Mobility, Morgan Stanley

Adam Jonas is a Managing Director and leader of Morgan Stanley's Global Auto & Shared Mobility research team. Adam joined the firm's investment banking division in Chicago in 1996, specializing in corporate finance and M&A in the automotive industry. In 1999, Adam moved to Equity Research and joined the Firm's European Autos team, based in London, serving as the lead European auto analyst from 2003 to 2010. In 2010, Adam returned to the US to lead the Global Autos & Shared Mobility teams, collaborating with his research colleagues to tell the story of the future of transportation and Auto 2.0. Adam earned his bachelor's degree in business administration (with distinction) from the University of Michigan.

Panelist: Karin Olander, Automotive Journalist @ Dagens Industri

Karin Olander has been a journalist for more than 30 years, working for national tv, radio and news agency in Sweden and abroad. During 2018 based in London. Education in political science and journalism at the university of Gothenburg and university of Angers, France. The last 14 years she has been covering the global automotive sector both from a financial point of view and from the product side, including testdrives of new cars and features. She was awarded as The best motor industri journalist by KAK (Swedish Royal Automotive Club) 2016. Married, mother-of -three, living outside Gothenburg, Sweden.

Panelist: Stan Young, Advanced Transportation & Urban Scientist

Dr. Young is the Mobility Systems team lead for the National Renewable Energy Laboratory’s Center for Integrated Mobility Science. He currently serves as the DOE technologist in city for the Columbus Smart City program, led the Urban Science pillar for the DOE Systems and Modeling for Accelerated Research in Transportation initiative, and coordinated the DOE’s Transportation Systems COVID-19 Rapid Response for Safe and Efficient Mobility for Return to Operations. Dr. Young is a graduate of Kansas State University, served in the United States Peace Corps, and was previously on staff at the University of Maryland Center for Advanced Transportation Technology, the Kansas Department of Transportation, and the Johns Hopkins University Applied Physics Laboratory.

Some Thoughts on Powering Future Cars and Driverless Vehicles

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Smart Driving Car Summit
Session 14
Princeton University/ORFE

April 1, 2021

UNIVERSITY OF SOUTH CAROLINA
College of Engineering and Computing

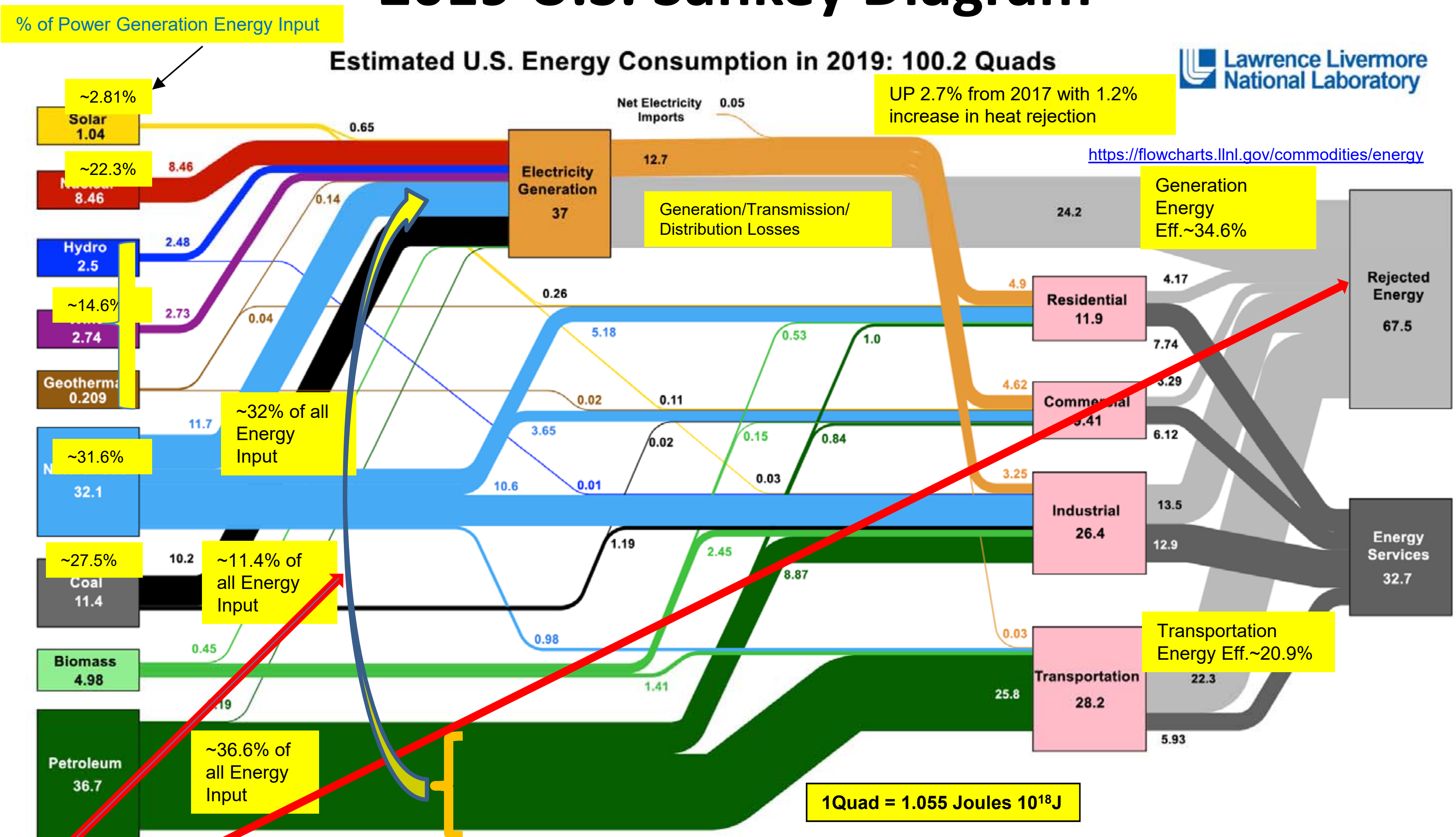
What Will *Power* Safely Driven Cars?

