Ammonia Fuel
It Works – What's Next?

10TH ANNUAL MEETING OF NH3FUEL ASSOCIATION
SACRAMENTO, CALIFORNIA
SEPTEMBER 23, 2013

Dr. Steve Wittrig
Senior Advisor, Advanced Energy Systems
Clean Air Task Force (www.catf.us)
tswittrig@catf.us

Clean Air Task Force

- **Founded in 1996. Initial mission was advocacy and legal action to support cleaner coal power technology.**
- **NGO based in Boston. Does not accept donations from industry or government.**
- **Evolution to climate change and stronger technology base to supplement advocacy.**
- **Mission – CATF works to help safeguard against the worst impacts of climate change by catalyzing the rapid global development of low carbon energy and other climate-protecting technologies through research and analysis, public advocacy leadership and partnership with the private sector.**

CLEAN AIR TASK FORCE

The Prize – 21st Century

(With Apologies to Daniel Yergin)

A zero carbon fuel

That can be used for transportation and power generation

That is scalable from global chemical to global energy proportions

That is an inherently clean fuel with regard to traditional pollutants and CO_2

That has a century long history of large scale handling and use

That is competitive in energy pricing to current fuels

That holds promise for low or no carbon production (through CCS on standard technology or advanced technology for renewables or nuclear)

That *appears to be* within easy reach through optimization of production, use and safety regulations

CLEANAIR TASK FORCE

What We Know

- **Ammonia average price over last 20 years is $300 per tonne. Equivalent to $1.60 gal gasoline and $16 per MMBTU LNG**
- **Lowest cost ammonia production today is $100 per tonne**
- **Ammonia can be produced from zero carbon energy (hydro, nuclear, wind)**
- **Ammonia diesel engines are proven and essentially equivalent in cost (either with diesel blending, precracking or advanced engines)**
- **Ammonia turbines with precracking are efficient and flexible**

- **In general, these technologies have considerable headroom and are primarily in need of engineering optimization and field prototyping for commercialization.**

CLEAN AIR TASK FORCE

Ten Years In -
Why Haven't Things Moved Forward?

- **Complexity of total value chain to support commercialization of individual pieces**
- **Skepticism of incumbents that find it easy to dismiss large vision for "ammonia economy"**
- **Safety issues**
- **"Too good to be true"**
- **"If I haven't heard of it, there must be something really wrong with it."**

CLEANAIR TASK FORCE

Disruptive Innovation - Seeing What's Next
Clayton Christensen

- **"Never expect someone to understand change when their livelihood depends on not understanding it." – Upton Sinclair**
- **"Hit 'em where they ain't." – Wee Willie Keeler**

Disruptive Innovations: Discovery-driven planning

1. **Make Projections**
2. **What assumptions must prove true for the projections to happen?**
3. **Implement a plan to learn -- to test whether the critical assumptions are reasonable**
4. **Invest when key assumptions prove valid**

TABLE 1-1
Overview of Potential Customer Groups

Customer Group	Indentifier	What Could Happen	Signals
Nonconsumers	People who lack the ability, wealth, or access to conveniently and easily accomplish an important job for themselves; they typically hire someone to do the job for them orcobble together a less- than-adequate solution	New-market disruptive innovation	• Product/service that wealth, or access to helps people do more conveniently and easily conveniently what they accomplish an important are already trying to job for themselves; they get done • Explosive *rate* of growth in new market or new context of use
Undershot custo-mers	Consumers who consume a product but are frustrated with its limitations; they display willingness to pay more for enhancements along dimensions most important to them	Sustaining up-market innovation (radical and incremental)	• New, improved products and services introduced to existing customers • Integrated companies thrive; specialist companies struggle

CLEANAIR TASK FORCE

How Might It Work?