The Questions:

- ***What are the fuel options for future safely driven vehicles?***
- ***What are the principal advantages of each potential fuel?***
- ***What is needed for any one or more to emerge as acceptable options?***

Historically, transportation has been fueled by liquid and/or compressed hydrocarbons, principally petroleum products and natural gas because of their high energy density (yielding adequate range).

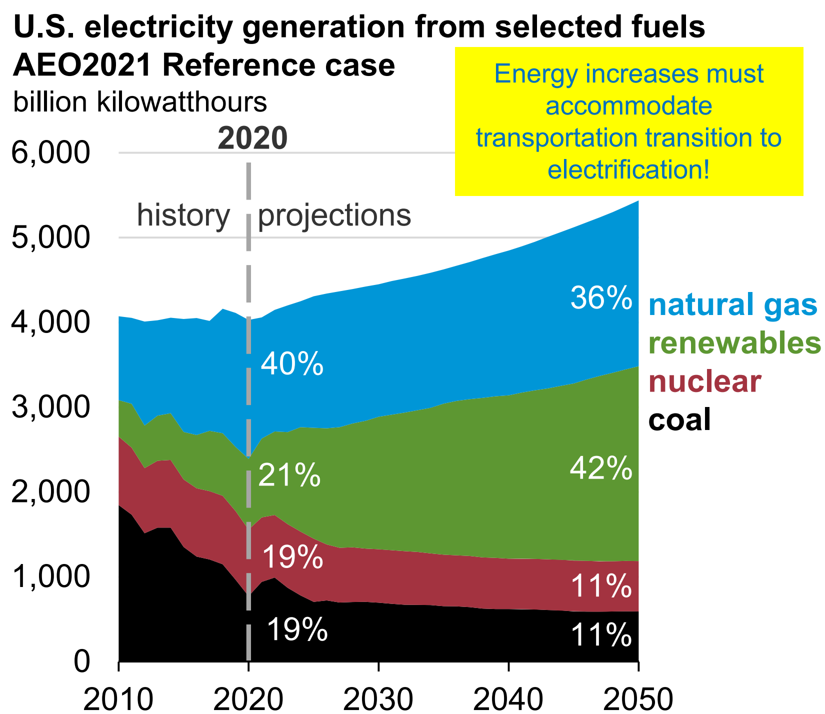
2019 U.S. Sankey Diagram



- Moving significantly toward electrification of ground transportation requires re-distribution in fossil fuel use paradigms from transportation into electrical generation
- Current rejected energy in *both* power and transportation sectors suggest potential for very large energy efficiency gains yet to be realized => ***potential for large carbon emission reductions!*** => ***time for accommodating longer term evolution***
- ***Limiting energy resource forms, distributing energy in fewer forms, depending on grid and local power distribution all contribute to reducing national energy flexibility and energy security, especially in the longer term***

University of South Carolina
College of Engineering and Computing

US *Power* Sector Projections through 2050



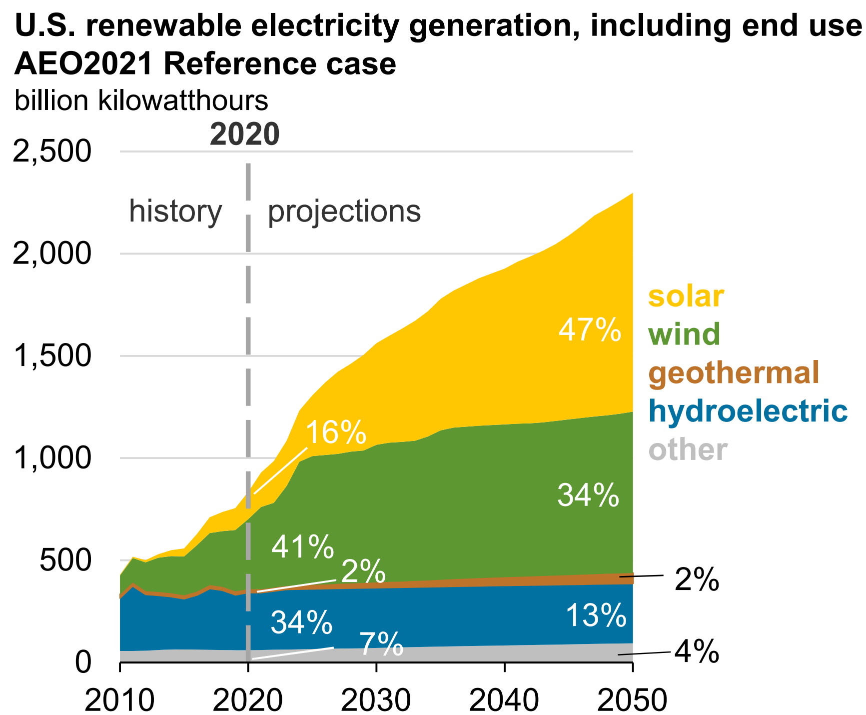


Chart Data from 2021 US EIA, Annual Energy Outlook (2021)

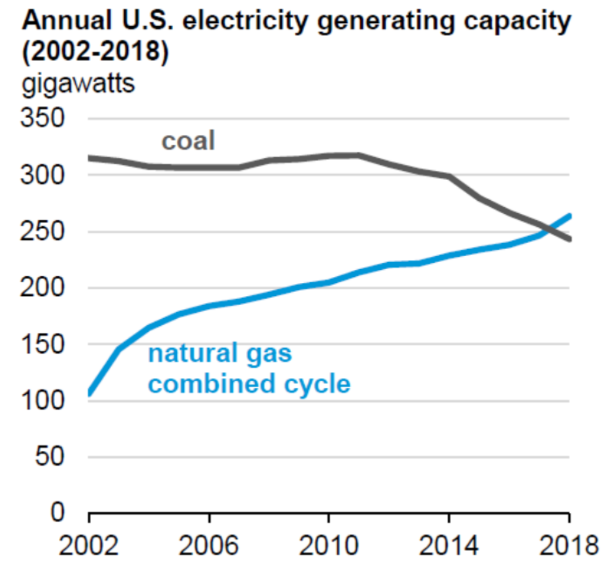
Opinions -

- **Projections suggest ~60% contribution from coal/NG/nuclear through 2050 (probably much longer)**
  - **Credible federal policies for energy fuel source/carbon price can influence projections**
- **“Gaseous fuels” will be critical (enabling combined cycle and hybrid gas turbine applications)**
- **Major growth of solar/wind renewables across all states and offshore will be needed**
- **Carbon capture/recycling/storage technologies will be essential to controlling/reducing carbon intensity for the power sector (which is projected to include large transportation use).**
- **Battery-based storage will require major supplementation by other methods (“E-fuels”)**

Combined Cycle & Hybrid Gas Turbines

- ***Thermal efficiency for Rankine Cycle (RC)-based power plants: ~<40% on Natural Gas, (NG) even lower on coal***
  - ***Start up times to full load for RC systems Typically many hours***