- Identify niche markets with non–consumers or under-served customers
- Minimize exposure to objections
  - **Professional management of fuel and equipment**
  - **No requirement for distributed retail sales**
  - **Business-to-business relationships along the value chain enabling contracts, shared risk management and detailed metrics**
- Create and grow profitable applications
- Learn, iterate and create next level of markets

CLEAN AIR TASK FORCE

Some Initial Market Possibilities For Discussion

Incremental Power Plants - NH3 Diesel Engines

- **One of the most promising early applications for ammonia as a fuel is large stationary diesel gen sets.**
- **There are over 200 GW of medium to large diesel engines that run on a continuous basis producing electricity. These installations often feature a dozen or more engines install in a kind of ‘modular power plant’.**
- **These modular power plants can be installed very quickly, scaled up as necessary, and redeployed when not needed or if the economic conditions change.**
- **Continuous duty generators are extremely sensitive to fuel price. At today's prices the typical engine will use 2 to 3 times the price of the engine in diesel fuel every year. In many cases, switching to ammonia may be a direct and significant cost savings.**
- **A number of innovators have been experimenting with using waste heat from these engines to partially reform, or upgrade, the fuel, thus increasing the efficiency of the engine .This is a promising approach, and has the potential to improve the energy efficiency of the engines by 10 to 25%. If ammonia were the same cost as diesel on an energy content basis, this reforming strategy would be a very strong incentive to switch to ammonia as a fuel.**

CLEANAIR TASK FORCE

Japan Power Production

- Japan has just shut down the last of its operating nuclear power plants.
- This has left a large gap in power supply that is being filled by de facto conservation and hydrocarbons.
- Japan already has a large and long established LNG import infrastructure and has typically paid a premium contractual price for LNG (recently around $15 per MMBTU).
- A new complementary path for clean energy development is necessary.
- Ammonia has several advantages over LNG at an equivalent energy cost.
  - **It does not require billion dollar regasification terminals.**
  - **Transport and storage is more flexible not as expensive as pipelines or vulnerable to interruption by earthquakes.**
  - **It can provide power at smaller scale (easing requirements on grid management).**

CLEAN AIR TASK FORCE

Alaska – Stranded Gas, Stranded Cities

- **Alaska has been injecting gas into the northern oil fields for decades to maintain pressure for oil production. This gas has some of the lowest lifting costs in the world.**
- **This is the reason for all the multi billion dollar project proposals for pipelines to the continental US and LNG to Asia. None have come to fruition because the mega-upfront capital costs and long construction schedules cannot bear the risk of gas pricing ten years from project start up.**

- **Alaska also has a problem with energy supply to the southern end of the state. As an example, the locally produced gas for Anchorage is declining and threatening to strand the city with very unattractive power options.**
- **There is now a serious discussion of a pipeline from the North Slope just for Alaska supply (Anchorage, Fairbanks and several towns along the route). The full project (with a LNG export terminal) is estimated at $45 - $65 billion.**

CLEANAIR TASK FORCE

Alaska – Stranded Gas, Stranded Cities

- **Ammonia production on the North Slope (with very cheap gas, probably strong support from government and industry players and ample engineering infrastructure) for delivery to Alaskan cities and towns (and eventually Asia) could become a very attractive proposition.**
  - **It doesn't require mega-investment to prove the markets or even to build the first plant.**
  - **The market risk is much smaller (ammonia is a valuable, fungible commodity that is easily shipped to buyers in a deep market).**
  - **It is much more flexible in market distribution (e.g., reduced southern AK demand in summer sends product to Asia seasonally).**
  - **It can be stored easily.**
  - **It is not as vulnerable to earthquakes or high pressure pipeline failure.**
- **If this concept becomes attractive when compared to a $50 billion pipeline project, Alaska could well become the proving ground for both power and transport applications.**
- **And a very significant supplier of ammonia energy carrier.**

CLEAN AIR TASK FORCE

Starting Points For Transportation

- **There are several entrepreneurs and institutions that are advancing the technology of engines for ammonia fuel.**

- **The South West Research Institute (one of the leading engine development and testing organizations in the world) has developed and tested prototypes of ammonia engines and filed seminal patents in the area.**
- **The Iowa Energy Center at Iowa State University is developing the technology and testing procedures for diesel engines powered by ammonia.**
- **Sturman Industries is developing ammonia engines based on advanced concepts in valves, computerization and optimization of injection strategies.**
- **Greg Vezina (Hydrofuel) has developed gasoline/ammonia and diesel/ammonia vehicles. From all appearances, these are well developed prototypes. He also is in discussions with Ontario government for ammonia locomotives and an electrical generator manufacturer in Japan to use his technology with diesel generators in Japan.**

CLEANAIR TASK FORCE

Low Carbon Ammonia (And Front End For CCS)