  RC coal firing => RC NG firing reduces CO_2 emissions per kw-hr by ~40%



Combined Cycle Gas Turbines (CCGT)

- **Natural Gas CCGTs:** > **62.2% at ~ 500 megawatt unit sizes in the field today!**
  - Start to full power < 30 min
  - Natural gas/hydrogen/ammonia operations currently under R & D

    NG RC => NG-CCGT's reduces CO_2 emissions per kw-hr by ~45%;

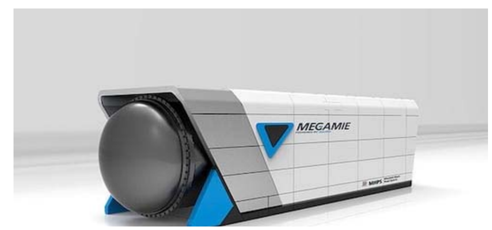
Coal RC => NG CCGTs => 12 lbs CO_2 emitted per 100 miles!

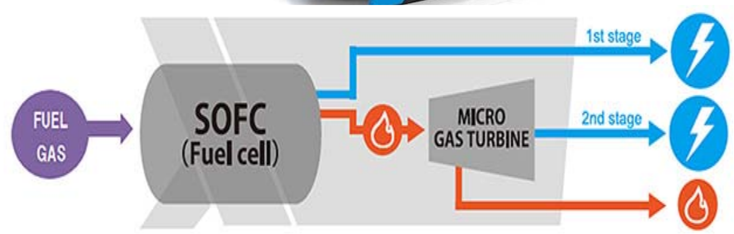
- **Liquid-Fueled CCGTs**: ***Super-light/extra/light l(ow Va/S) crude firing avoids refining energy losses, achieving additional CO_2 emission reductions***

Base load power generation dynamics for CCGTs critical for back-up and integration of renewable (wind/solar) power generation variability

Gas Turbine/FC Hybrid Systems

- **Example - Mitsubishi Hitashi Power Systems (MHPS)**
  - Operating on reformed NG using ceramic SOFC stacks at ~900℃, and Micro gas turbine (MGT) - Combined heat and power (CHP) efficiency >65%
  - **Principal can be advanced to operate on hydrogen, and other E-fuels**





Concerns with Where We Are & Where We are Heading

The original questions:

- *What are the fuel options for future safely driven vehicles? Hybrid EV's using MeOH, Ammonia*
- *What are the principal advantages of ~~each potential~~ fuel flexibility? Energy security & future uncertainty*
- *What is needed for any one or more to emerge as acceptable options? Technically Driven Decision Making*

Historically, transportation has been fueled by liquid and/or compressed hydrocarbons, principally petroleum products and natural gas because of their high energy density (yielding adequate range).

But
- ***The public and the government potentially see Combustion as "dirty ", like cigarettes", so there is a win-win….the sector must address climate change anyway…Let's just eliminate "combustion" from transportation!***

- ***Governments, Vehicle manufacturers => all-electric, battery powered vehicles***
  - ***Best long term profitability for the industry, least complicated manufacturing/power systems, especially if the energy source aboard is only a battery (Least vehicle environmental impact through use)***
  - ***No more complicated, maintenance issues (Bad for dealerships; are they really needed?)***

Good for the short term…but Is the "one-egg in the basket" solution best for the long term? In US terms, Can we address climate change, continue to use carbon containing energy carriers (with CCS), or must we lose national energy-independence once again?

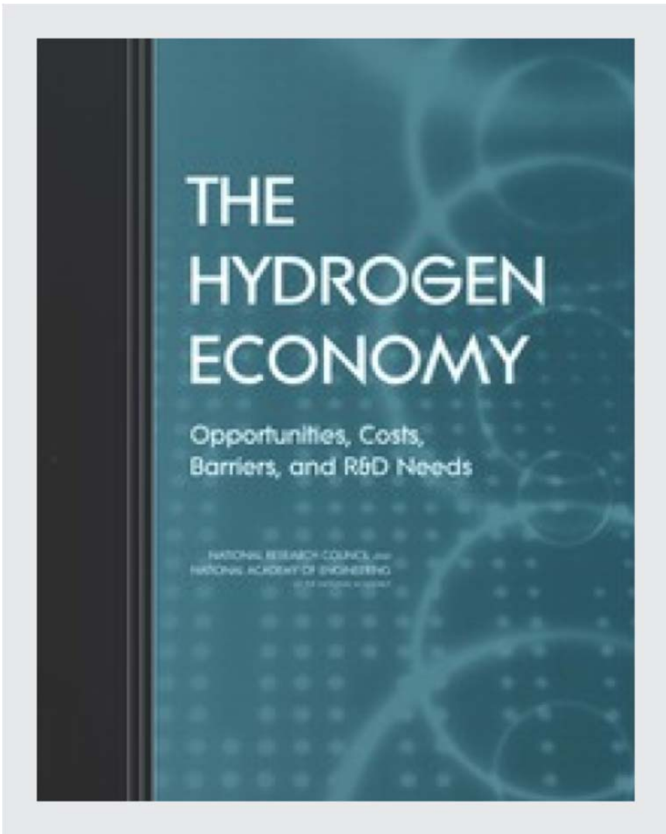
Few downsides for battery powered vehicles in urban areas, mainly recharging, ideal for fleets. But long distance, non-urban use, and/or no home charging station? There are only ~115,000 fueling stations for gas/diesel vehicles now. Maybe we need only 500,000 fast charging stations; wait, gas stations have from ~ 6 -100 (!) pumps. And the transportation system, and others electricity users will all depend on near real-time integrity of the renewable and base load power generation and grid (Wait until an entire region of charging stations drops out.)

Finally, have we really thought through the limited resource issues associate with batteries, the nations that have essentially cornered their availability, or will be manufacturing nearly all of the combustion engines for future hybrids generated by major manufacturers world wide? Are we really ready to jeopardize our national energy independence, creating other dependences that can be politically manipulated?

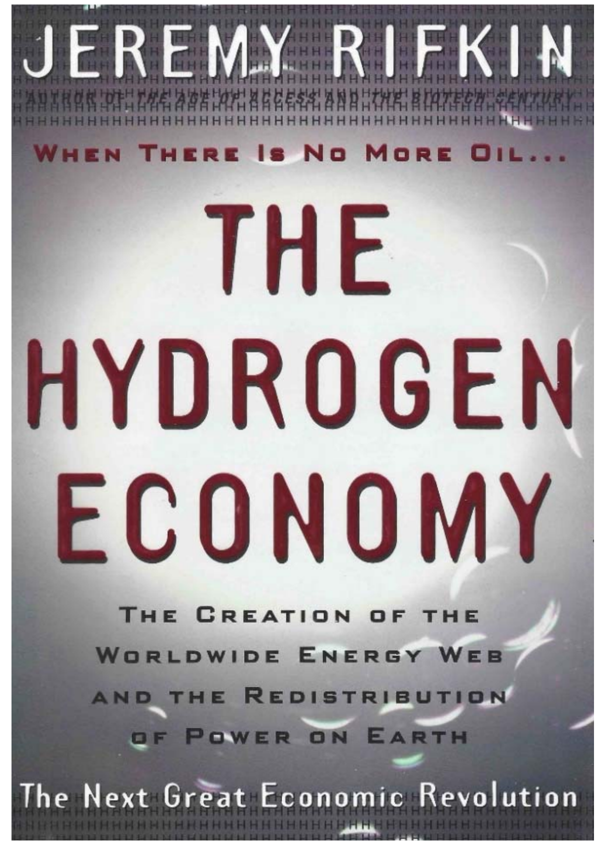
Extra Sides

The "Hydrogen Economy, E-Fuels, & Fuel Cells"

The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs (2004) https://www.nap.edu/catalog/10922