- **Ammonia plants emit pure (sequestration-ready) CO_2.**
- **There are active markets to purchase CO_2 for enhanced oil recovery.**
- **Ammonia plants built close to EOR fields can sell their waste CO_2 to be sequestered in oil fields after use.**
- **This co-product value can reduce production cost for eventual fuel use.**
- **These operations will also supply a great deal of experience and technology for carbon capture and for CO_2 transportation and sequestration.**

CLEANAIR TASK FORCE

Appendix

CLEAN AIR TASK FORCE

Partnerships For Innovation
Working Across Boundaries To Create Value

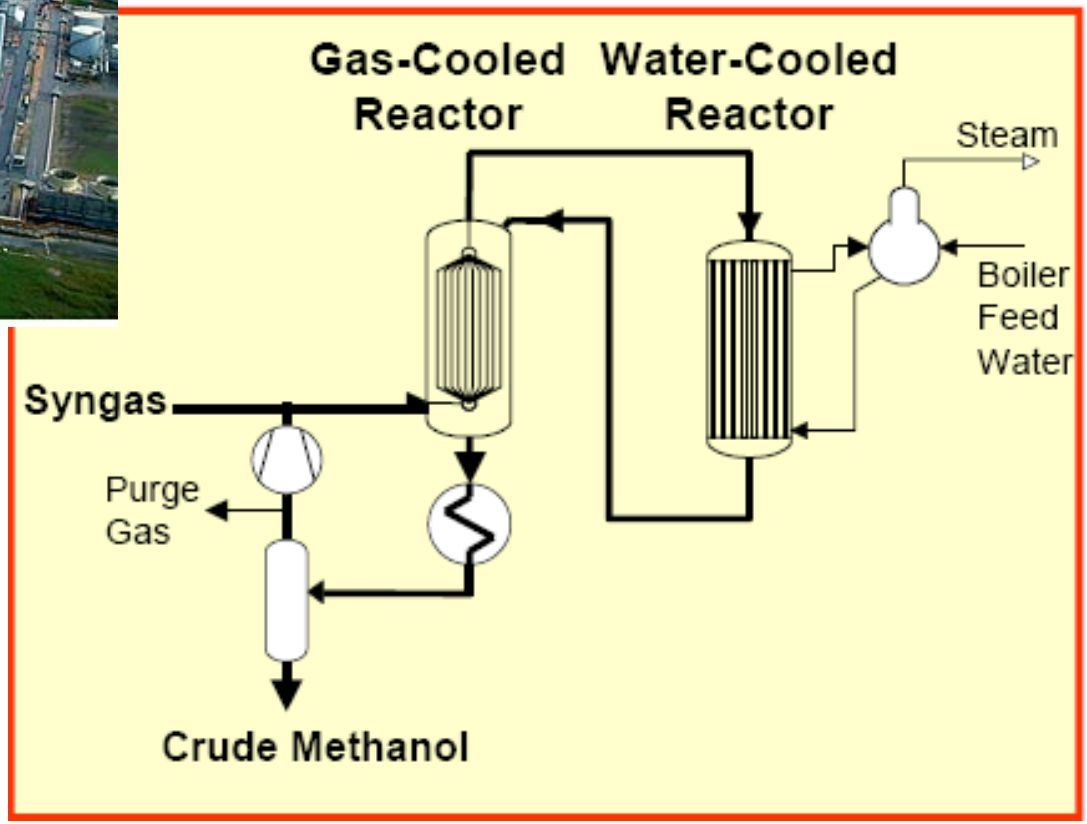
Steve Wittrig **Director, Advanced Technologies, BP**