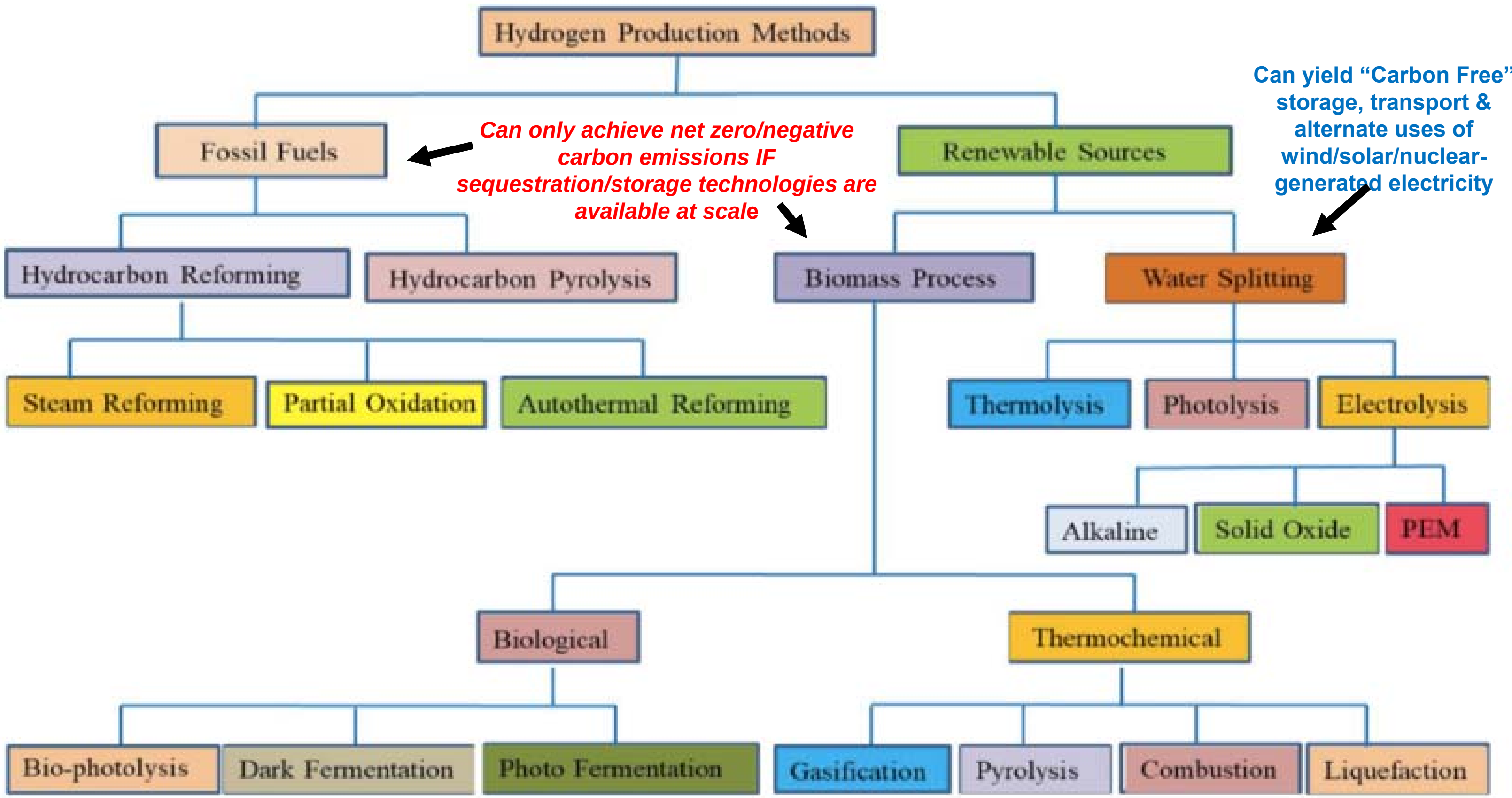


Penguin Putnam Inc (2002) http://www.pemnguinputnam.com



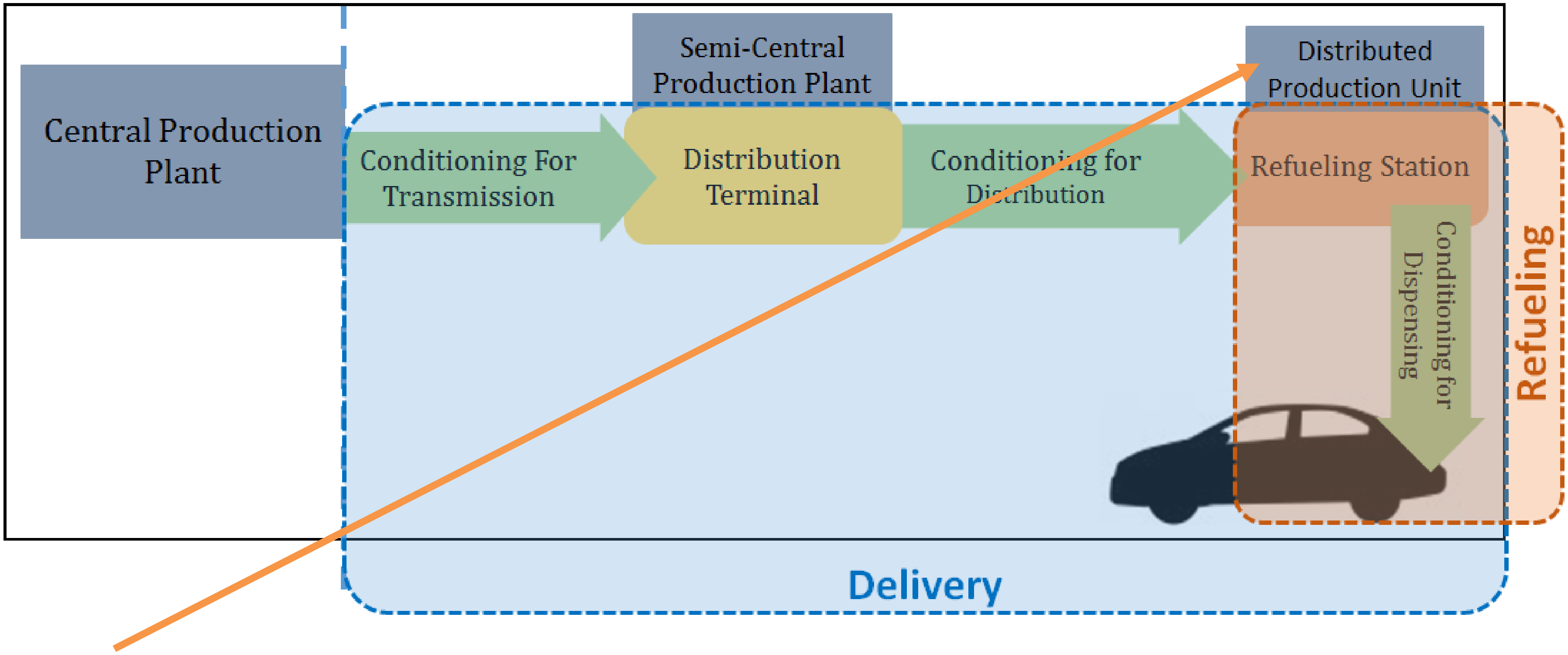
- *The "Hydrogen Economy"' concept became much more popular with the emerging focus on "carbon mitigation" that occurred in the early 2000's (but concept is traceable to the 60s and 70's, > 50 years ago!)*
- **Distribution, storage, and many other issues identified in this era as major barriers to wide implementation of national and global hydrogen-based energy economies remain to be fully resolved and/or widely demonstrated today. Robust hydrogen economies are likely "still down the road"**

The "Hydrogen Economy" Resource Evolution



- **Liquid ammonia with direct utilization, including combustion & fuel cell, use has the highest total energy efficiency & the lowest total cost in comparison to LH_2, MCH** *From Aziz (2018) Proc 2014, AIP Int Conf on Sci and Appl (ICSAS)*
- **Significant commercial interest in ammonia production/use** *DOE (ARPA-E, EERE, National Labs); https://www.ammoniaenergy.org/*
- **Current Industrial and agricultural safety practices (e.g. toxicity) require careful address for future commercial applications involving substantial interfaces with general consumers, (use already common in agriculture/fertilizer sector today)**

Infrastructural Issues Are Key



- **Emphasizing local battery charging and/or electrochemical production of E-Fuels do not adequately address major energy security limitations associated with integrating renewable power into grid load dynamics, assuring reliability of needed electrical generating capacity, or accommodating locally more than a few hours of central power grid disruption.**
- **Grid disruptions are a key problem in terms of projected climate change effects and desire to integrate larger and larger fractions of renewable power.**

Is there "One Best Way" for All?

- US (10.2 million sq km) compared to "Europe" (9.8 million sq km), ~ includes large areas, formerly part of the USSR
- "EU", including the UK (4.3 million sq km), half the US land area & a population of 510 million (US ~ 330 million)
- Entire population of PA is essentially the same as Île-de-France (Greater Paris), ~**1/10th** the land area of PA – very different population distributions
- Clearly, the EU highway & railway system emphases are entirely different than in the US, in part as a result of history, in terms of geography population distribution, & natural energy resource availability

Should the same energy, transportation, & infrastructural demographic solution be expected as "best" for both?

World wide?