4th Annual Conference on Corporate R&D and Innovation Management

Shanghai, April 16, 2008

Large Integrated Projects
New Technology

Atlas Megamethanol Plant in Trinidad

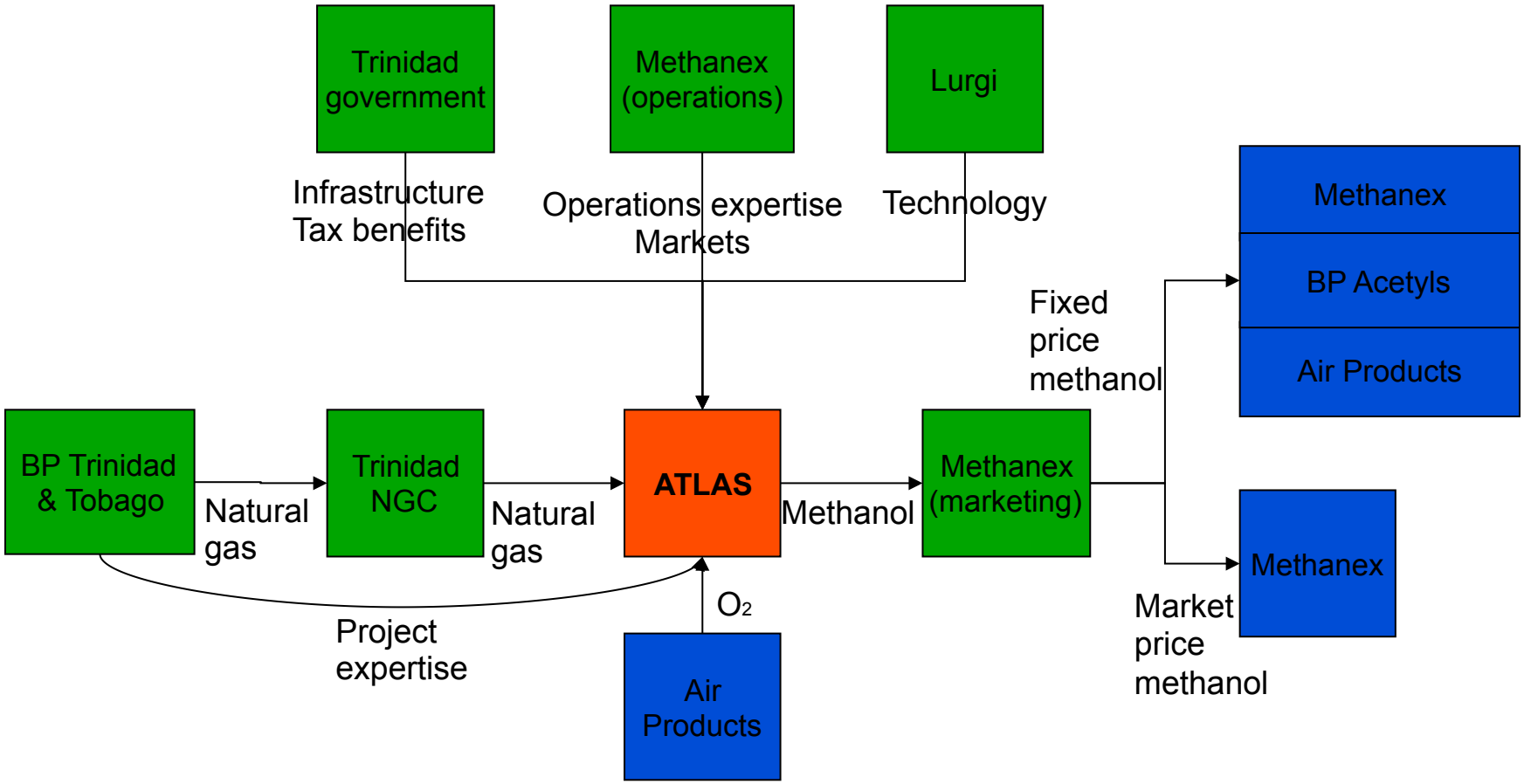


1. Desulphurisation
2. Steam reforming at high pressure (35-40 bar) and low temperature (700-800 deg. C)
3. Autoreforming at high pressure
4. Methanol synthesis
5. Distillation

Atlas Megamethanol

- Partnership (BP, Lurgi, Methanex, Trinidad) to introduce low cost methanol technology
- Commissioned in 2003
- 20% lower cost of production than next lowest cost plant in the world
- Methanol loop is design basis for large methanol plants being built around the world

Atlas deal structure



Atlas Megamethanol

BP

Strengths
- Large capital projects
- Previous projects in Trinidad
- Methanol buyer

Opportunities
- Gas sales contract
- New market development
- Distinctive strategy for gas conversion

Trinidad Govt

Strengths
- Infrastructure
- Policy support for project

Opportunities
- Diversification for Trinidad gas markets
- Jobs and downstream development for Trinidad

Lurgi

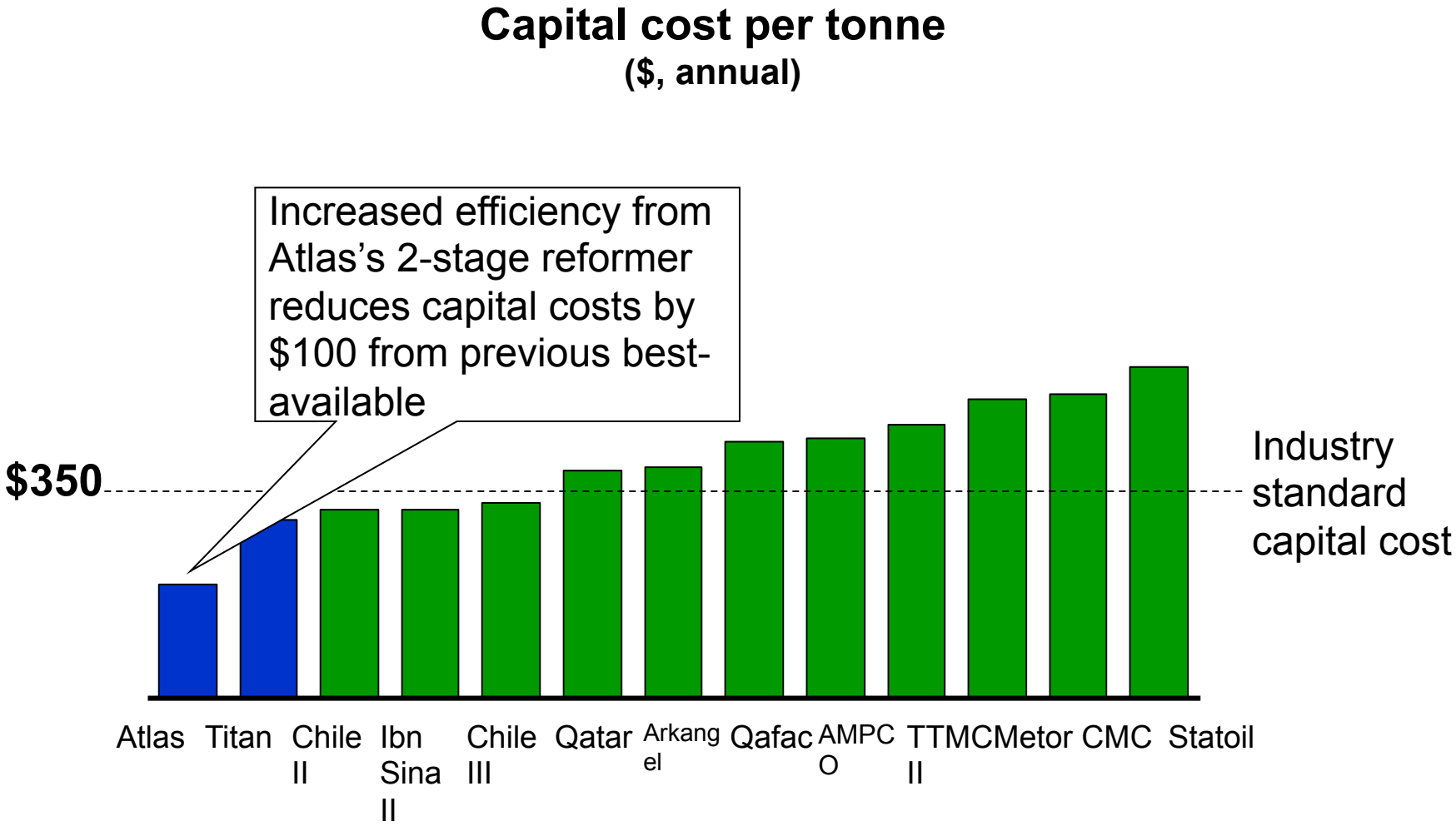
Strengths
- World leader in syngas and methanol technology

Opportunities
- Commercialize and exploit new inventions and know-how for low cost methanol production

Issues and Answers

Issues with the relationship	Response
➢ Introduction of large amount of new methanol into a commodity market, price risk	➢ Partner with leading marketer (Methanex) ➢ Develop new markets for low cost methanol ➢ BP guaranteed pricing for 25% of methanol
➢ Technology risk of new reactors and process flow	➢ External assessment and assurance on technology ➢ Contingency in project for delays ➢ Process guarantees from Lurgi

Atlas capital cost advantage



Source: CMAI; Amoco, 1998